ANIMAL NUTRITION HANDBOOK

Second Revision

☛ ***This handbook has not been proofread thoroughly, so . . . !?***

Contents

A Tribute to the Stockman

Behold the Stockman!
Artist and Artisan, he may be polished,
or a diamond in the rough . . .
but always a Gem.

Whose devotion to his animals is
second only to his love of God and family,
whose gripping affection is
tempered only by his inborn sense of
the true proportion of things,
who cheerfully braves
personal discomfort to make sure
his live stock suffer not!

To him,
there is rhythm in the clatter of the horse's hoof,
music in the bleating of the sheep and the lowing of the herd.

His approaching footsteps call forth the whinny of recognition.
His calm, well-modulated voice
inspires confidence and wins affection.
His coming is greeted with demonstrations of pleasure,
and his going with evident disappointment.

Who sees something more in cows than the drudgery of milking,
more in swine than the grunt and squeal,
more in the horse than the patient servant,
and more in sheep than the golden hoof.

Herdsman, shepherd, groom . . . yes, and more!
Broad-minded, big-hearted, whole-souled;
whose life and character linger long after the cordial greeting
is stilled and the hearty handshake is but a memory;
whose silent influence forever lives.

May his kind multiply and replenish the earth!

(Herbert W. Sanford & Unknown Cartoonist)

INTRODUCTION

INTRODUCTION

1. **Nutrition**

A. Definition?

- To "Nourish!"
- "Means all the processes whereby food & oxygen are presented to & utilized by living cells, and waste products are eliminated!"

B. "*The great French chemist Antoine Lavoisier (1743-1794) is frequently referred to as the founder of the science of nutrition. He established the chemical basis of nutrition in his famous respiration experiment carried our before the French Revolution. His studies led him to state 'La vie est une fonction chimique (life is a chemical process)!' Thereafter, chemistry became an important tool in nutrition studies.*" (Maynard et al., 1979)

C. Steps?

- "**Procurement**" ⇒ Ingestion ⇒ Digestion ⇒ Absorption ⇒ Assimilation ⇒ Metabolic functions & resulting metabolites ⇒ "**Excretion!**"

D. Nutrients:

1) Six basic nutrients:

a) Water - Often overlooked and not considered as a nutrient when formulating diets for animals, but extremely important.
b) Carbohydrates - Definition? Hydrates of carbon formed by combining CO_2 & H_2O (photosynthesis). The primary component found in animal feeds.
c) Protein - Found in the highest concentration of any nutrient (except water) in all living organisms and animals. All cells synthesize proteins, and life could not exist without protein synthesis.
d) Lipids - Organic compounds that are characterized by the fact that they are insoluble in water, but soluble in organic solvent (benzene, ether, etc.)
e) Minerals - Inorganic, solid, crystalline chemical elements that cannot be decomposed or synthesized by chemical reactions.
f) Vitamins - Organic substances that are required by animal tissues in very small amounts. The last group of dietary essentials to be recognized.

2) Indispensable nutrients:

- Those cannot be synthesized in the body from other substances, or those cannot be synthesized fast enough to meet its needs.
- Thus, must be supplied from the diet!

3) Dispensable nutrients:

- Those can be synthesized from other substances in sufficient quantity to meet its needs.
- But, still very important!

4) Use of the term, "Essential or Non-Essential Nutrient" for amino acids, minerals, and vitamins?

- May not be appropriate terminology for some nutrients - e.g., amino acids!
- Including the word "dietary," thus, "dietary essential or non-essential" nutrient?

2. Nutritional Guidelines

A. Requirements - Statement by Braude (1978. Proc. Annu. Int. Minerals Conf.):

"*. . . Should reexamine the whole concept of requirements for a certain nutrients. In the past, we have been mainly concerned with crude quantitative aspects -* ***how much?***

Subsequently, also with the crude qualitative aspects - ***of what?*** *and* ***in what form?*** *Now we have to add, perhaps, the most awkward question -* ***for what?***

And, this brings us to the basic disciplines of **biochemistry** *and* ***physiology****!*"

B. Consideration?

1) No longer worried about gross deficiencies or excesses, which can produce clinical symptoms.
2) Rather, catering for the situation:

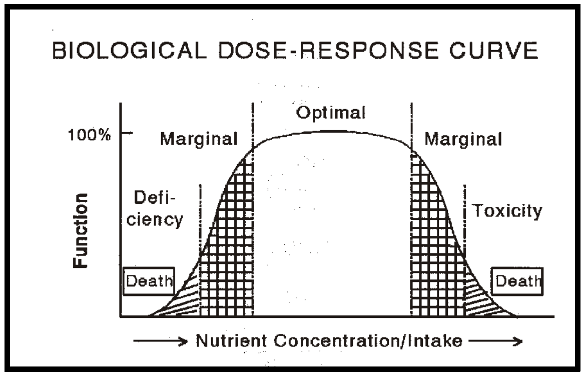
   a) Deficiency signs may not be severe enough or even absent.
   b) But, may impair growth performance, thus could be costly.
   ☛ *That is, to optimize the performance of animals!*

3) Interdependence of mineral elements/vitamins and other nutrients:

   a) May occur in the process of digestion, absorption and(or) metabolism.
   b) Understandings in these areas can lead to ↑ in the rate and efficiency of growth.

4) The form of nutrient & its availability are crucial!
5) Some minerals are becoming scarce and costly (e.g., phosphorus), ∴ avoid generous margins and wasteful usage! (How about vitamins?)
6) Need to focus attention on a very important, but often ignored nutrient, "water!"

- Biological dose & response curve: (Adapted & redrawn from Mertz, 1981. Science 213:1332)



NUTRIENT REQUIREMENTS

☞ *See Maynard et al. (1979), Swenson and Reece (1993), Kellems and Church (1998) and other references for details on the "maintenance, growth, reproduction, and lactation requirements."*

1. **Maintenance**

A. Maintenance? - "*The state in which there is neither gain or loss of a nutrient by the body*." (Maynard et al., 1979)

B. Maintenance requirement:

1) Regardless of the purpose of feeding an animal, a substantial portion of food/feed is used for supporting vital body processes, which are essential for life.
2) That portion consisted of the amount of needed to keep all the necessary tissues of an animal intact, which is not growing, working, or yielding any product.
3) This demand for food/feed is referred to as the maintenance requirement, and tissue breakdown would occur if this demand is not met.
4) A proportion of food/feed used for maintenance would differ depending on a multitude of factors such as species, age, rate of growth/production, etc.

☛ For a large segment of human population, the maintenance requirement may consist of the primary need for food, but this is not true for many farm animals simply because they are usually fed for productive purposes!

C. Fasting catabolism:

1) The animal getting no feed, doing no external work, and yielding any product is still carrying out vital/essential body processes such as respiration, circulation, maintenance of muscular activities, production of internal secretions, etc.
2) With no feed, the nutrients needed to support those activities must come form the breakdown of body tissues, and this is referred to as "fasting catabolism."

D. Energy metabolism of fasting - "Basal metabolism or basal metabolic rate"

1) Energy expended in the fasting animal is represented by the fasting "heat production," and can be measure in the respiration calorimeter (or other method of indirect calorimetry).
2) Can provide a useful basis of reference for other phases of energy metabolism.
3) By eliminating all the potential factors that may increase heat production, the minimum energy expenditure compatible with the maintenance of life can be obtained, and such a minimum value is called "*basal metabolism* or *basal metabolic rate*."
4) Heat production is obviously related to body size, and it is commonly accepted (. . . some variations/deviations though!) that "0.75" to be the power of body weight best related to basal metabolism.
5) Basal metabolism per day:

   a) "Adult homeotherms" - May be represented by the general formula "BM (kcal) = $70\text{Wkg}^{0.75}$, where the coefficient 70 represents an average value for the kilocalories of basal heat produced per unit of metabolic size in experiments with groups of adult mammals." (Maynard et al., 1979)
   b) Basal metabolism is highest in the newborn and gradually decreases during the growth period, and there are also some species & intraspecies differences, as would be expected.

E. "Basal metabolism" & "maintenance requirement?"

1) Under practical conditions, an intake of feed energy enough to balance the "fasting metabolism" is not an adequate "maintenance" value.
2) Perhaps, influenced by heat increment from ingested feed, energy to consume feed, normal activity, group size, body composition, environmental temperatures, etc.

F. Endogenous nitrogen metabolism

1) There is a minimum essential N catabolism associated with the maintenance of the vital processes of the body.
2) This catabolism is measured as the minimum urinary excretion 0n a N-free. energy adequate diet, and called "endogenous urinary N."
3) Absorbed proteins/amino acids needed for maintenance must offset the endogenous urinary losses, metabolic fecal losses (associated with the digestion of the diet), and

"adult growth" (. . . refers to the growth and renewal of hair, nails, feathers, and other epidermal tissues, which continue throughout life).

G. Minerals and vitamins?

1) Active metabolism of minerals continues during fasting, but catabolized minerals may be re-utilized instead of being excreted. Nevertheless, there is a constant excretion of mineral elements during fasting.
2) Various vitamins are, obviously, important for maintenance, as well as for productive purposes, but limited information is available on the vitamin requirements for maintenance.

2. **Growth**

A. What is Growth?

"*Throughout the animate kingdom, from the simplest microorganisms to the most complexly organized beings, that inexhaustible power of growth which ever since the genesis of the first protoplasm in the infinite past has created the structure of the fossil remains of former ages as well as our own existence-this capacity to grow, has remained as the most remarkable phenomenon of nature, the supreme riddle of life.*" (Rubner, M. 1908; Translation - Mendel, L. B. 1917. Am. J. Med. Sci. 153:1-20.)

B. Definition of the term "growth" by Schloss (1911; Cited by Maynard et al., 1979):

"A correlated increase in the mass of the body in definite intervals of time, in a way characteristics of the species."

1) Has very broad implications - Variability due to individuals, species, and developmental phase/size.
2) Considered that the maximum size and development are fixed by heredity, and nutrition is an essential factor determining whether the genetic potential will be reached.
3) Growth involves:

a) An increase in the structural tissues such as muscle and bone and also in organs, but should be distinguished from the increase that results from fat accretion in the reserve tissues.
b) Thus, essentially, growth is characterized primary by an increase in protein, minerals and water.

(1) Also, various vitamins are required!
(2) A minute amount of lipid goes into the structure of each cell, but this does not represent a specific dietary requirement (except, essential fatty acids) because of the synthesis of lipid frm carbohydrates.

C. Energy requirements for growth

1) Various nutrients are needed for growth, but the need for energy is by far the largest & primarily determines the total feed required.
2) The maintenance portion of the total energy need during growth increases with body size, but the additional need for the growth depends on the rate and the composition of the tissue being formed.
3) The amount of energy represented by the "tissue growth" decreases with age, thus reflecting the declining rate of body increase measured on a percentage basis.
4) The amount of energy stored per "unit of body increase" becomes larger with age because of its lower water content & higher fat content.
5) The "true growth tissue" contains only a trace of fat, but a certain amount of fat accretion is inevitable consequence of growth. And, in practice, a considerable amount of fattening is an integral part of growing animals for meat!

D. Protein requirement for growth

1) The theoretical minimum protein requirement for growth is the amount actually stored in the body, but this is far below the actual requirement because of the wastage in digestion and metabolism.

   a) Digestible protein can be used to taken into account the loss in the digestion.
   b) Wastage during the metabolism can be difficult to assess, and it is mostly determined by the efficiency that digested protein can supply amino acids needed for body tissue synthesis.

2) Amino acid proportions needed would not change regardless of the rate of growth, thus an appropriate amino acid balance in the diet is important for efficient and optimum protein nutrition.
3) At a very slow rate of growth? Proportions needed may differ somewhat because the needs for maintenance dominate (. . . some differences in amino acid proportions between the maintenance & growth).
4) Thus, protein quality has some impact on satisfying the amino acids/protein needs for maintenance & growth, and assessing the protein quality is very important.
5) "Wool production?" - Differ from muscle growth:

   a) Despite a negative N & energy balance, wool growth continues at the expense of the breakdown of other protein tissues.
   b) Wool fiber - Practically pure protein, and has quite different amino acid patterns vs. muscle (e.g., 10 times Cys vs. muscle protein on % basis).
   c) Practical significance - ???

E. Mineral requirements for growth

1) Some 20 mineral elements are now considered to be dietary essential, but only about half of those may have to be considered in evaluating feeds for animals.
2) Over 70% of the mineral matter of the body consists of Ca and P, and almost 99% of Ca and 80% of P are in the bones and teeth. A deficiency of either one, along with vitamin D, affects bonedevelopment.
3) The development of the skeleton cannot be assessed via the increase in weight and(or) dimension of the body or bones themselves, and the real measure is the density and strength of the bones, i.e., Ca & P and their histological structure.

F. Vitamin requirements for growth

1) Various vitamin needs for growth have been elucidated, but many data are still less precise than desirable.
2) More is known about the vitamin requirements for growth than other phases of the life cycle because deficiencies are more frequent in rapidly growing animals.
3) Often excess vitamins are provided to insure that a deficiency will not occur.

3. **Reproduction**

A. Nutrient requirements for reproduction?

1) Although there are no substances needed by the reproductive organs, which are not needed by the tissues, the metabolic pathways followed by some of the nutrients provided by the blood stream may differ from others.
2) Generally, considerable less critical than during rapid growth or heavy lactation, but certainly more critical than for maintenance.
3) Nutrient deficiencies before breeding? The result may be sterility, low fertility, silent estrus, or failure to establish or maintain pregnancy.

B. During growth:

1) Under feeding energy or protein can result in delayed sexual maturity in both the male and female.
2) Both under- and over-feeding of energy can result in reduced fertility. (Overfeeding may be more detrimental to fertility!)
3) In the male, under-nutrition decreases the number and vigor of the sperm and may cause cessation of spermatogenesis.

C. During pregnancy:

1) If the severely undernourished female during the development becomes pregnant, the drain of her body by the developing young may result in permanent damage, death of the fetus in utero, or the birth of a weak animal.
2) Energy needs for most species during pregnancy are more critical during the last one-third of the pregnancy.

3) Protein is more critical for development of the fetus in the late stages vs earlier stages, as is true for Ca, P , and other minerals and vitamins.
4) Only a relatively small portion of the total nutrient requirements are used for fetal tissue growth, even in the late gestation, indicating that the increases in other bodily functions associated with pregnancy. [The metabolic rate of pregnant female is higher (e.g., 1.5 times in a pregnant cow vs. a nonpregnant identical twin!), thus the needs are higher!]
5) With a moderate deficiency, fetal tissues tend to have priority over the dam's tissues, thus depleting the dam's body reserves.
6) If the deficiency is severe, may result in resorption of the fetus, abortion, malformed young, birth of dead, weak, or undersized young . . . just like ones severely undernourished during growth.

D. After parturition?

◦ When the dam's tissues are deleted of critical nutrients during gestation, tissue storage in the young is almost always low, nutrient concentrations in the colostrum are reduced, milk production declines, and survival of the young is much less likely.

E. Egg production:

1) Unlike mammals, birds produce eggs, which contain sufficient nutrients for the embryo to develop outside the body and no special food is required after hatching.
2) In addition to the energy requirement, there are large demands for protein and especially for mineral matter, and also for vitamins to produce an egg (. . . plus additional requirements for the actual production of the egg).
3) The average egg contains about 2 g of Ca - Nearly all of the Ca is in the shell, which contains 94% Ca carbonate. Thus, the Ca requirement of the laying hen is much, much higher than other classes of birds and other species!

4. **Lactation**

A. "*The cow is the foster mother of the human race. From the day of the ancient Hindoo to this time have the thoughts of man turned to this kindly and beneficient creature as one of the chief sustaining forces of human life!*" [W. D. Hoard (1836-1918); Cited by Maynard et al., 1979]

B. Mammary growth and lactation:

1) Milk secretion involves both intracellular synthesis of milk and subsequent passage of milk from the cytoplasm of the epithelial cells into the alveolar lumen.
2) Milk removal includes the passage withdrawal of milk from the cisterns and the active ejection of milk from the alveolar lumina.

3) Mammary growth that occurs during critical hormone-dependent stages of development, including prepubertal to late gestation, is sensitive to the plane of nutrition:

   a) Nutrient density can alter secretion of one of more hormones such as somatotropin and corticoids that regulate mammary growth and differentiation.
   b) The extent of pubertal development of the mammary gland is small, but the interactions between hormones and nutrition are important for continual and full development.
   c) An increase in nutrient density (both protein and energy) during the late stage of gestation result in an increase in mammary growth and milk yields in the bovine, rats, and pigs.

C. Biosynthesis of milk components:

1) Milk fat:

   a) Fats in bovine milk are characterized as mixed triglycerides with a large proportion of short-chain fatty acids.
   b) Major sources of fatty acids (ruminants) - Acetate and β-hydroxybuterate from rumen, triglycerides present in circulating chylomicrons and low-density lipoprotein, and cytoplasmic acetyl-CoA from glucose through glycolysis & citric acid cycle.

2) Milk protein:

   a) Major protein synthesized in bovine mammary epithelial cells? - Casein proteins (major portion!), β-lactoglobulin, and α-lactalbumin.
   b) Mechanisms? - Seem to be similar to most other protein-synthesizing cells.

3) Lactose:

   a) A disaccharide composed of glucose and galactose is the predominant carbohydrate found almost exclusively in milk.
   b) Glucose is the only precursor of lactose, and one glucose unit is converted to galactose.

4) Others:

   a) Ca, P, K, Cl, Na, and Mg are the primary minerals in milk.
   b) Vitamins cannot be synthesized by the mammary gland, thus via microbial synthesis or directly from feed. The vitamin content of milk can be increased by increasing its content in blood that supplies mammary gland.

D. Lactation in general:

1) Milk of most domestic species contains 80 to 88% water, thus water is critical nutrient needed to sustain lactation.
2) The requirement for all nutrients are increased during lactation and are directly related to the production rate - Especially, water and energy in ruminants? Protein may have a less noticeable effect, if the shortage is only for a short period, that is!
3) Milk production varies widely among and within species - e.g., in cows, peak yield usually occurs between 60 and 90 days after parturition and then gradually declines at a rate of 8-10% per month.
4) High-producing animals may have to rely on body reserves (protein & energy) to produce milk during the peak yield period simply because feed consumption peaks later.
5) The composition of diet would affect the composition of milk, especially butterfat and, to a lesser extent, protein and lactose in ruminant species - e.g., % butter fat can be increased by increasing fiber in dairy rations.
6) In nonruminant species, changes in diet may have a minimal effect on milk composition.
7) Mineral deficiencies (especially, Ca) can result in "weakened" skeletal system.
8) Often the effect of nutrient deficiencies during the lactation carry over into pregnancy and the next lactation.

DIGESTION AND(OR) METABOLISM STUDY

☛ Some other techniques used in nutrition studies (e.g., determining "true" digestibility, bioavailability, protein quality, and requirements) are included in appropriate sections!

☛ The chemical analysis is the first step for determining the nutritive value of feed, but the actual value of ingested nutrients depends on many factors. The first, and perhaps the most important consideration is "digestibility!"

1. **A Digestion Study** (Apparent Digestibility)

☛ Not considering metabolic fecal nutrient, thus the use of the term "apparent" digestibility!

A. A digestion study consists mostly of:

1) Running a proximate analysis of feed/feed ingredient,
2) Feeding an animal a given amount of feed, or feeding at a constant rate,
3) Collecting feces from given amount by use of a marker or collecting feces at a given time on a constant rate feeding,
4) Running a proximate analysis of feces, and
5) The difference is the apparent digestible portion of the feed/feed ingredient.

B. Collection of feces:

1) Use of marker in the diet at beginning and end of the collection period.

a) Some desirable properties of markers are: physiologically inert, contain no element under investigation, and will not diffuse.
b) Types of markers include: ferric oxide, chromic oxide, carmine, and soot.
c) Use of markers is not desirable in animals with larger and more complicated digestive tracts, like ruminants.
d) Using the marker method requires accurate measurement of the total amount of feed.

2) Use of metabolism or digestion stalls:

a) Can confine the animal for quantitative collection of the feces uncontaminated by urine.
b) An essential feature of these stalls is that the animal must have freedom of movement, particularly as regards lying down or getting up.
☛ Can also be designed to collect urine separately for the nutrient balance study.

3) Fecal collection bags - A bag on a harness arrangement attached to the animal, in which feces and(or) urine can be collected from animals grazing on pasture.

C.. Digestion studies generally consist of two periods:

1) Adjustment/adaptation period to free digestive tract of any prior undigested feed and accustom animal to test feed/ingredient and the facility.
2) Collection period - Actual collection of feces (& also feed samples).
3) For pigs, adjustment & collection periods of 3 to 5 days each are commonly used, whereas these periods must be extended to 8 or 10 days for ruminant species.

D. Formula:

$$\text{Apparent digestibility (\%)} = \frac{\text{Nutrient intake - nutrient in feces}}{\text{Nutrient intake}} \times 100$$

2. **Indicator Method** (Apparent Digestibility)

A. Conducting a “conventional” digestion study is a laborious and time consuming procedure, thus investigators have tried to find an indirect method of assessing digestibility.
B. One “accurate & useful” indirect method is the “Indicator Method,” which involves the use of an “inert reference substance” as an indicator:

1) Ideal specifications of indicators are:

a) Totally indigestible and unabsorbable,
b) Have no pharmacological action on the digestive tract,
c) Pass through the tract at a uniform rate,

d) Are readily determined chemically, and
e) Preferably a natural constituent of the feed under test.

2) Indicators being used? - Chromic oxide, lignin, insoluble ash, Mg ferrite, and various naturally occurring "chromogen" compounds.

C. By determining the ratio of the concentration of the reference substance to that of a given nutrient in the feed and the same ratio in the feces resulting from the feed:

1) The apparent digestibility of the nutrient can be obtained without measuring either the feed intake or feces output.
2) Formula:

$$\text{Apparent digestibility} = 100 - \{100 \; \frac{\text{\% indicator in feed}}{\text{\% indicator in feces}} \times \frac{\text{\% nutrient in feces}}{\text{\% nutrient in feed}}\}$$

MINERALS IN GENERAL

1. **Historical Perspectives**

A. The importance of mineral salts (NaCl) has been known even in the ancient times.
B. The importance of minerals in bones & teeth has been recognized very early, even though Ca was not discovered until 1808.
C. More than 150 years ago, some scientists suggested a relationship between variations in supply of trace elements and human/animal health - e.g. Fe and health [Fe as a constituent of blood (1832)] & goiter in man & deficiency of environmental iodine (1850's). (☛ But, these ideas were greeted with skepticism & controversy!)
D. The study of mineral metabolism & feeding has only existed since 1920's or 1930's:

1) Advances in chemistry & physiology enabled scientists to initiate mineral studies.
2) Synthetic diets - Useful in identifying individual macro- & microelements.
3) Interrelationships observed between chemical composition of organisms and Earth's crust were useful in understanding the importance of minerals.

E. Refinements in research/analytical techniques & instrumentation, and general understandings of metabolism have taken great prominence since about 1950!

2. **Essentiality**

A. Criteria for essentiality - Stated & debated by many investigators, e.g., "*Considered to be an essential if its deficiency consistently results in an impairment of the function from optimal to sub-optimal!*"
B. Examples of some suggested criteria:

1) Present in all healthy tissues of all living things.

2) Concentration from one animal to the next is fairly constant.
3) Withdrawal from the body induces the same physiological and structural abnormalities regardless of species.
4) Its addition either reverses or prevents these abnormalities.
5) Abnormalities induced by deficiency are always accompanied by pertinent, specific biochemical changes.
6) Biochemical changes can be prevented or cured when the deficiency is eliminated.

C. Some minerals do not meet those criteria, but found in living tissues:

1) Occur more less constantly but in variable concentrations.
2) May reflect a contact with environment or contamination because distribution patterns are often similar to environmental levels!
3) e.g., Aluminum, antimony, cadmium, mercury, germanium, rubidium, silver, gold, bismuth, titanium, and zirconium.

☛ An essential element shows a normal distribution, suggesting the existence of internal control mechanisms?

3. **Essential Elements**

A. Classification based on the content: [Georgievskii, 1982. In: Georgievskii et al. (Ed.)]

% BW	Element	Class
1-9	Ca	Macro
0.1-.9	P, K, Na, S, Cl	
0.01-.09	Mg	
0.001-.009	Fe, Zn, F, Sr, Mo, Cu	Micro
0.0001-.0009	Br, Si, Cs, I, Mn, Al, Pb	
0.00001-.00009	Cd, B, Rb	
0.000001-.000009	Se, Co, V, Cr, As, Ni, Li, Ba, Ti, Ag, Sn, Be, Ga, Ge, Hg, Sc, Zr, Bi, Sb, U, Th, Rh	Trace

B. Classification based on the function: [Georgievskii, 1982. In: Georgievskii et al. (Ed.)]

Essential	Essential?	Function (uncertain)	
Calcium	Fluorine	Lithium	Lead
Phosphorus	Silicon	Beryllium	Antimony
Potassium	Titanium	Boron	Caesium
Chlorine	Vanadium	Scandium	Barium
Sodium	Chromium	Aluminum	Mercury
Zinc	Nickel	Gallium	Tin
Molybdenum	Arsenic	Germanium	Bismuth
Selenium	Bromine	Rubidium	Radium
Sulfur	Strontium	Zirconium	Thorium
Magnesium	Cadmium	Silver	Uranium
Iron			
Copper			
Cobalt			
Manganese			
Iodine			

4. **Principal Functions of Minerals**

A. Structural

1) Minerals serve as stable insoluble compounds in bone tissues.
2) Bones usually contain more than 80% of inorganic salts in the organism.
3) Bone tissues are highly reactive & plastic, and capable of undergoing continuous structural changes.

B. Homeostasis

1) Maintenance of ionic equilibrium - All liquids in the organism are electrically neutral under normal conditions. Cations are formed by metals (Na^+, K^+, Ca^{2+}, Mg^{2+}, etc.), whereas anions are formed by acid residues (Cl^-, HCO_3^-, SO_4^{2-}, HPO_4^{2-}, $H_2PO_4^-$).
2) Maintenance of osmotic pressure:

   a) Ionized salts poduce a certain osmotic pressure, and important in promoting the migration of water and soluble substances in the tissue.
   b) Maintained by Na, Cl,and bicarbonate ions in the ECF, and K, Mg and organic substances in the ICF.

3) Maintenance of acid-base balance:

   a) The disturbance of acid-base equilibrium is counteracted in three ways - Chemical buffering, pulmonary mechanism, & excretion of H^+ ions.
   b) Buffering capacity of blood & ICF - 1° due to Hb & bicarbonate & phosphate to some extent:

      (1) Hb - 1° protein buffering agent in blood (potassium salt) - $KHbO_2 \rightarrow O_2 + KHb$; $KHb + H_2CO_3 \rightarrow HHb + KHCO_3$; $HHb + O_2 + KHCO_3 \rightarrow KHbO_2 + H_2CO_3$; $H_2CO_3 \rightarrow CO_2 + H_2O$ (account for > 70% of buffering capacity in blood).
      (2) Phosphate buffer system (Na_2HPO_4) - $Na_2HPO_4 \rightarrow$ 2 Na ions + HPO_4^{2-}; $HPO_4^{2-} + H^+ \leftrightharpoons H_2PO_4^-$; $H_2PO_4^- + OH^- \rightarrow HPO_4^{2-} + H_2O$ (only small buffering capacity in blood & tissues, but 1° buffers in urine).
      (3) Carbonate buffer system ($NaHCO_3$) - $NaHCO_3 \rightarrow Na^+ + HCO_3^-$; $HCO_3^- + H^+ \leftrightharpoons H_2CO_3$; $H_2CO_3 \rightarrow CO_2 + H_2O$

C. Cell Membranes

1) Phosphate groups in lipid molecules are important for the property of membranes, i.e., permeability, ion transfer and generation of nerve impulses.
2) Bivalent metals (especially, Ca) can participate in bonding of cell membranes (i.e., combine with ⊖-charged groups).
3) Sodium pump moves Na ions out of the cell & moves K ions into the cell.
4) Membrane potential can be created by the difference between ionic composition of Na & K (1° by the difference in K ions on either side of the membrane).

D. Enzyme Systems

1) Metalloenzymes - e.g., cytochrome oxidase (Cu), NADH-dehydrogenase (Fe), pyruvate carboxylase (Mn), carboxypeptidases (Zn), etc.
2) Minerals may serve as an activator of one or more enzyme systems:

    a) Examples - Na, K, Rb, Cs, Mg, Ca, Zn, Cd, Cr, Cu, Mn, Fe, Co, Ni, Al.
    b) How? - Perhaps, ↑ selectivity of the enzyme with respect to substrate, direct participation in the catalytic process by oxidation-reduction reactions, ↑ bonding of substrates to the enzyme by creating a coordination bond & altering the shape of substrate, and(or) binding/holding coenzyme & substrate to the enzyme at the same time.

E. Hormones (interaction of minerals and hormones)

1) Direct incorporation into the hormone structure - e.g., disulfide bridges (insulin, prolactin, etc.) & I for thyroid hormones.
2) Formation of complexes with hormones - e.g., Zn and insulin (Zn enhances bonding/liberation of insulin & protein granules of β-cells).
3) Participation in the formation of enzyme systems at target organs - Hormones may interact with metal ions . . . component of enzyme systems and(or) hormone may be acting as an ion carrier?

F. Functions via microflora - Some elements are essential elements for microorganisms, which in turn can produce metabolites that are beneficial for the host - e.g., Co for microorganisms to produce vitamin B_{12}, reduction of sulfates to sulfides by bacteria, which can be used for the synthesis of sulfur amino acids & others.

5. **Metabolism of Minerals**

A. General:

1) Present in feeds as organic compounds and mineral salts.
2) Once dissolved or acted by enzymes (e.g., phytin by phytase), then minerals become assimilable or utilizable.
3) Minerals in feeds & digestive juices: a) Present in chyme as ions, b) Interact & form various organic complexes, and c) Under certain conditions, form salts of low solubility, which are practically inassimilable.
4) Minerals are excreted extensively into the GI tract (along the entire GI tracts): a) Ensures normal metabolism of minerals, and b) Creates optimum conditions for absorption of minerals.
5) Exchange between the GI tract & blood: a) Very extensive for a number of elements, and b) Quantitative estimation of secretion/absorption is very difficult!

B. Absorption and excretion:

1) The wall of the GI tract is permeable to minerals in both directions.
2) The site of absorption is generally known, but little is known about the mechanism:

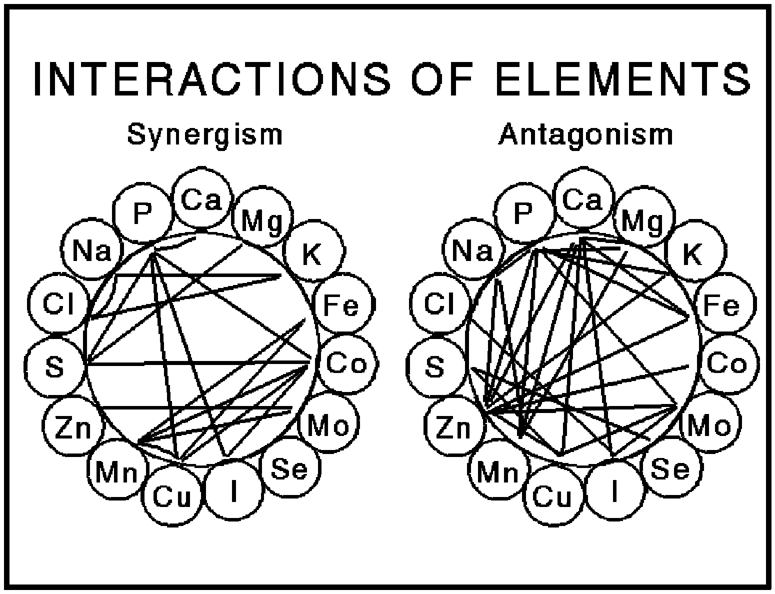
   a) Some minerals are absorbed by active transport (e.g., Ca & Fe).
   b) Most by facilitated diffusion (e.g., Co, Cr, Cu, Mn & Zn).
   c) Others by passive diffusion.
   d) Few by more than one mechanism (e.g., Ca).

☛ With exception of Na & K, most minerals form salts & other compounds, thus relatively insoluble & not readily absorbed.

6. **Interaction of Minerals**

A. Interactions in general:

1) May interact with each other, other nutrient and non-nutritive factors.
2) May be synergistic or antagonistic.
3) Interactions can take place: a) in the feed itself, b) in the digestive tract, and c) during tissue & cell metabolism.



B. Interactions among minerals:

1) Metabolic interactions of essential elements: [Redrawn from Georgievskii, 1982. In: Georgievskii et al. (Ed.)]
2) Synergism in the digestive tract - Mutually enhance their absorption?

   a) Direct interactions - e.g., Ca with P, Na with Cl, Zn with Mo.
   b) Through phosphorylation & activation of digestive enzymes - e.g., P, Zn & Co on their liberation from feed, and subsequent ↑ absorption of others.
   c) Indirect interactions, i.e., stimulation of growth/activity of microflora - e.g., Stimulation of rumen microflora by Co, which in turn may have beneficial effects on others.

2) Synergism at the tissue and cell metabolism level:

   a) Direct interaction in structural process - e.g., Ca & P in bone hydroxyapatite, Fe & Co in formation of Hb, etc.

b) Simultaneous participation in the active center of enzymes - e.g., Fe & Mo in xanthine & aldehyde oxidases, Cu & Fe in cytochrome oxidase, etc.
c) Activation of enzymes, i.e., ↑ synthetic processes that need other minerals - e.g., Mg on synthetases with subsequent participation of P, S & others.
d) Activation of endocrine systems - e.g., I & thyroid hormones → ↑ anabolic processes → ↑ retention of P & Mg in the body.

3) Antagonism in the GI tract - May be one- or two-sided:

a) P & Mg or Zn & Cu - Inhibit absorption of each other.
b) K inhibits absorption of Zn & Mn, but not the other way around.
c) Simple chemical reactions - e.g., Formation of Mg phosphate, Cu sulfate, Ca-P-Zn salt, etc.
d) Adsorption at the surface of colloidal particles - e.g., Fixation of Mn & Fe on particles of insoluble Mg or Al salts.
e) Antimetabolic effects of B, Pb, Tl & others - Interfere with breakdown of feed ingredients, liberation & absorption of ions.

4) Antagonism in the tissue metabolism:

a) Competition for an active center of enzyme - Mg^{2+} & Mn^{2+} in alkaline phosphatase, cholinesterase, etc.
b) Competition for a carrier - Fe^{2+} & Zn^{2+} for a bond with plasma transferrin.
c) Activation of enzymes with opposite functions - e.g., Cu and ascorbate oxidase ⇔ Zn/Mn and lactonases.
d) Antagonistic effect on a given enzyme - e.g., Activation of ATPase by Mg^{2+} and inhibition by Ca^{2+}.
e) Reduction of toxic effect - e.g., ↓ of Pb concentration in the body by addition of Cu, Zn & Mn.

C. Interaction with other substances:

1) Vitamin D - Affects absorption of Ca, P, Mg, Zn & others.
2) Fats - Affect absorption of Mg & Ca.
3) Protein - Affects the degree of utilization of P, Mg, Zn, Cu and others.
4) Chelates (AA, polypeptides, proteins, porphyrin derivatives & other heterocyclic compounds, organic acids, etc.) - Form complexes with minerals.
5) Others - Antibiotics, antioxidants, other vitamins, carbohydrates, etc.

7. Fish & Minerals in General

A. General:

1) One difficulty associated with fish research is that fish can absorb minerals from water via gills & skin.

2) The primary difference between fish & land animals is osmoregulation, and other aspects may be very similar.
3) Mineral requirements have been studied only sparsely, and there are still many questions on requirements/optimum physiological functions in most fish species.

B. Difficulty in studying/establishing mineral requirements:

1) The exchange of ions from the environment across gills & skin complicates the quantitative determination.
2) Requirements for some trace elements are so small, and difficult to formulate/provide a purified diet & water low in the mineral in question.
3) Detection/measurement of some minerals - Still difficult despite advances in the technique, and reported "normal values" range widely from one Lab to the next.
4) Mineral content of blood, muscle, liver & bones - Changes in the function of organs/tissues are very slow until a clinical toxicity or deficiency develops, and a wide range of tissue concentrations are compatible with optimum growth & functions.

C. Distribution of elements:

1) Most species accumulate & retain minerals from environment - e.g., Salmonid fish can absorb Ca, Mg, Na, K, Fe, Zn & Cu from environment to satisfy their nutritional requirements. (But, considerable variations in the incorporation rate!)
2) Eggs can absorb certain minerals from water (e.g., Na, Fe & Zn in rainbow trout), and absorption of others (e.g., Mn, Se) by eggs after fertilization has been demonstrated.
3) Absorption/accumulation in embryos may increase with the development of gills.

D. Skeletal tissue metabolism:

1) Like most vertebrates, the skeleton represents a reservoir of Ca, P and other ions.
2) Morphologically, fish bones consist of dermal bones of head, internal skeleton, and scales.
3) Histologically, basically similar to that of higher vertebrates, but do not have any hematopoietic element within the bone.
4) Two types of fish bones - Cellular (confined to only a few groups of fish, e.g., Salmonidae, Cyprinadae & Clupeidae) & acellular (. . . formed from osteoblast cells . . . incapable of extensive modeling).
5) Scales:

    a) Formed by replacement of dermal connective tissues during intramembranous ossification.
    b) Consist of two layers - A superficial mineralized bony tissues & hydrodentine layer.
    ☛ But, there are many variations in fish scales & their structures.

6) Mineral phase of fish bone - Poorly crystallized apatite, and crystals in acellular bones are smaller & more strained vs. cellular bones. Main constituents of fish vertebrae are Ca, P, carbonate with small amounts of Mg, Na, Sr, Pb, citrate, F, hydroxide, and sulfate.

E. Environmentally induced toxic elements - Fish & aquatic organisms can accumulate & retain trace elements drawn from their environment.

1) The solubility of trace elements in natural water is affected by pH, type & level of ligand & chelating agents, oxidation state, and redox environment of the system.
2) Soluble forms? Usually ions or un-ionized organometallic chelates or complexes absorbed via gills & body surfaces, and also from ingestion of food or water.
3) Regulation of abnormal concentrations - variations among species:

(a) Certain fish & crustaceans can excrete high proportions of excessive metal intake.
(b) Fingerlings/newly hatched fish may be poor regulators of excess intakes.
(c) Gills, GI tract, feces & urine are involved in regulatory & excretory processes.

8. **Methods of Studying Mineral Metabolism**

A. Absorption & retention by the balance study:

1) Absorption = Element_{feed} - Element_{feces}
2) Retention = Element_{feed} - (Element_{feces} + Element_{urine})
☛ True absorption or retention cannot be determined by the balance method!

B. Absorption rates at various sections of the GI tract using inert substances (Cr, polyethylene glycol, etc.):

1) Sacrifice animals or use fistula.
2) % Absorption = 100 x [1 - (E:label) in feces or chyme/(E:label) in feed]

C. The use of radioactive indicators:

1) Possible to study, e.g., a) Exchange between digestive tract & blood, b) incorporation of minerals into tissues, c) magnitude of reserves, & d) transplacental passage.
2) Interpretation of results is often very difficult.

D. Angiostomy of blood vessels and analysis of blood:

1) Use catheters in blood or lymph vessels.
2) Useful in studying dynamics of absorption, type of bonds formed with carriers, accumulation in the live/other organs, etc.

E. Perfusion of isolated rumen, intestine, etc. - Useful in studying ion transport mechanisms, role of various segments in absorption, interaction of elements, etc.
F. Obtain samples via fistula and incubate (*in vitro*) - Useful in studying the effect (or function) of minerals on microflora of the digestive tract, etc.
G. Slaughter or biopsy technique - Can determine the mineral content of important organs & tissues (liver, bones, skin, etc.).

9. **Determination of Requirements - Methods**

A. Factorial method:

1) Based on:

a) Deposition in the body (D) - Usually by chemical analysis of animals slaughtered at various stages of growth.
b) Endogenous losses (E) - By analysis of urine, and by radioisotope studies of losses via feces.
c) Deposition in fetus & reproductive tissues (F) - By chemical analysis during various stages of pregnancy.
d) Elimination via milk (M) - By estimating/determining milk yield/d and composition.
e) Actual assimilation of element from feed (Y) - Usually by radioisotope studies.

2) Formulas for estimating the daily requirement: (D, E, F & M → mg or g/day & Y = % of daily intake)

a) Growing animals - (D + E)/Y * 100
b) Pregnant animals - (F + E)/Y * 100
c) Lactating animals - (M + E)/Y * 100

☛ Accuracy & reliability of the estimate depend on completeness and reliability of data used in calculation.

B. Balance tests:

1) The oldest and most popular method used until recently - Most often used for macroelements.
2) Complicated, laborious and require a high accuracy from collection to analysis.
3) The balance of minerals is affected by many factors (environment, physiological conditions, etc.).
4) Loss of minerals from skin?
☛ May have a limited-value in estimating the requirement.

C. Practical feeding trials:

1) Use various dietary levels, and estimations are made based on productivity, health, reproductive capacities, etc.
2) Advantages include simplicity, minimal use of equipment(s) and applicability under many different conditions.
3) Drawbacks include the need for more animals/standardized feedstuffs, time consuming, animal's access to other sources (e.g., soil).
4) Popular and fairly reliable method.

D. Analysis of organs, tissues & whole body:

1) Based on the initial & final compositions.
2) Can determine actual deposition in organs and tissues, and it does not involve collection of urine or feces (& also less analytical work?).
3) Drawbacks include difficulty in determining mineral content of whole body of large animals, and also must be conducted over a long period of time.

10. **Mineral Supplementation? (e.g., Pigs)**

- Mineral content of corn-soybean meal & mineral requirements:

Mineral	Corn	SBM	Corn-SBM	Requirement[a]
Calcium, %	0.02	0.28	0.07	0.60
Phosphorus, %	0.28	0.65	0.32	0.50
Available P, %	0.04	0.20	0.08	0.23
Sodium, %	0.01	0.01	0.01	0.10
Chlorine, %	0.05	0.05	0.05	0.08
Magnesium, %	0.11	0.14	0.14	0.04
Potassium, %	0.33	2.00	0.66	0.23
Sulfur, %	0.11	0.40	0.16	?
Copper, ppm	4	20	7	4
Iron, ppm	33	165	60	60
Manganese, ppm	6	28	10	2
Zinc, ppm	19	46	24	60
Iodine, ppm	0.03	0.16	0.06	0.14
Selenium, ppm	0.07	0.07	0.07	0.15

[a]Mineral requirements for 20-50 kg pigs (NRC, 1988).

VITAMINS IN GENERAL

1. Historical Perspectives

☛ See Maynard et al. (1979), McDowell (1989) & others.

A. Various diseases plagued the world since the existence of written records (at least) - e.g., scurvy, beriberi, night blindness & pellagra - Became known as "vitamin deficiency diseases" later.

1) Beriberi - The earliest documented deficiency disorder, and recognized in China as early as 2,600 B.C.
2) Scurvy, night blindness & xerophthalmia - Described in the ancient Egyptian literature around 1,500 B.C.
3) Various remedies used for disorders:

a) Livers for night blindness & xerophthalmia - Around 400 B.C. by Hippocrates.
b) Broth of evergreen needles for scurvy - Used by Canadian Indians to cure Jacques Carter's crew affected by scurvy.
c) Juice of citrus fruits for scurvy - By James Lind in 1747.
d) Cod liver oil for rickets - Used long before anything was known about the cause. Feeding to farm animals started early 1800's?
e) ↑ consumption of vegetables, fish and meat, and substitution of white rice with barley to cure beriberi. Used by the Japanese physician, Takaki, in the late 1800s.

B. In the early 1800s:

1) Prout stated that "*Three proximate principles provided the essential nutritive constituents of all organized bodies*."
2) Saccharine principle - carbohydrates, oily principle - fats, and albuminous principle - proteins.

C. For many years, "Three principles + minerals" are considered to be adequate to meet all the nutritive needs of the body.

D. Then came a gradual recognition that minute amounts of other organic compounds must be present in the diet!

1) In the late 1800s, people recognized the relationship between the diet & diseases, i.e., certain foods cured or prevented diseases!
2) In 1881, the Swiss biochemist N. Lunin stated that "*With diets composed solely of purified fat, protein, carbohydrates, salts and water ... animals did not survive!*"
3) Takaki (1887) noticed that the incidence of beriberi can be reduced by supplementing polished rice diet with more meat, vegetable & milk.

4) Eijkman (1897) found that polyneuritis in bird & beriberi can be cured by adding polishings back to a polished rice diet.
5) Hopkins stated in 1906, "*No animal can live on a mixture of pure protein, fat and carbohydrate, and even when the necessary inorganic material is carefully supplied, the animal still can not flourish.*" ☞Termed an unknown essential nutrient as an "Accessory Growth Factor!"
6) Medical community's reactions?

   a) The scientists trained in medicine were reluctant to believe that certain diseases resulted from a shortage of specific nutrients in foods.
   b) Possible reasons for slow evolution of knowledge of the vitamin? - A dominant status of pathologists (Pasteur & Koch) during latter part of 19th century, and medical doctors at that time had little or no training in chemistry.

E. In 1912, Casimir Funk proposed the term "vitamine" for a distinct factor that prevented beriberi - Derived from words "vital amine!" Found to be later that not all vitamines contain nitrogen (amine), thus the term changed to "vitamin" later.
F. After 1913, the extension of the knowledge of vitamins proceeded very rapidly!
G. By 1915, E.V. McCollum and M. Davis found that rats may require at least two essential growth factors:

   1) "Fat-soluble A" factor that was found in butter - Extractable from food with fat solvents.
   2) "Water-soluble B" factor that was associated with beriberi - Extractable with water.

H. 1930s & 1940s - A "golden age" of vitamin research, i.e., isolation, identification, establishment of metabolic functions of various vitamins, etc.

2 Definition of Vitamin

A. Wagner and Folkers [1964. Cited by Sullivan, Univ. of Nebraska] - An organic compound, which:

   1) Is a component of natural food, but distinct from carbohydrates, fats, proteins, minerals & water.
   2) Present in food in a minute amount.
   3) Is essential for a development of normal tissues, health, growth and maintenance.
   4) Can result in a specific disease or syndrome when absent from the diet or not properly absorbed or utilized.
   5) Cannot be synthesized by the animals and must be obtained exclusively from the diet.

B. Later by Folkers [1969. Cited by Sullivan, Univ. of Nebraska]:

1) An organic substance of nutritional nature present in low concentration as a component of enzymes, and
2) It catalyzes reactions and may be derived externally or by intrinsic biosynthesis.

3. **Deviation from the Classic Definition**

A. Ascorbic acid - Synthesized from glucose by most species often in sufficient amounts to meet their needs.
B. Vitamin D - Produced from precursors in the skin by ultraviolet light, and also its active form can be considered as a hormone.
C. Niacin - Can be produced from Trp.
D. Choline - Can be produced by amination & subsequent methylation of Ser.

4. **Classification of Vitamins** (McDowell, 1989)

Vitamin	Synonym
Fat soluble:	
Vitamin A_1	Retinol
Vitamin A_2	Dehydroretinol
Vitamin D_2	Ergocalciferol
Vitamin D_3	Cholecalciferol
Vitamin E	Tocopherol
Vitamin K_1	Phylloquinone
Vitamin K_2	Menaquinone
Vitamin K_3	Menadione
Water soluble:	
Thiamin	Vitamin B_1
Riboflavin	Vitamin B_2
Niacin	Vitamin pp, Vitamin B_3
Vitamin B_6	Pyridoxol, Pyridoxal, Pyridoxamine
Pantothenic acid	Vitamin B_5
Biotin	Vitamin H
Folacin	Vitamin M, Vitamin B_c
Vitamin B_{12}	Cobalamin
Choline	Gossypine
Vitamin C	Ascorbic acid

5. **General Characteristics of Vitamins**

A. Fat soluble vitamins:

1) Consist of only C, H & O.
2) Metabolized along with fat in the body - Digested with fat & require fat for absorption and transport. Transported in the blood by lipoproteins or specific binding proteins.
3) Stored in the liver (vitamins A, D & K) or adipose tissues (vitamin E), ∴ can serve as reserves.
4) Tissue accumulation can reach toxic levels & vitamin A & D toxicities are well defined. (∴ megadoses are potentially dangerous!)
5) Signs of deficiency can be directly related to functions of the vitamin.

B. Water soluble vitamins:

1) In addition to C, H & O, some also contain N, S or Co.
2) Generally associated with fluid compartments of the body.
3) No appreciable storage, ∴ must be supplied continuously in the diet.
4) Excess (i.e., > tissue saturation) - Excreted in urine, ∴ generally non-toxic.
5) Deficiency is rarely caused by a single vitamin, and difficult to relate signs to functions in most instances, i.e., non specific! Symptoms are often reflection of the most limiting vitamin in the diet.

6. **Vitamin Deficiencies and Requirement**s

A. Borderline deficiency - May be deficient in vitamin(s) but exhibiting no known symptoms of vitamin deficiency or very difficult to detect. Can result in a poor performance, thus costly!

B. Multiple deficiencies:

1) Usually don't see a single vitamin deficiency in practical situations.
2) Symptoms are often a combination of signs described for various vitamins, or may be entirely different symptom(s).
3) Various conditions such as unthriftiness, reduced appetite & poor growth are common to malnutrition in general.

C. Vitamin needs becoming more critical?

1) Possible reasons for ↑ needs in recent years:

a) Selection, cross breeding, etc.- Meatier & faster growth, thus alter vitamin needs?
b) Genetic differences in animals - Can alter vitamin needs?
c) Increased use of the confinement & slotted floors (or cages) - ↓ the opportunity for coprophagy, and change in the environment can lead to ↑ stress, disease levels, etc., which would affect the vitamin needs.

2) New varieties of plants, newer methods of handling & processing of ingredients & feeds - Variations in vitamin levels & availability.
3) Trends in early weaning in swine - ↑ vitamin requirements.
4) Increased use of grain-soy type diets - Less use of vitamin rich sources.
5) Increased use of antimicrobial agents - ↓ biosynthesis of many vitamins.

D. Vitamin contents in corn & soybean meal vs. requirements (e.g., with pigs)

Vitamin, unit/kg	Corn	SBM	Corn-SBM	Requirement[a]
Vitamin A, IU	200	-	161	1300
Vitamin D, IU	-	-	-	150
Vitamin E, IU	21	3	17	11
Vitamin K, mg	-	-	-	.5
Vitamin C, mg	-	-	-	?
Riboflavin, mg	1.1	3.0	1.4	2.5
Pantothenic acid, mg	5.1	16.5	6.9	8.0
Niacin, mg	-	28.0	4.8	10.0
Vitamin B_{12}, µg	-	-	-	10.0
Choline, mg	500	2600	850	300
Pyridoxine, mg	6.2	6.0	4.0	1.0
Thiamine, mg	3.7	6.0	4.0	1.0
Folacin, mg	0.3	0.6	0.4	0.3
Biotin, mg	0.07	0.30	0.11	0.05

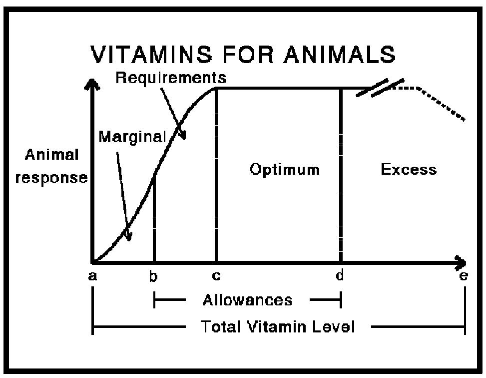
[a]Requirements for 20-50 kg pigs (NRC, 1988).

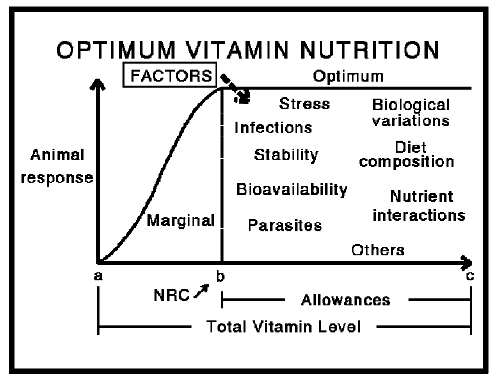
☛ Vitamines routinely supplemented in swine diet - Vitamins, A, D, E & K, riboflavin, pantothenic acid, niacin, vitamin B_{12} (& choline?). (Pyridoxine, folacin & biotin - ?)

E. Requirements

1) Requirements/allowances:

a) NRC - Usually close to minimum levels required to prevent deficiency signs.
b) Allowances - Total levels fed to compensate for factors affecting the need.
c) Optimum vitamin nutrition for animals: (Adapted & redrawn from McDowell, 1989)





F. Factors that can affect the requirements:

1) Physiological status of animals and the purpose of production - Age, health, nutritional status, etc., and also purposes or production of meat, milk, eggs, wool, developing fetus(es), etc.
2) Presence of vitamin antagonists - Interfere with the activity of vitamins by cleaving a molecule (e.g., thiaminase on thiamin), forming a complex with vitamin (e.g., avidin & biotin), and occupying reaction sites of vitamin (dicumarol & vitamin K).
3) Level of other nutrients in the diet - e.g., Level of fat (absorption of fat soluble vitamins), Se (affects vitamin E status/requirement), and vitamin D (Ca & P would be affected).
4) Body reserves - Body stores of fat soluble vitamins and vitamin B_{12}, e.g., vitamin A (stored in liver & fatty tissue) can be enough to meet the requirement for a period up to 6 mo, or even longer.

7. **Supplementation**

A. Various species - Metabolic needs are similar, but dietary needs for vitamin differ widely. (Mainly due to the difference in their ability to synthesize vitamins.)
B. Swine, poultry & other monogastric animals:

1) Depend on their diets to a greater extent compared to ruminants.
2) Intestinal synthesis of B vitamins - Although not extensive vs ruminants, considerable! But, occurs in the lower tract, thus the absorption rate would be low!?
3) Those habitually practice coprophagy (rat, rabbit, etc.)? Significant contributions from the intestinal synthesis of B vitamins!

C. Horses:

1) Lack of information on the type & level of vitamins needed in horses fed so called "well-balanced" diets.
2) Most likely to be deficient in vitamins A & E (& D in the confinement), but the requirements can be met with a high-quality, sun-cured hay!
3) Deficiency of vitamin K and B vitamins in mature horses? - Less likely vs other nonruminants, but, the absorption rate of vitamins synthesized in the cecum is unknown!
4) Supplementation? With ↑ use of the total confinement and uncertainty in the absorption rate, likely to see ↑ vitamin supplementation!

D. Ruminants:

1) Grazing animals - May be deficient in vitamin A (if low in carotene), and possibly vitamin E?
2) Diet + biosynthesis - May be adequate to meet the B vitamin requirements?

    a) The ability to synthesize B vitamins (adequate amounts) - As early as 8 d & certainly by 2 mo after birth.
    b) Significant contributions by ruminal flora!

3) Under specific conditions (stress & high productivity) - May need supplementation, e.g., thiamin & niacin!?
4) Beneficial effects of a complete B-vitamin mixture:

    a) Fed to cattle entering feedlot during the first mo → ↓ stress & ↑ gains. [Lee, 1984. Feedstuffs 56(39):16]
    b) Fed to feedlot calves → ↓ morbidity, indicating the inadequate synthesis of B vitamins under stress? (Zinn et al., 1987. J. Anim. Sci. 65:267.)

DIGESTIVE PHYSIOLOGY

- *See Kidder and Manners (1978), Maynard et al. (1979), Davenport (1982), Moran (1982), Swenoen and Reece (1993), Kellesm and Church (1998), Yen (2001) in Lewis & Southern (2001), Jurgens (2002), and others for details/additional information.*

INTRODUCTION

1. **Classification of Various Digestive Systems?**

   A. Variations among the GI tracts of the common domestic animals are related to the type of diets they consume & utilize.
   B. Generally, animals are classified into groups based on their type of diet . . . with many subgroups:

      1) Herbivores - Animals that consume primarily plant materials.
      2) Carnivores - Animals that eat other animals.
      3) Omnivores - Animals that eat a combination of plant and animal matter.

   C. Classifying animals based on their digestive physiology?

      1) Nonruminant animals

         a) Pigs - Nonruminant animals that are omnivorous, thus consume both plant and animal matter.
         b) Poultry - Nonruminants that are omnivorous, and they have a complex foregut (three sections that replaces the normal stomach) and a relatively simple intestinal tract.
         c) Dogs and cats - Nonruminant animals that are carnivorous.
         d) Horses and mules - Nonruminant animals, but they are herbivorous and have a rather large and complex large intestine.
         e) Rabbits - A nonruminant animal that is a herbivore with a complex large intestine.

      2) Ruminant animals

         a) Capable to consume and digest plant materials and classified as herbivores.
         b) Include cattle, sheep, goats, deer, elk, and many other wild species.

2. **Similarities & Differences Between Pigs & Poultry**

   A. Similarities?

      1) Are nonruminants, thus less "meaningful" symbiotic relationships with microorganisms along the gastrointestinal system vs ruminants.

2) Need amino acids, not protein *per se*.
3) Have a limited ability to utilize fibrous components of the diet.
4) Diets consist predominantly of grains and soybean meal in the modern production system, ∴ more susceptible to mineral and(or) vitamin deficiencies.
5) Are raised in confinement facilities in the modern production system.
6) Are relatively fast growing & efficient in conversion of feed to body tissues.

B. Differences

1) Pigs are delivered in the "litter," and chicks are hatched from the "egg" - "Chicks" embryonate away from its dam, ∴ eggs must contain all essential nutrients before being laid/incubation!
2) Pigs have hair, and chicks have feathers - "Chicks" - Feathers make up a relatively larger proportion of body weight, ∴ influencing the requirement for certain amino acids.
3) Pigs have an immature digestive system at birth, whereas chicks have a full complement of digestive enzymes at hatching - "Chicks" can utilize corn and soybean meal diets efficiently from day one, whereas baby pigs must depend on milk or milk-based diets!
4) Chicks have higher metabolic rate, respiration rate and heart rate. (May want to read : "Schmidt-Nielsen, K. 1970. Energy metabolism, boy size, and problems of scaling. Fed. Proc. 29:1524-1532.")
5) Laying hens mobilize large amounts of Ca, and are susceptible to leg problems. (Also true for lactating sows!)
6) Chicks have a different digestive tract and digestive process:

   a) No teeth.
   b) Have a crop and gizzard, and no true stomach for storage or enzyme secretion.
   c) Have two ceca which contribute little to digestion.
   d) Have a very fast rate of digesta passage.
   e) Absorb fatty acids via portal system - Lymphatic system is poorly developed.
   f) Excrete N as "uric acid" - Influences the requirement for certain amino acids, and dietary metabolizable energy values.

3. **How About Horses and Ruminant Species?**

A. Horses?

1) Classified as one of the nonruminant species based on the anatomy of the digestive tract.
2) But, more specifically, the horse is a "hind gut fermenter," thus may have some advantages of both nonruminant and ruminant species in terms of satisfying the protein/amino acid and vitamin needs, an also the utilization of fiber.
3) Horses & digestive system?

a) Horses may have evolved as a continuous grazer and better equipped to utilize small frequent meals rather than large meals of readily fermentable concentrates.
b) Their digestive system can be easily overwhelmed, and develop various problems such as excessive gas production, colic, stomach rupture, laminitis, etc.

4) Feed to maintain hindgut function:

a) Maximize the contribution of forage - Ensure adequate fiber intake.
b) More frequent, smaller meals - Regularity of feeding might be crucial.
c) Reduce carbohydrate overload of the cecum - Manage the feeding program to promote gut homeostasis.

B. Ruminant species?

1) Ruminants, so named because they ruminate (chew the cud).
2) There are major modifications of the GI tract relating to the stomach area, which is divided into four compartments - a nonsecretory forestomach and a secretory stomach compartment.
3) A few species (such as the camel & related species), the stomach has only three compartments, thus classified as pseudoruminants.
4) In herbivores, 20% or more of the diet may consist of substances that can be digested only by the action of microorganisms.
5) Ingested feed is subjected to very extensive pregastric microbial fermentation:

a) Most of the ingesta (60 to 75%) are fermented by microbes before being exposed to the gastric and intestinal digestive processes.
b) Thus, very different system vs a typical nonruminant animal.

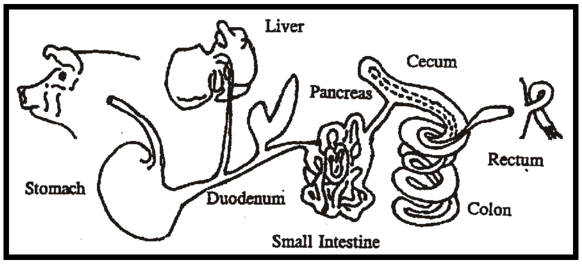
6) The symbiotic relationship between microorganisms and host is developed to the highest degree in ruminants simply because the rumen provides the favorable environment.

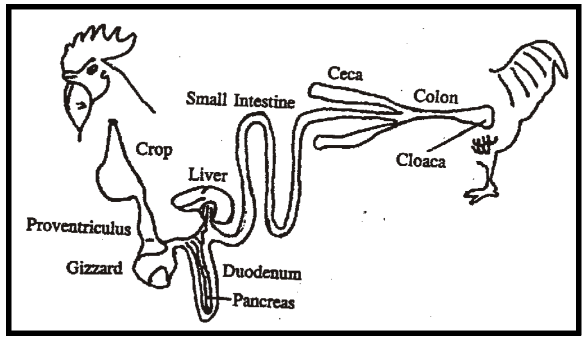
FROM FEED DETECTION TO ESOPHAGUS

1. Food/Feed for Our Animals?

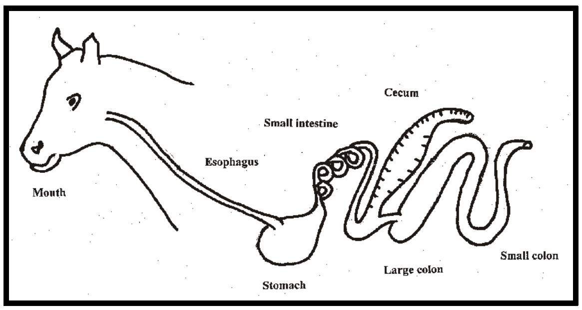
"*We feed our horses hay and oats, with grass for cows and sheep and goats.*
Chickens look for grain to eat, while ducks find worms, and dogs get meat.
Cats have meat and milk and fish.
To each, its own peculiar dish. Some are fussy, others not,
but pigs, of course, will eat a lot.
(Kidder & Manners, 1978)

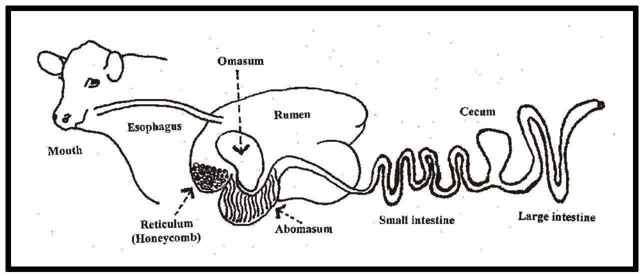
2. **Pig's & Fowl's Gastrointestinal System** [Redrawn from Moran (1982)]





3. **Horse's & Cattle's Gastrointestinal System** [Redrawn from Jurgens (2002)]





4. **Sight & Smell**

A. Normally, all domestic species use their eye to some degree in finding food, thus it must be considered as one of the initial steps/aspects of nutrition.

B. Smell & taste have a great effect on the palatability and consumption of feedstuffs:

1) Much remains to be learned about the interaction of the chemical sense in determining food intake & their practical applications.
2) Goats - Enjoy a wide variety of plants that are distasteful to others because they do not have taste receptors that correspond to bitter taste sensations in humans.
3) Cattle prefer Bermuda grass to many other kinds of forage, but may eat poisonous weeds that they usually ignore when forage is scarce, indicating they can distinguish feedstuffs, perhaps based on smell and(or) taste.

C. Some proposed models on food preference in ruminants [Pisani, J. M. (Accessed 2005). http://canis.tamu.edu/wfscCourses/Concepts/FoodPref.html]:

1) Euphagia - Animals would have preprogrammed capacity to recognize nutrients and toxins through the smell and taste?!
2) Hedyphagia - Animals harvest nutritive food because they are pleasant to smell, taste and touch. Contrarily, animals avoid toxical foods because they smell and taste bad.

3) Body morphology and size:

   a) Morphological adaptations of ruminants constrain the range of foods they can eat.
   b) Mouth size, mobility of lips, form of teeth & development of multichamber stomach determine that some are grassers (e.g., cattle, sheep, bison), browsers (e.g., giraffe, deer, some antelopes), or mixed (e.g., goat, some antelopes).
   c) Smaller animals - Should select foods with high digestibility because of their higher metabolic rate vs larger animals.

4) Learning through foraging consequences - Based on positive or negative "postingestive feedback" as determinant of food preferences, which involve possibly taste receptors (olfactory) and viscera receptors.

D. Pigs and poultry:

1) Fowl and pig retinae have both rod and cone cells, thus they can see "color" - It is thought that primates, birds, reptiles, amphibians and fish perceive color much better than domestic mammals such as pigs.
2) Birds have poor sense of smell, thus they depend mostly on acute eye sight in seeking food, whereas pigs are completely opposite!
3) Poultry:

   a) Eyes occupy a larger proportion of head in fowl than in pigs, and also domestic fowl's eyes are located laterally on the head (vs frontal in pigs), thus a much greater panoramic view or larger retinal image for birds vs pigs.
   b) Have a greater No. of visual cells communicating to the brain (vs pigs).
   c) Have a poorly developed sense of smell.
   ☞ Their sense of smell may be oriented toward other purposes, i.e., other than feed detection and(or) evaluation such as ascertaining "orientation & direction."

4). Pigs:

   a) Eyes are recessed and shielded, and also their eyes are located more frontally (i.e., about 70° visual axis) than other non-carnivorous animals, thus a lower visual capacity compared to birds. (Probably, the result of an evolutionary protective mechanism arising from extensive burrowing in the search of food?)
   b) Overall, pigs are well equipped with olfactory apparatus, and the sense of smell is used extensively in seeking/evaluating feeds. (Also, important in detection of sex steroids, identification of individuals, etc.)

5. **Mouth**

A. Prehension:

1) Refers to seizing and conveying of food to the mouth.
2) Vary among different animals, but the lips, teeth, and tongue are the principal prgans of this function.
3) The dog & cat often use their forelimbs to hold food, but it is passed into the mouth largely by the movement of the head and jaw.

B. The relative importance of the mouth and its components (teeth, tongue, cheek, and salivary glands) varies with species.

C. In most species, the functions of the mouth would be to bring in feed, mechanically brea it up, and mix it with saliva, which act as a lubricant to facilitate swallowing.

D. Pigs:

1) Snout for rooting & digging for food, lips for prehension, and cheeks to aid mastication and mixing.
2) Teeth? Incisors for biting, grazing, etc., molars for chewing to divide food into fine particles, thus increasing the surface area, and to mix with saliva for swallowing. Also, have canine teeth, which is long and sharp in the male.

E. Poultry:

1) No teeth and swallow their food whole.
2) Comprised largely of "hard" tissues, i.e., very little oral manipulation of food.
3) Thus, having a difficulty in consuming larger or smaller particles because:

   a) Cannot divide if too large, and
   b) Reduce the efficiency (i.e., need the additional work, which ↑ the energy expenditure) if too fine.

F. Horses:

1) Prehensive agents include teeth, upper lips, and tongue, but the sensitive, mobile lips during feeding from a manger.
2) During the grazing, the lips are drawn back to allow the incisor teeth to severe the grass at its base - Use both vertical & lateral movements of the jaws to shred fibrous plant materials.
3) Upper jaw is wider than lower jaw, thus mastication on only one side of the mouth at a time.

G. Ruminant species - Cattle & sheep:

1) No upper incisors & only an upper dental pad and lower incisors, which act in conjunction with lips and tongue for prehension of feedstuffs.
2) The lips have only limited movement, thus the tongue is the main perhensive organ.

3) The tongue is long, rough, & mobile - Can be readily curved through herbage, which is drawn between incisor teeth & dental pad & severed by movement of the head.
4) Because of the shape and spacing of the molar teeth, can chew only on one side of the jaw at the time - Lateral jaw movements can help shredding tough plant fibers.

H. Dogs and cats:

1) Carnivores, such as dogs and cats, often swallow large chunks of meat with little mastication.
2) The teeth are adapted to the tearing of muscle and bone, while the pointed molars are adapted for the crushing bones and also mastication of food to a limited extent.
3) Convey fluids to the mouth by means of the tongue - The free mobile end of which forms a ladle.

6. **Taste**

A. Total No. of taste buds in the mouth: [Kare & Ficken, 1963. In: Y. Zotterman (Ed.) Olfaction and Taste]

Animal	Number
Chicken	24
Pigeon	37
Japanese quail	62
Duck	200
Parrot	350
Kitten	473
Bat	800
Pig	15,000
Rabbit	17,000
Calf	25,000
Human	*9,000*

1) Taste buds - A group of cells that are approximately 20 x 90 µm in size.
2) Taste buds are located throughout the oral cavity, particularly on tongue in pigs, whereas they are restricted to or located on the back of the mouth in birds.

☛ Taste apparatus is present in fowl, but not extensive as in swine!

B. Consumption of various solutions by pigs (Kennedy & Baldwin, 1972. Anim. Behav. 20:706; See Figure on the left) and chicks (Kare & Medway, 1959. Poult. Sci. 38:1119; See figure on the right):

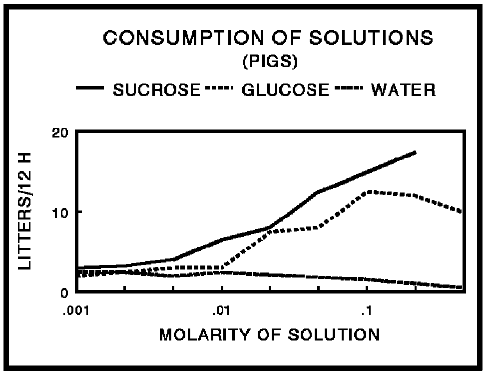
C. The Bottom Line?

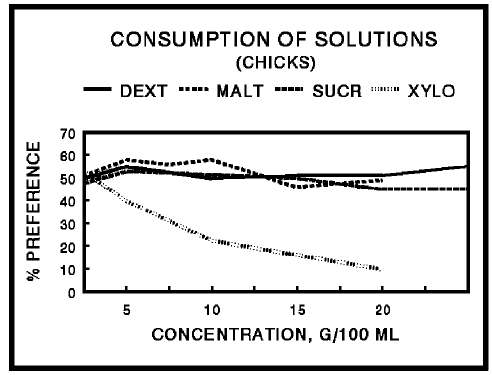
1) Taste preferences exist in swine! But addition of sugar/flavors in the diet has been resulted in very inconsistent responses or minimal effects on performance.
2) A sense of taste also exists in poultry:

(1) But, may be associated more with "aversion" rather than "preference."

(2) Ingredients with different taste had minimal beneficial or adverse effects on poultry.

☛ May respond to flavor changes more when water is a medium rather than feed because of the absence of a fluid saliva & mastication in birds.





7. **Salivary Glands**

A. Pigs:

1) Saliva contains water, mucus, bicarbonates, & ptyalin (or salivary α-amylase), and moistens feed, lubricates esophagus, initiates starch digestion, and other functions.
2) Types? a) Serous - Contains water, electrolytes & α-amylase, b) Mucus - Contains mucoproteins/glycoproteins, and c) Mixed.
3) Glands (three pairs are responsible for most secretions):

a) Parotid - Largest, triangular in shape & located at the apex ventral to the ear, and secrete fluid devoid of mucin.
b) Submaxillary or submandible - Found ventral to the parotid & just behind mandibles, and secrete mucin-containing saliva (mixed).
c) Sublingual - Closely associated with the tongue & found below the floor of mouth, and secrete mucin-containing saliva (mucous).

4) Type of diets & saliva flow rate: (Cromwell. Pers. Comm.)

Feed	mL/1st 5 min
Corn	55
Potatoes	27
Milk	0

a) Secretion rate is affected by the DM content of diets.
b) ≈ 1-2 liters/d on a conventional dry diet.
c) Saliva flow is stimulated mostly by the presence of food in the mouth.

B. Poultry - Minimum in the quantity, and glands composed entirely of mucus cells, thus secrete only thick mucus type saliva. Probably, saliva is nothing more than just lubricating "food bolus" in poultry!?
C. Horses - Contains no enzyme, and secretion is stimulated by "scratching" of feed on mucus membrane of inner cheeks. May secrete up to 10 gal/day?
D. Ruminants:

1) Production is relatively continuous, but greater when eating & ruminating - Can reach 12 gal/day in cattle & 2 gal or more in sheep.
2) Contains no enzymes, but has an additional importance, i.e., provides N, P, Na for rumen microbes.
3) Also, highly buffered (particularly rich in HCO_3 & PO_4), which aid in maintaining an appropriate pH in the rumen.

E. Dogs & cats:

1) Saliva of carnivores contains no enzyme.
2) Unlike horses, the salivary reflex in dogs (& humans) can be conditioned by the sight of food!?
3) Salivary secretion has the special function of evaporative cooling - The parotid gland of the dog under intense parasympathetic stimulation is capable of secreting at 10 times the rate (per g of gland) in humans, thus, as effective as evaporation of sweat in humans?

7. **Esophagus**

A. Food passes from the mouth to the stomach or forestomach via the esophagus:

1) Made up of four layers - a) an outer connective tissue, b) a layer of muscle, c) submucosa, and d) mucosa.
2) Dogs, cattle, and sheep - The muscular layer consists of only striated muscle fibers.
3) Pigs, horses, and humans - The portion adjacent to the stomach is composed of smooth muscle.
4) Esophagus is normally closed at the pharyngoesophageal junction by the upper esophageal sphincter (an intrinsic or functional sphincter at this region in all, even though some may not have anatomically defined sphincter).

B. The central nervous system controls the contractions:

1) "Peristaltic action" (wave of contractions) moves food (as a form of "bolus") to the stomach in nonruminant animals.
2) e.g. - In the dog, it takes about five seconds for food to move from the mouth to the stomach.
2) The bolus can be moved in both directions in the ruminants, and the process is called "rumination."

3) In contrast to most species, horses seldom vomit:

   a) Reasons? Perhaps, they have only one-way peristaltic movement, or because of the marked tonus of the lower esophageal sphincter!?
   b) Only domestic species in which acute gastric dilatation can occur to the point of rupture of the stomach wall!

B. Poultry:

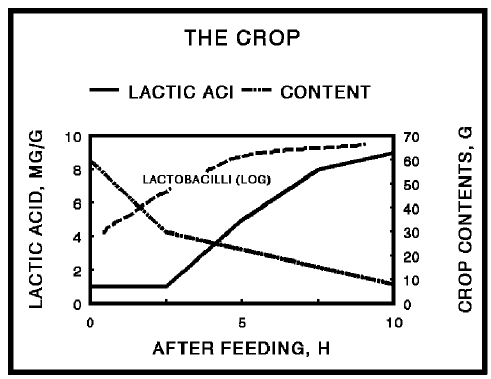
1) Relatively similar to that of the pig but most birds (except insect-eating and some waterfowl) have the "crop," and their esophagus is longer in terms of body dimension.
2) The crop in general:

   a) Is an esophageal "outpocketing."
   b) Mucus glands in the upper esophagus lubricate & move "bolus" to the crop.
   c) The crop is filled & emptied by peristaltic movements.
   d) A main function of the crop? - Probably serving as a food storage site.

3) But, there are some microbial & digestive activities in the crop:

   a) Hydrolysis of starch.
   b) Lactobacilli & lactic acid production: [Jayne-Williams and Fuller, 1971. In: D.J. Bell & B.M. Freeman (Ed.) Physiology & Biochemistry of the Domestic Fowl]

      ▹ Organic acids (. . . mostly lactic & acetic acids) account for ≤ 3% of maintenance needs!



4) The importance of crop?

   a) Maintaining the microbial balance (e.g., inhibition of *E. coli*).
   b) But, not essential for "well-being" or maximal performance of the bird unless feed is restricted severely, i.e., the crop provides more flexibility to the animal!

STOMACH

1. **Functions of the Stomach in Nonruminant Species**

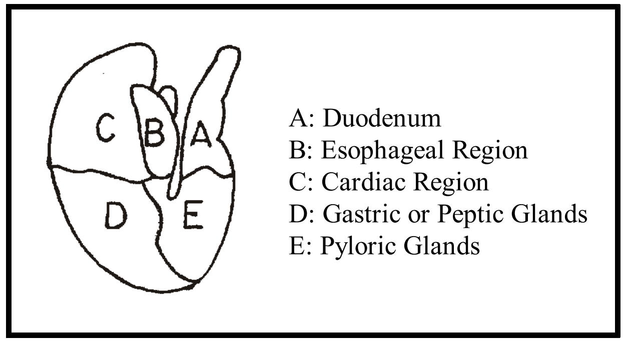
   A. Mixing and storage of the ingested food.
   B. Initiation of protein and fat digestion.

☛ Its most important function is storage of food and the controlled release of its contents into the duodenum.

2. **Swine**

A. Serving as a reservoir for food, but some digestion in the stomach:

B. The pig's stomach - See the figure [Redrawn from Pekas (1991) in Miller et al. (1991)]



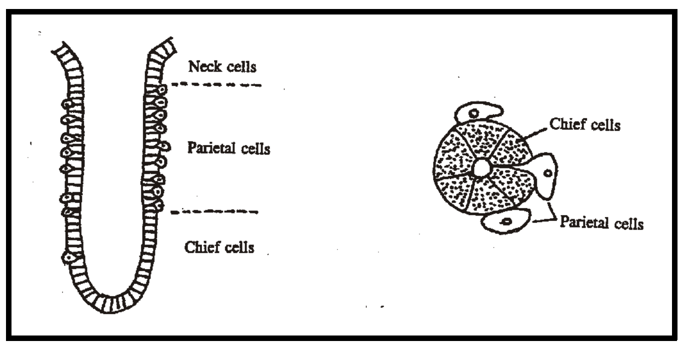
C. Esophageal:

1) An extension of the esophagus into the stomach.
2) Glandless area, thus no secretion.
3) Subject to "ulceration" - Processing (e.g., fine grinding, pelleting, etc.) or diets that tends to make stomach contents more fluid can cause "ulcer" in pigs!

D. Cardiac:

1) Located adjacent to the esophageal area, and occupies about ⅓ to ½ of the stomach area in the pig.
2) Secretes mucus, which can protect stomach linings from HCl.

E. Fundic or gastric:



1) The major secretory portion of the stomach.
2) Three types of cells:

a) Neck cells are responsible for secretion of mucus.
b) Oxyntic (parietal) cells are responsible for secretion of HCl & exchange of Na^+ with H^+. ("HCl" denatures protein, activates pepsin (from pepsinogen), provides optimal pH for pepsin, etc.)
c) Chief cells are responsible for secretion of enzymes [pepsinogen & rennin (acts on casein to form a curd)], electrolytes (Na, K, Cl) and water.

F. Pyloric:

1) The last region before entry into the SI.

2) Responsible for secretion of a hormone, gastrin - Gastrin is responsible for secretion of acid, water, electrolytes, enzymes, etc.

G. Control of gastric secretion:

1) Cephalic phase:

a) Food perception by senses can lead to "vagal stimulation" of glands.
b) Plays significant part in the initiation of eating after fasting.
☛ Make small contributions in swine & poultry because their gastric lumens are seldom empty between meals!

2) Gastric phase:

a) A combination of distension and chemical sensors.
b) Distension of the stomach can activate neural receptors.
c) Chemical stimulations involve pH and(or) digesta sensitive cells.

3) Intestinal phase:

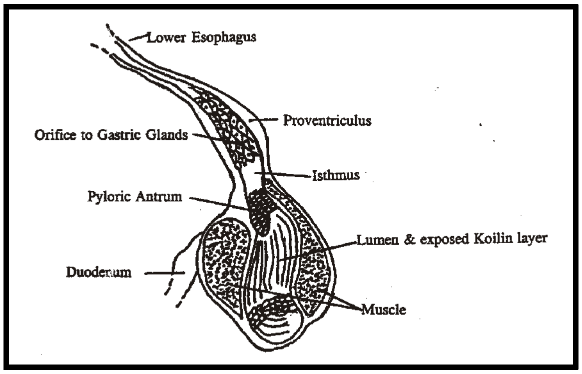
a) The response to digesta in the duodenum, which is mediated by hormonal and neural mechanisms.
b) Hormones in this phase include gastric inhibitory polypeptides (GIP), cholecystokinin, etc.
c) Neural mechanisms would be expected, but have not been clearly demonstrated.

☛ "Gastrin" is probably the focal point of controlling gastric secretions!

3. **Poultry**

A. Use the crop for storage, and proventriculus and gizzard for gastric digestion:

1) Proventriculus provides HCl and pepsinogen.
2) Gizzard is a site for grinding & gastric digestion.



B. Proventriculus-gizzard complex - Redrawn from Hill, 1971. In: D.J. Bell & B.M. Freeman (Ed.) Physiology & Biochemistry of the Domestic Fowl.

1) Proventriculus:

a) An ovoid structure found between the lower esophagus and gizzard.
b) Two types of cells for secretion:

(1) "Oxynticopeptic" cells are structurally intermediate between chief and oxyntic cells of mammals, and are responsible for secretion of pepsinogen and HCl.
(2) The second type is similar to the neck cells of mammals, and those cells are responsible for secretion of mucus.

c) Little is known about the control of gastric secretion, but mechanisms similar to those of mammals may exist.

2) Gizzard (ventriculus or "muscular stomach"):

a) It combines the activity of grinding and proteolysis.
b) Has a massive musculature and extremely durable luminal lining.
c) The luminal lining is synthesized continually as it's worn away by constant abrasions.
☞ However, the response to the addition of "grits" in diets, thus in the gizzard, has been very inconsistent in terms of performance!

4. **Horses**

A. Compared to others, have a small stomach - ≈ 10% of volume: [Capacities (L) of Digestive Tract (Argenzio, 1993. In: Swenson & Reece (Ed.) Dukes' Phisiology of Domestic Animals. 11th Ed. Comstock Publishing Assoc., Ithaca]

Item	Horse	Pig	Dog
Stomach	17.96 (8.5%)	8.00 (29.2%)	4.33 (62.3%)
Small Intestine	63.82	9.20	1.62
Cecum	33.54	1.55	0.09
L. colon	81.28	8.70 (Colon + rectum)	0.91 (Colon + rectum)
S. colon & Rectum	14.77		
Total	211.34	27.45	6.95

B. Does not have as extensive muscular movement activity as other species, and ingesta tends to arrange itself in layers - A reason for being prone to greater digestive disorders?
C. A flow rate - Relatively fast.

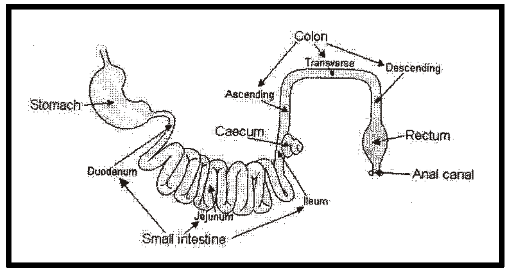
1) A large meal passes more quickly vs feed eaten continuously in small amounts.
2) Passing of majority of ingesta to the small intestine within 12 h following a meal?

D. When the stomach remains empty, the excess gas produced can cause rupture of the stomach. Thus, "continuous consumption" would be optimum?

5. **Ruminant Species** - Please see Section 3 ("Rumen Microbiology and Fermentation").

6. **Dogs and Cats**

A. Dog's digestive tract in general - Perhaps, typical of "carnivores!?"



1) See the figure - Available at: http://137.222.110.150/calnet/vetAB5/page2.htm:
2) Anatomy of digestive tract: [Currie, W. B. 1988. Structure and Function of Domestic Animals. Butterworth, Boston]

a) The dog's stomach seems to be typical of "carnivores."
b) The most striking feature is the apparent simplicity of the gut in general:

(1) The small intestine is short and has a wide luminal diameter.
(2) Cecum is poorly developed, and colon is unremarkable - Seems like elongated rectum!
(3) In view of the fecal mass passed by dogs, the anatomical structure of the lower gut is quite consistent with its simple reservoir function.

B. The dog's stomach:

1) A sac-like structure designed to store large volumes of food and begin the digestive process.
2) In the interior surface, a series of folds called gastric folds, which help grind and digest food.
3) The inner stomach lining secretes acids and enzymes to break food down as the initial step in the digestive process.
4) Once eaten, most food leaves the stomach within 12 hr.

INTESTINAL SYSTEM

- Regardless of the species, most of digestion and absorption of nutrients take place in the small intestine!

1. **Swine**

◦ *Articles by Pekas [1991. In: Miller, Ullrey & Lewis (Ed.)] and Yen [2001. In: Lewis & Southern (Ed.)] contain excellent diagrams of the swine intestinal system.*

A. Swine intestinal system in general:

1) The SI in a fully grown pig:

   a) ≈ 18 m long, and the body length to SI length ratio is ≈ 1:14. (Ratios for other species - horse = 1:12, cattle = 1:20, sheep/goat = 1:27, dog = 1:6 & cat = 1:4.)
   b) ≈ 90% as jejunum & remaining 10% divided equally between duodenum & ileum.

2) The LI (a fully grown pig) - ≈ 5 m long & first 7-8% being cecum.

B. Duodenum:

1) Primarily a mixing site for digesta:

   a) Responsible for secretion of viscous & alkaline substances, which protect the intestinal wall from "acidic" gastric contents.
   b) "Bile" (stored in the gall bladder) from liver contains 97% water, 0.7% salts, 0.2% pigments, 0.06% cholesterol & others.
   c) Pancreatic secretions:

      (1) Alkaline substances are rich in bicarbonate, and buffer "acidic" contents from the stomach.
      (2) Digestive enzymes include lipase, amylase, trypsin, chymotrypsin, carboxypeptidases, etc.
      (3) Controlled by two hormones - (a) "Secretin" stimulates bicarbonate & water flow, and (b) "CCK-PZ" stimulates enzyme flow.

2) The volume of secretions in a 40-kg pig:

   a) Bile, 2 L/day & pancreatic fluids, 5 L/day, thus total fluids of 10 L/day.
   b) The flow from the stomach is ≈ 3 L/day, plus passage of ≈ 2 kg of feed & 5 L of water/day!

C. Jejunum & ileum:

1) "Villi" cover the SI, which increase the surface area:

   a) Longest in the jejunum, and the length decreases progressively.
   b) Very active area with rapid turnover of cells - ≈ 20-30 million cells sloughed off/min.

2) Brush boarder enzymes are located at the brush boarder of the intestinal villi:

   a) Enzymes include aminopeptidase, dipeptidase, sucrase, maltase, lactase, phosphatase, polynucleotidase, lecithinase, etc.

b) Enzymes are integral parts of the membrane at the brush boarder, i.e., not secreted, but "shed" into the lumen.

☛ The jejunum digests & absorbs the majority of nutrients!

D. Cecum and colon:

1) The site to retrieve nutrients remained in digesta before excretion - primary nutrients recovered are water & electrolytes.
2) Fairly high in the microbial population:

a) "VFA" produced by microbes:

(1) Can be absorbed, and may be an important source of energy.
(2) May contribute as much as 30% of maintenance energy for older animals vs. only 2-3% for young animals (some differences among species!).

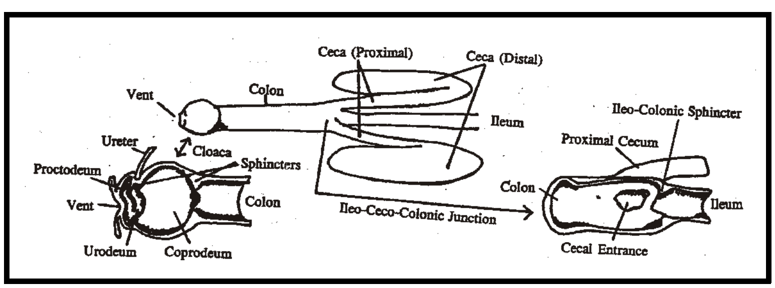
b) Microbial vitamin K & B-vitamins? - Questions on the absorption, but obtaining vitamins via coprophagy may be important in some situations?
c) Synthesis of amino acids:

(1) When lysine is infused into the cecum, "N" appears as urea in the urine or excreted in the feces, indicating that AA synthesized are used by other microbes or metabolized by the intestinal wall.
(2) Thus, may have no or little value to the pig.

E. Apparent digestion coefficients: (Keys & Debarthe, 1974. J. Anim. Sci. 39:57)

Item	Site	Wheat	Corn	Barley
DM	Duodenum	3.9	4.1	2.5
	Ileum	68.5	66.6	63.6
	Rectum	81.7	80.7	81.0
Energy	Duodenum	4.5	-7.3	-5.9
	Ileum	69.6	65.8	62.2
	Rectum	82.9	78.4	80.2
Protein	Duodenum	42.3	20.1	25.9
	Ileum	74.5	74.6	66.7
	Rectum	84.1	81.7	78.7

2. **Poultry**



A. Small intestine:

1) ≈ 125 cm long & occupies ≈ 50% of the total GI tract in adult chickens.
2) Relatively short, but ↑ absorptive effectiveness by using "back & forth" peristalsis.

3) In general, similar to swine in anatomy and functions.

B. Large intestine - See the figure (Redrawn from Moran, 1982).

1) Have a short colon and two long ceca (vs a short cecum & long colon in swine).
2) Ceca - Only fluids, solutes and fine particulate matters enter the ceca:

a) The VFA production site, but make a small contribution to the overall needs.
b) Vitamins can be synthesized, but their availabilities are low.

3) Colon - Probably acts more to convey ileal and cecal digesta rather than active fermentation & absorption.

☛ Both the ceca & colon are capable of absorbing water, electrolytes, glucose & amino acids.

C. Cloaca - Combines functions of both rectum & bladder into one, and mechanisms are present to conserve water & NaCl (processes require energy) if the situation demands.

3. **Horses** [http://www.ianr.unl.edu/pubs/horse/g1350.htm]

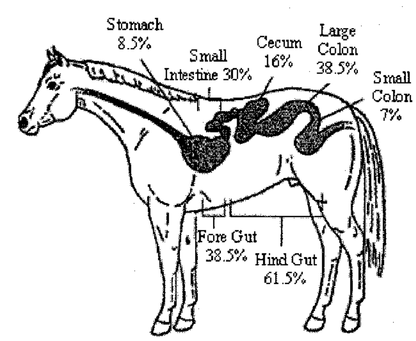


Figure 1. Digestive system of the horse.

A. Small Intestine:

1) About 30% of the volume of the total digestive tract, and the main site of both digestion & absorption.
2) Horses do not have a "gallbladder," thus a direct secretion of bile into duodenum.
3) Flow rate - Affected by the size of meal (↑ with larger meals), physical form (e.g., ↑ with pelleted diets & liquids), etc.
4) Within 2 - 4 h, undigested & unabsorbed ingesta to the cecum & colon - Easy to overwhelm the digestive capacity of the stomach and small intestine because of the limited capacity/volume.
5) Designed to digest carbohydrates & proteins in grains in the upper gut, thus important to feed small amounts, 2-4 times each day for safer, more efficient digestion.

B. Large intestine or cecum and colon:

1) Together, about 50% (over 60%?) of the volume of the total digestive tract.
2) Sites for microbial digestion/fermentation:

a) Contain an active flora of bacteria similar to the microbial population in the ruminants.

b) Bacterial breakdown of cellulose and other carbohydrates to produce VFA (acetic, propionic, butyric), and bacterial synthesis of B vitamins and protein.
c) Some absorption of VFA from cecum, but microbial protein/amino acids - ???

3) With large amounts of concentrates, rapid fermentation & production of excessive gas or lactic acid, causing colic or laminitis.
4) Flow rate - Relatively slow . . . may be several days after eating?
5) The diameter of different segments of the large colon varies & arrangement includes several flexures where the colon turns back onto itself, susceptible to digestive upsets when nutrient flow is abnormal. (Fewer problems with hay & pasture though!)

4. **Ruminant Species**

- Although there might be some differences, many aspects of the ruminant gastrointestinal structures and functions other than rumen seem to be similar to those described for pigs.

5. **Digs and Cats**

A. See "Digestive Tract in General" described briefly in the section for stomach.
B. Small intestine:

1) A tube-like structure & the longest portion of the intestinal tract - About two and a half times the animal's total body length.
2) In the dog - Duodenum (connected to the gall bladder & pancreas by the duct) is bout 10" long in a 40-lb dog, jejunum (covered with villi & the main absorption site) is the longest, and the shortest part is the ileum.

C. Large intestine:

1) In the dog - Basically connects the small intestine to the anus.
2) About 16" in length in a 40-lb dog.
3) Distinct parts: Cecum - a small, finger-like projection near the junction with the SI - function unknown), and colon - longest & terminates just inside the anus to the final portion of the LI, rectum. The terms "colon" & "large intestine" are commonly used interchangeably
4) The primary function is to absorb water from the digesta/ingesta & the other function being to store fecal matter.

LIVER AND PANCREAS

1. **Liver**

A. About 3 and 1.75% of body weight for the fowl and swine, respectively.

B. Vital to digestion & assimilation of absorbed nutrients:

1) Bile for emulsification of dietary fat - See "Biosynthesis & degradation of bile acids" by Martin et al. (1983).
2) Makes metabolic modifications - Majority absorbed nutrients pass through the liver.
3) Mostly associated with the maintenance metabolism in adult animals (i.e., in those not involved in reproduction!).

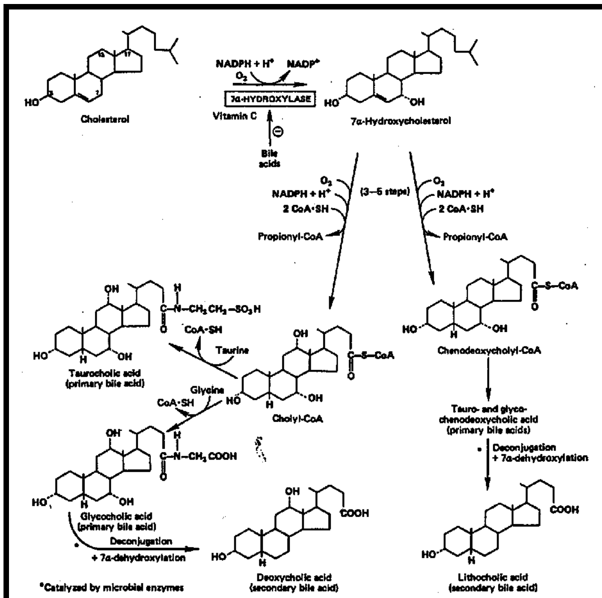


Figure 41-2. Biosynthesis and degradation of bile acids.

C. Lobes - Two in the fowl and several lobes in the swine, but fundamentally similar in shape, location of gall bladder and major vessels.

D. Vascularization:

1) Pigs receive blood from the portal vein (nutrients) & hepatic artery (O_2), and blood exits through the hepatic vein and lymphatic system.
2) Similar in the fowl, but a contribution of lymphatic system is small (vs swine) simply because it is poorly developed in birds.

E. Bile & digestion/absorption of lipids:

1) Formed by the hepatocyte - All bile acids are steroidal compounds synthesized from cholesterol in the liver:

   a) Composition - Water, bile acids, mucin, pigments, cholesterol, esterified & free fatty acids and inorganic salts.
   b) Cholic & chenodeoxycholic acids are 1° acids, but pigs produce little cholic & hyocholic acid takes place as the 1° trihydroxy unit.
   c) To reduce their toxicity, all bile acids are conjugated with taurine in fowl & either taurine or glycine in pigs.
   d) Secondary bile acids - Arise from microbial fermentation when 1° acids are within the intestine . . . after absorption, can be reused by the live for bile synthesis.
   e) Bile pigments - Metabolic end products of heme catabolism & give the bile its characteristic color . . . biliverdin, bilirubin . . .

2). Secreted from the live directly into the duodenum or via gallbladder (stores bile, which is little more concentrated vs hepatic bile).

3) Control of bile movement - "More" via intramural plexus coordination (e.g., gastric digesta/lipids & neural receptors) than the hormone, cholecystokinin (CCK)?
4) Enterohepatic circulation - ≈ 99% of the primary and secondary bile acids are absorbed in the ileum and return to the liver via hepatic portal vein.
5) Daily bile acid use by the animal - Far exceeds its capacity for synthesis:

   a) An enterohepatic recirculation to cope with the demand.
   b) Control of the total pool of bile to meet the needs.

5) Functions of bile:

   a) Emulsification - The bile salts have considerable ability to lower surface tension, ∴ capable of emulsifying fats (micelle formation).
   b) Neutralization of acid - The bile is a reservoir of alkali.
   c) Excretion of cholesterol, and also many drugs, toxins, bile pigments, inorganic substances (e.g., Cu, Zn & Hg), etc.

2. **Pancreas**

A. Three major functions:

1) Supplying enzymes to the SI for starch, protein & fat digestion.
2) Secretion of water, bicarbonate & others into the duodenum area.
3) Supplying hormones to manipulate nutrient metabolism on a moment-to-moment basis.

B. Gross appearance & anatomy:

1) Swine - a) Pinkish-red in color, b) difficult to discern because of connective tissues, adipose tissues, etc., and c) ductules permeate the gland & give rises to one duct, which supply zymogens to the duodenum area.
2) Fowl - a) Grey-white in color, b) visually apparent, c) have three separate lobes with ductules, and d) all ducts meet on a common papilla with two bile ducts at the duodenal-jejunal junction.

C. Exocrine tissues & endocrine islets:

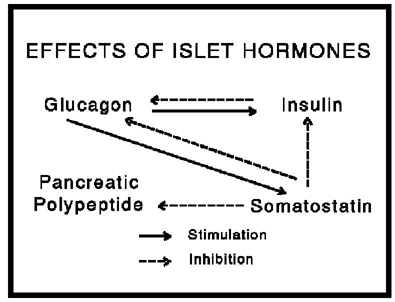
1) Acinar tissues dominate pancreatic tissues:

   a) Acinar cells are responsible for secretion of enzymes or zymogens.
   b) Centroacinar & duct cells are responsible for secretion of water, electrolytes, etc.

2) Islets of Langerhans - Distributed throughout the pancreas:

a) Four types of cells - A-cells, glucagon; B-cells, insulin; D-cells - somatostatin, and F-cells, pancreatic polypeptide.
b) A-, B- & D-cells are found in every islets in pigs, whereas A-/D- or B-/D-cell composite in birds.

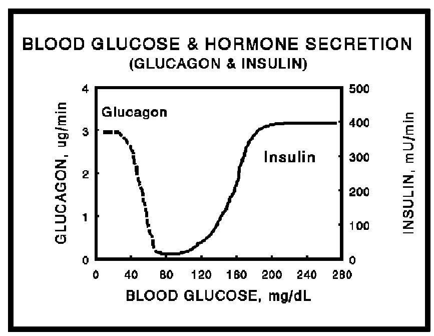
D. Islet hormones:



1) The islets may function as secretory units in the regulation of nutrient homeostasis.
2) Effects of islet hormones: (Redrawn from Ganong, 1983)
3) Somatostatin:

a) Responsible for coordinating "GI tract activities" & regulate the rate of energy (& other nutrients) entry into the animal - responsible for a short term regulation?
b) But, also seems to be involved in a long term homeostasis through instructions from the brain.

3) Insulin - Has glycogenic, antigluconeogenic, antilipolytic, and antiketotic activities. i.e., insulin is a hormone of "energy storage!"
4) Glucagon - Has glycogenolytic, gluconeogenic, lipolytic, and ketogenic activities, i.e., glucagon is a hormone of "energy release!"
5) Control of insulin & glucagon secretions:



a) Many factors affect insulin & glucagon secretions, but the principal factor seems to be plasma glucose.
b) Blood glucose and insulin/glucagon secretions - Redrawn from Ganong (1983).
c) Insulin-glucagon molar ratios (I/G): (Ganong, 1983)

Condition	Hepatic glucose storage (S) or production (P)[a]	I/G
Glucose availability:		
Large CH_2O meal	4+ (S)	70
IV glucose	2+ (S)	25
Small meal	1+ (S)	7
Glucose need:		
Overnight fast	1+ (P)	2.3
Low-CH_2O diet	2+ (P)	1.8
Starvation	4+ (P)	.4

[a]1+ to 4+ indicate relative magnitude.

(1) Need energy - Lower I/G ratios & favor glycogen breakdown & gluconeogenesis.

(2) Energy need is low - Higher I/G ratios & favor deposition of glycogen, protein & fat.

6) Insulin & glucagon for swine & fowl - Both species have a comparable set of enzymes:

a) Insulin:

(1) Swine - Insulin removes circulating glucose rapidly for hepatic & adipose tissue fatty acid synthesis, i.e., stimulation of pyruvate dehydrogenase & acetyl CoA carboxylase.
(2) Fowl - Not responsive to hypoglycemic action of insulin. (Fatty acid synthesis is largely restricted in the liver!)

b) Glucagon:

(1) Swine - Glucagon affects lipolysis of hepatic stores, but has minimal effect on adipocytes.
(2) Fowl - Glucagon can elicit strong lipolytic response.

☛ These differences can lead to "obesity" in pigs, and "rapid" release of fatty acids in birds (possibly to cope with daily stress of life?)!

7) Pancreatic polypeptide:

a) Function or significance has not been completely elucidated.
b) Isolated first in chickens - It decreased hepatic glycogen without changing plasma glucose, and also decreased plasma glycerol & free fatty acids.
c) Inhibits pancreatic secretions & relaxes gallbladder.

GASTROINTESTINAL HORMONES

- Secretion and motility in the GI tract are regulated by a combination of nervous & hormonal stimuli.

1. **Polypeptide Hormones in Genral**

A. Produced by mucosa of various parts of the tract.
B. Either act locally or released into the circulation.
C. Many are structurally similar, and exhibit "overlapping" activities:

2. **Gastrointestinal Polypeptide Hormones**: (Martin et al., 1983)

Established hormones:

Gastrin	
AA residues	17

MW	2100
Homologue	CCK-PZ
Location	G cells of antrum & duodenum, brain
Stimulus	Gastric distention & protein in the stomach
Actions	Stimulates acid & pepsin secretion, gastric mucosal growth & possibly lower esophageal sphincter
Cholecystokinin (Pancreozymin) or CCK-PZ	
AA residues	33
MW	3883
Homologue	Gastrin
Location	Mucosa of entire small intestine, brain, islets, etc
Stimulus	Fat, protein & their digestion products
Actions	Stimulates gallbladder contraction, pancreatic enzyme secretion, pancreatic growth, and inhibits gastric emptying
Secretin	
AA residues	27
MW	3056
Homologue	Glucagon
Location	Mucosa of duodenum & jejunum
Stimulus	Low pH in the duodenum (threshold pH, 4.5)
Actions	Stimulates pancreatic & biliary HCO_3^- secretion, and augments action of CCK-PZ on pancreatic enzyme secretion

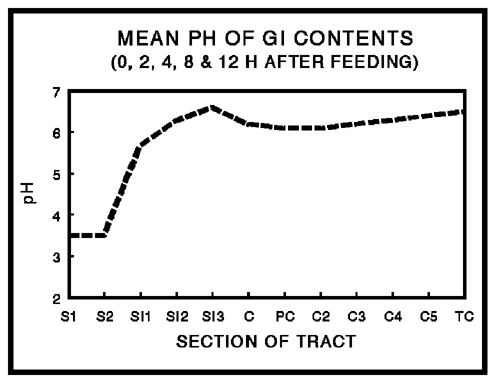
Other hormones:

Gastric inhibitory polypeptide (GIP)	
AA residues	43
MW	5105
Homologue	Secretin, glucagon
Location	Mucosa of duodenum & jejunum, brain
Stimulus	Glucose or fat in the duodenum
Actions	Stimulates release of insulin from pancreas, inhibits gastric H^+ secretion & astric motility, and antilipolytic
Vasoactive intestinal polypeptide (VIP)	
AA residues	28
MW	3100
Homologue	Secretin
Location	Mucosa of entire small intestine
Stimulus	?
Actions	Inhibits gastric H^+ and pepsin secretion, stimulates pancreatic HCO_3^- secretion & secretion from intestinal mucosa, and inhibits gastric & gallbladder motility
Motilin	
AA residues	22
MW	2700
Homologue	?
Location	Mucosa of duodenum & jejunum
Stimulus	Alkaline pH (8.2)
Actions	Stimulates gastric motility
Enterogastrone	
AA residues	?
MW	?
Homologue	?
Location	Mucosa of small intestine
Stimulus	Fat in the intestine
Actions	Inhibits gastric H^+ secretion
Entero-oxyntin	
AA residues	?
MW	?
Homologue	?
Location	Mucosa of small intestine
Stimulus	Protein in the intestine

Actions	Stimulates gastric H^+ secretion
Enteroglucagon	
AA residues	?
MW	3500-7000
Homologue	Glucagon
Location	Mucosa of small intestine
Stimulus	Glucose or fat in the intestine
Actions	Glycogenolysis
Chymodenin	
AA residues	43
MW	4900
Homologue	?
Location	Mucosa of small intestine
Stimulus	Fat in the intestine
Actions	Specific stimulation of chymotrypsin secretion by the pancreas
Bulbogastrone	
AA residues	?
MW	?
Homologue	?
Location	Duodenal bulb
Stimulus	Acid in the duodenal bulb
Actions	Inhibits gastric H^+ secretion

THE pH AND DIGESTIVE PROCESS

- Digestive secretions & type of reactions change as ingesta or digesta moving through the GI tracts in the digestion process.



1. **Mean pH of Gastrointestinal Contents** - Redrawn from Clemens et al. (1975. J. Nutr. 105:759.)

2. **Significance of pH in the GI Tract**

A. Low pH in the stomach prevents multiplication of ingested bacteria (except lactobacilli).
B. Digestive enzymes have a fairly narrow range of optimum pH, ∴ decrease the rate of hydrolysis or activity at either side of the peak.

3. **Summary of the Digestive Process**: (Martin et al., 1983)

Enzyme	Activation & optimum pH	Substrate	End products or action
Salivary gland of mouth - Secrete saliva in reflex response to presence of food in mouth.			
Salivary amylase	Cl ion needed; pH 6.6-6.8	Starch; Glycogen	Maltose + 1:6 Glucosides + Maltotriose
Stomach glands - Chief cells & parietal cells secrete gastric juice in response to reflex stimulation & chemical action of gastrin.			
Pepsin A (fundas)	Pepsinogen conv.	Protein	Proteoses;

& B (pylorus)	to active pepsin by HCl; pH 1-2		Peptones
Rennin	Ca needed for activity; pH 4	Casein of milk	Coagulates milk

Pancreas - Presence of "acid-chyme" from the stomach activates duodenum to produce secretin, which stimulates flow of pancreatic juice & CCK-PZ, which stimulates production of enzymes.

Trypsin	Trypsinogen conv. to active trypsin by enterokinase at pH 5.2-6; auto-catalytic at pH 7.9	Protein; Proteoses; Peptones	Polypeptides; Dipeptides
Chymotrypsin	Chymotrypsinogen conv. to active form by trypsin; pH 8	Protein; Proteoses; Peptones	Same as trypsin; more coagulating power for milk
Carboxypeptidase	Procarboxypeptidase to active form by trypsin	Polypeptides at the free carboxyl end	Lower peptides; Free amino acids
Pancreaticamylase	pH 7.1	Starch; Glycogen	Maltose + 1:6 glucosides + Maltotriose
Lipase	Activated by salts, phospholipids, colipase; pH 8.0	1° triacyl-glycerols	FA, Mono- & Diacylglycerols, Glycerol
Ribonuclease		Ribonucleic acid	Nucleotides
Deoxyribonuclease		Deoxyribonu-cleic acids	Nucleotides
Cholesteryl ester hydrolase	Activated by bile salts	Cholesterol esters	Free cholesterol + FA
Phospho lipase A_2		Phospholipids	FA, lysophospholipids

Liver & gallbladder - CCK, and also possibly gastrin & secretin, stimulates the gallbladder & secretion of bile by the liver.

(Bile salts &alkali)		Fats - also neutralize acid chyme	FA, Bile salt conjugates & Emulsified micelles

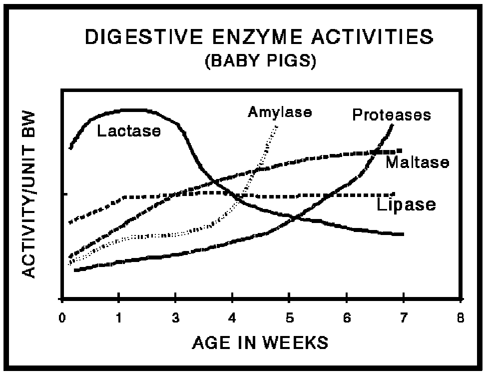
Small intestine - Secretions of Brunner's glands of the duodenum and glands of Lieberkuhn.

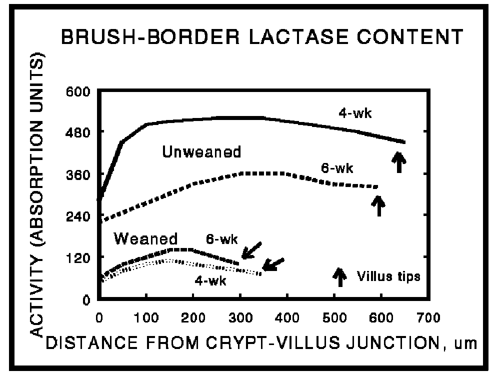
Aminopeptidase		Polypeptides at the free amino end	Lower peptides; Free amino acids
Dipeptidase		Dipeptides	Amino acids
Sucrase	pH 5.0-7.0	Sucrose	Fructose; Glucose
Maltase	pH 5.8-6.2	Maltose	Glucose
Lactase	pH 5.4-6.0	Lactose	Glucose; Galactose
Trehalase		Trehalose	Glucose
Phosphatase	pH 8.6	Organic phosphates	Free Phosphate
Isomaltase		1:6 glucosides	Glucose
Polynucleotidase		Nucleic acid	Nucleotides
Nucleosidases		Purine or pyrimidine nucleosides	Purine or Pyrimidine bases; Pentose phosphate

DIGESTIVE ENZYME ACTIVITIES IN PIGS

1. **Digestive Enzyme Activities** - [Adapted & redrawn from PIC Publ. 11(1). The figure on the left]

2. **The Brush-Border Lactase Content in Weaned & Unweaned Piglets** (Adapted & redrawn from Miller et al., 1986. J. Agric. Sci. Cambridge 107:579. The figure on the right)





3. **Age and Digestive Specimen on Protease & Amylase Activities in Pigs** (Shields et al., 1980. J. Anim. Sci. 50:257)

Age, wk:	0	2	4	6	8	10
Amylase activity[a]						
Total	15	52	98	208	540	1222
Pancreas	5	10	48	164	317	939
Intestinal contents	1	20	21	15	158	207
Intestinal mucosa	9	22	29	29	65	76
Protease activity[b]						
Total	6	12	49	84	166	338
Pancreas	5	9	38	57	77	169
Intestinal contents	1	3	11	27	89	169

[a]Grams of starch hydrolyzed per minute.
[b]Milligram tyrosine equivalents produced per minute.

4. **The Bottom Line?** - "*Pigs have an immature digestive system at birth!*"

   A. Enzyme profile - Geared toward digesting milk sugar & fat during the first 4 to 5 weeks.
   B. Enzymes necessary for starch & plant protein digestion are increasing, but still not adequate.
   C. Thus, to alleviate potential problems, complex diets must be fed to young pigs! (Complex diets - Diets containing many special ingredients that are highly palatable & digestible such as milk products (dried skim milk, dried whey), fish products, lipids, sugar, rolled oat groat, etc.)
   D. Birds, on the other hand, have a full complement of digestive enzymes from day one, thus can utilize a simple, corn-soybean meal-based diet from day one!

FOOD FOR THOUGHT!

1. Superalimentation?

Effects of superalimentation on performance of pigs[a]: (Pekas, 1985. Growth 49:19)

	Control	Super Alimentation	Response (% of C)	*P*-value
Body weight, kg				
Day 1	48.3	45.2	-	NS
Day 8	56.4	56.1	-	NS
Day 31	77.3	85.5	+ 10.5	.05
23-d period				
DM, kg	70.9	93.1	+ 31.3	.025
Gain, kg	21.0	29.3	+ 40.0	.005
Gain:feed	.30	.32	+ 7.3	NS

[a]Superalimentation - Started on day 8 at 120% of control intake.

RUMEN MICROBIOLOGY AND FERMENTATION

- *References: Allison (1993) & Leek (1993) in "Dukes' Physiology of Domestic Animals" by Swenson & Reece, ed. (1993), "http://arbl.cvmbs.colostate.edu/," and others.*

INTRODUCTION

(Herbivorous strategies or utilization of forages in General; http://arbl.cvmbs.colostate.edu/)

○ **Professional Fermentors?** - Two distinct strategies evolved for "professional fermentors"

A. Cranial fermentors (or ruminants) - e.g., Cattle, sheep, and deer.

1) Have a large, multi-compartmented section of the digestive tract between the esophagus & true stomach.
2) The forestomach can house a very complex ecosystem that supports fermentation.

B. Caudal fermentors, aka cecal digestors - e.g., Horses & rabbits

1) Similar to pigs & humans through the stomach and small intestine.
2) But, their large intestine, where fermentation takes place, is complex and exceptionally large.

C. Similarities & differences?

1) The process and outcome of fermentation are essentially identical in the rumen of a cow or the cecum of a horse.
2) However, the position of the "fermentation vat" in relation to the small intestine has very important implications for the animal's physiology and nutrition.
3) Summary?

Function		
Ability to efficiently digest and extract energy from cellulose	Yes	Yes
Ability to utilize dietary hexose sources directly	No	Yes
Ability to utilize the protein from fermentative microbes	Yes	No

☛ Remember? The small intestine is the only site where simple sugars and amino acids can be absorbed in all animals!?

4) Utilization of dietary starch?

a) Horses? - Starch to glucose by amylase & maltase in the SI, and glucose is absorbed into circulation.
b) Ruminants? - Very little is absorbed as glucose, and starch & others are fermented to VFA in the forestomach.

5) Protein?

a) The bodies of microbes can be a source of high quality protein!
b) Because the fermentation vat of a horse is behind the small intestine, all their microbial protein is lost - ?
c) Ruminants - Microbes can flow into the stomach and small intestine, where they are digested and absorbed as amino acids and small peptides.

MICROBIOLOGY OF THE RUMEN

1. **Introduction**

A. Gastrointestinal tracts of ruminant species (& also others)? - Colonized by a diversity of microorganisms, and the use of fibrous feedstuffs by microbes depends on the metabolic activities anaerobic microbes in the rumen and the large intestine.
B. Rumen & large intestine? - Occupied by highly concentrated populations of bacteria, and also by protozoa and anaerobic fungi.
C. Gastrointestinal tract? - Perhaps, the most intimate environment that animals are exposed to, and has a profound impact on the physiology and health of the host animal.

2. **Forestomach Fermentation**

A. In the simple stomach species? - Before reaching the acidic stomach, fermentation is limited to the ethanolic or lactic acid type, which may have minor impacts on the nutrition of the animal (. . . obviously, some exception though!).
B Forestomach fermentation? - Occur at nearly neutral pH, and may be separated from the acidic region.
C. Ruminants:

1) Are the most diverse (about 155 species) and best known of the herbivores with extensive forestomach fermentation systems.
2) But, there are also others such as Camelidae (camel, llama, alpaca, guanaco, and vicuna), hippopotamuses, tree sloths (Cholopus and Bradypus), and leaf-eating monkeys.

D. Reticulorumen:

1) A fermentation chamber, in which bacteria and protozoa are located.
2) Can convert plant materials to volatile fatty acids (VFAs), methane, carbon dioxide, ammonia, and microbial cells.

E. Some advantages of fermentation in the reticulorumen?

1) Allows digestion and then absorption of fermentation products that are of value to the host (e.g., microbial cells, VFAs, and B vitamins) before the acidic abomasum.
2 Change poor quality protein/N compounds to a "good-quality" microbial protein.
3) Selective retention of coarse particles extends fermentation time and allows for further mechanical breakdown during rumination (cud chewing).
4) Release of fermentation gas (mostly CO_2 & CH_4) from the system by eructation.
5) Toxic substances in the diet may be attacked by the microbes before being presented to the small intestine.

3. **Ruminal Microbes**

A. Available information? - Obtained mostly from studies of cattle and sheep.
B. Knowledge on wild ruminants is largely limited to that obtained by microscopic observations, but predominant bacteria species in rumen contents of deer, reindeer, elk, and moose are ones also found in cattle and sheep (based on cultural studies).
C. Important bacterial species in cattle and sheep and their fermentative properties:

1) Fermentative properties of ruminal bacteria: (Hespell, 1981)

Species	Function*	Products¶
Fibrobacter (Bacteroides) succinogenes	C,A	F,A,S
Ruminococcus albus	C,X	F,A,E,H,C
Ruminococcus flavefaciens	C,X	F,A,S,H
Butyrivibrio fibrisolvens	C,X,PR	F,A,L,B,E,H,C
Clostridium lochheadii	C,PR	F,A,B,E,H,C
Streptococcus bovis	A,S,SS,PR	L,A,F
Ruminobacter (Bacteroides) amylophilus	A,P,PR	F,A,S
Prevotella (Bacteroides) ruminocola	A,X,P,PR	F,A,P,S
Succinimonas amylolytica	A,D	A,S
Selenomonas ruminantium	A,SS,GU,LU,PR	A,L,P,H,C
Lachnospira multiparus	P,PR,A	F,A,E,L,H,C
Succinivibrio dextrinosolvens	P,D	F,A,L,S
Methanobrevibacter ruminantium	M,HU	M
Methanosarcina barkeri	M,HU	MC
Treponema bryantii	P,SS	F,A,L,S,E
Megasphaera elsdenii	SS,LU	A,P,B,V,CP,H,C
Lactobacillus sp.	SS	L
Anaerovibrio lipolytica	L,GU	A,P,S
Eubacterium ruminantium	SS	F,A,B,C
Oxalobacter formigenes	O	F,C
Wolinella succinogenes	HU	S,C

* C = cellulolytic; X = xylanolytic; A = amylolytic; D = dextrinolytic; P = pectinoiytic; PR = proteolytic; L = lipolytic; M = methanogenic; GU = glycerol-utilizing; LU = lactate-utilizing; SS = major soluble sugar fermenter, HU = hydrogen utilizer; O = oxalate-degrading.

¶ F = formate; A = acetate; E = ethanol; P = propionate; L = lactate; B = butyrate; S = succinate; V = valerate; CP = caproate; H = hydrogen; C = carbon dioxide; M = methane.

2) All of these bacteria are anaerobes & most are carbohydrate fermenters - Including gram-negative and gram-positive cells, sporeformers and non-sporeformers, and motile and nonmotile cells.
3) Obligatory anaerobic mycoplasmas (. . . cells enclosed by membranes rather than by rigid walls):

   a) Some interest because detected only in rumen & can ferment starch and other carbohydrates.
   b) But, minor in terms of proportions relative to total population components, and heir contributions would be small.

D. Numbers and relative volumes of bacteria and protozoa:

1) Approximate average volumes and numbers of microbial groups in the rumen of sheep: (Warner, 1962)

Organism	Avg. cell volume	Number/mL	% of total*
Ciliate protozoa			
Isotricha, Epidinium, Diplodinium sp.	1,000,000	1.1×10^4	33.55
Dasytricha, Diplodinium sp.	100,000	2.9×10^4	8.78
Entodinium sp.	10,000	2.9×10^5	8.79
Polyflagellated fungal zoospores	500	9.4×10^3	0.01
Oscillospiras and fungal zoospores	250	3.8×10^5	0.26
Selenomonads	30	1.0×10^8	0.09
Small bacteria	1	1.6×10^{10}	48.52

*Total microbial volume was about 0.036 mi per milliliter of rumen fluid.

2) Protozoa are far less numerous than bacteria, but they are so much larger than the bacteria that they may occupy a volume nearly equal to that occupied by the bacteria.:

   a) Most important ones are anaerobic ciliates that are differentiated on the basis of morphology. Most of them belong to two, "holotrichous & entodiniomorphid" protozoa.
   b) Numbers and kinds of protozoa are markedly affected by diet, and the variability among protozoa populations tends to be greater than the bacterial population.

4. **Rumen Ecology**

A. Rumen - An open ecosystem, and it is a dynamic system because conditions are continually changing (http://arbl.cvmbs.colostate.edu/).

1) Each milliliter of rumen content contains roughly:

a) 10 to 50 billion bacteria,
b) 1 million protozoa, and
c) Variable numbers of yeasts and fungi.

2) The environment of the rumen:

a) Anaerobic, and as expected, almost all these microbes are anaerobes or facultative anaerobes.
b) Fermentative microbes interact & support one another in a complex food web, with waste products of some species serving as nutrients for other species.

3) Bacteria? - Although many bacteria utilize multiple substrates, some of the major groups, each of which contain multiple genera and species, include:

Cellulolytic - Digest cellulose
Hemicellulolytic - Digest hemicellulose
Amylolytic - Digest starch
Proteolytic - Digest proteins
Sugar utilizing - Utilize monosaccharides and disaccharides
Acid utilizing - Utilize lactic, succinic, malic acids, etc.
Ammonia producers
Vitamin synthesizers
Methane producers

4) Protozoa?

a) Predominantly ciliates & seems to contribute substantially to the fermentation process.
b) Several studies have shown that lambs and calves deprived of their ruminal protozoa had depressed growth rates.
c) In general:

(1) Protozoa utilize the same set of substrates as bacteria.
(2) Different populations of protozoa show distinctive substrate preferences.
(3) Many utilize simple sugars and some store ingested carbohydrates as glycogen.

☛ Some protozoa - Cannot regulate glycogen synthesis, and when soluble carbohydrates are in abundance, they continue to store glycogen until they burst.

(4) An additional feature of protozoa is that many species consume bacteria. Perhaps play a role in limiting bacterial overgrowth?

5) Microbial populations?

a) Can vary with diet!

(1) Perhaps, reflecting substrate availability?
(2) e.g., Populations of cellulolytic bugs are depressed in animals fed diets rich in grain.

b) Environmental conditions in the "fermentation vat" can have profound effects:

(1) Rumen fluid normally has pH between 6 and 7.
(2) But, may fall if large amounts of soluble carbohydrate are consumed.
(3) If pH drops to about 5.5, protozoal populations become markedly depressed because of acid intolerance.
(4) More drastic lowering of rumen pH, as can occur with grain overload, can destroy many species and have serious consequences to the animal!

B. Newborn animals:

1) Glooming behavior among cud chewers may facilitates microbial transfer.
2) Strictly anaerobic bacteria (including cellulose digester) have been found in animals < 1 wk old.
3) Transmission of protozoa depends on close or direct contact, whereas normal rumen bacteria may be isolated from aerosols.

C. Established gastrointestinal populations create conditions that tend to exclude all but the most competent of "invaders."

D. Anaerobiosis (life in the absence of oxygen):

1) A fundamental property that limits both the kinds of microbes to colonize the fermentative system and reactions to occur.
2) Oxygen is metabolically removed by both bacteria and protozoa.
3) Short-chain VFA are the major end products of the fermentation simply because C skeletons cannot be completely oxidized to CO_2 in the absence of oxygen. (Also, the e-transport systems do not function, thus low ATP generation.)

5. **Basic Fermentation Chemistry**

A. Microbes that digest cellulose and other substrates also provide at least three other major "services?"

1) Synthesis of high quality protein in the form of microbial bodies:

a) i.e., Bacteria & protozoa, which can be digested and absorbed by the host animal.

b) Animals need certain amino acids, which their cells cannot synthesize, "indispensable amino acids" - Fermentative microbes can synthesize & provide them to their host!

2) Synthesis of protein from non-protein nitrogen sources:

a) Fermentative microbes can, for example, utilize urea to synthesize protein.
b) In some situations, ruminants are fed urea as a inexpensive dietary supplement.
c) They also secrete urea formed during protein metabolism into saliva, which flows into the rumen and serves as another nitrogen source for the microbes.

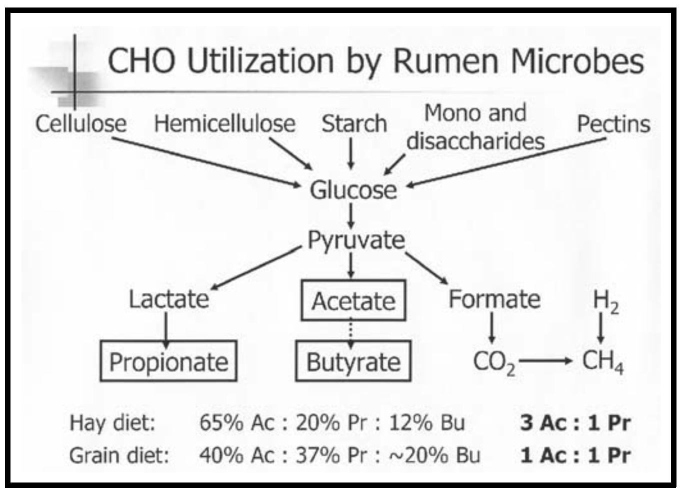
3) Synthesis of B vitamins:

a) Mammals can synthesize only a few B vitamins and require dietary sources of the others.
b) Fermentative microbes can synthesize all the B vitamins, and deficiency states are rarely encountered in some animals.

B. Substrates for fermentation (compiled by S. P. Schmidt, AU) - Also, may want to see subsequent sections on "Functions of Ruminal Bacteria & Protozoa and Manipulations of Ruminal Microbes!"

1) Carbohydrates:

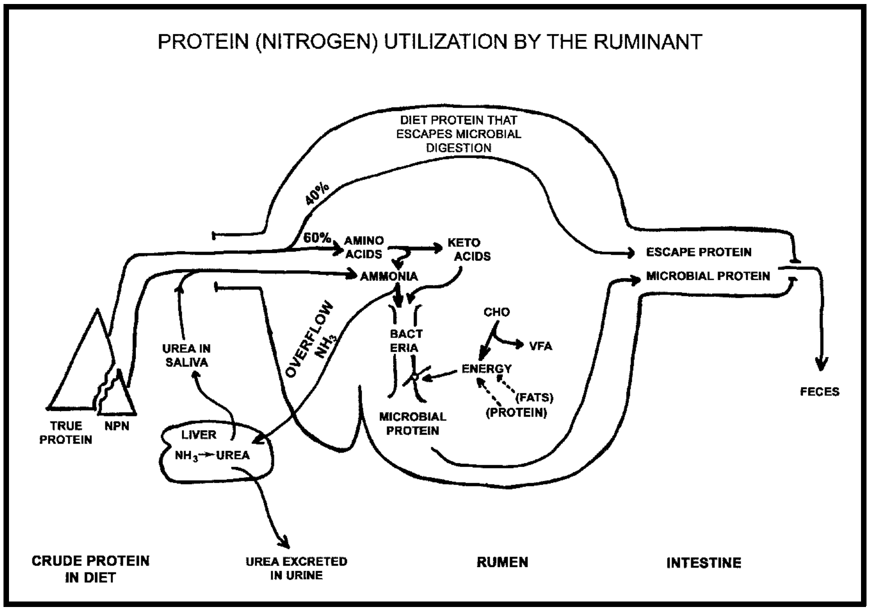
a) Carbohydrate utilization by the ruminant (See the Figure).
b) Most carbohydrates are utilized by rumen microorganisms, thus, very little glucose can be absorbed by ruminants.
c) VFA account for ≈ 70% or more of animal's energy needs by:



(1) Oxidation of VFA via TCA cycle.
(2) Conversion of propionate to glucose, then oxidize glucose.

2) Nitrogenous substances

a) Protein/N utilization by the ruminant:



b) Sources of rumen nitrogen:

(1) Feed - Protein N (SBM, CSM, grain, forage, silage, etc.) and nonprotein N (NPN; usually, means urea, but from 5% of N in grains to 50% of N in silage and immature forages can be NPN).
(2) Endogenous (recycled) N - Saliva and rumen wall.

c) Ruminal protein degradation/fermentative digestion - Enzymes of microbial origin:

(1) Proteases and peptidases of mcroorganisms (MO) cleave peptide bonds and release AA.
(2) AA deaminated by microbes, and release NH_3 and C-skeleton.
(3) MO use NH_3, C-skeleton, and energy to synthesize their own AA.
(4) Formation of NH_3 is very rapid, and very little AA left in the rumen.

d) Limitations of microbial protein synthesis:

(1) Two most likely limitations - Available energy and NH_3. These need to be synchronized.
(2) For diets containing urea, may also need: sulfur (for S-containing AA) and branched-chain C-skeletons (MO cannot make branched-chain C-chains). These are normally not a problem.

e) Protein leaving rumen:

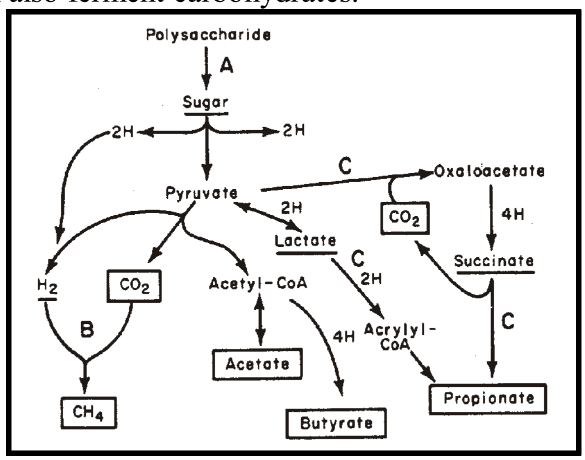
(1) Microbial protein.
(2) Escape protein (also called "bypass" protein).

(3) Proteins enter abomasum & small intestine, and digested by proteolytic enzymes similar to nonruminants.
(4) Escape vs. bypass protein? - Technically not "bypass."
(5) Reticular groove? - Important for young ruminants.

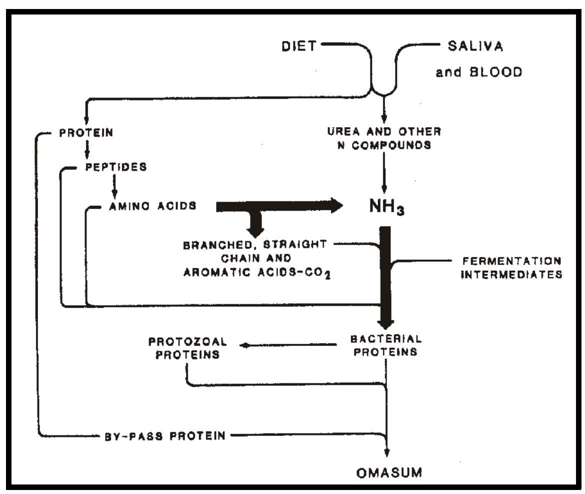
6. **Functions of Ruminal Bacteria**

A. Fermentation of carbohydrate by diverse bacterial species (Allison, 1993):

1) "☐" = Final product, and "__" = extracellular intermediate.
2) H = an electron plus a proton or electrons from reduced-pyridine nucleotides, A = carbohydrate fermenting species, B = methanogenic species, and C = lactate-fermenting species which often also ferment carbohydrates.
3) Catabolism by rumen microbes? Hexose - The Embden Meyerhof glycolytic pathway; Pentose - the pentose phosphate cycle coupled with glycolysis with some by phosphoketolase pathway; Pyruvate - a variety of mechanisms to from acetate, butyrate, H, CO_2, and propionate.



B. Transformation of nitrogenous substances in the rumen (Allison, 1993):



1) Proteins are hydrolyzed by bacteria, protozoa, and anaerobic fungi. Bacteria are most important!
2) Protozoa? - A main function being metabolism of bacterial protein rather than exogenous protein.
3) Ammonia is produced during microbial metabolism, and is a major source of N used for biosynthesis of microbial cells.
4) Many ruminal bacteria can grow with ammonia as the main source of N, but some require amino acids.
5) Considerable interest in inhibition of microbial proteases so that more dietary protein would "bypass" the rumen.

7. **Functions of Ruminal Protozoa**

A. Ruminal ciliate protozoa are metabolically versatile & capable of using all major plant constituents:

1) Entodiniomorphid protozoa - Engulf particulate matter and have enzymes that attack cellulose, hemicellulose, etc.
2) Holotrichs - Depend on nonstructural polysaccharide, especially, starch and soluble sugars.
3) End products? - Various organic acids, CO_2, and hydrogen.

B. Although bacterial predation is not important for protozoa, amino acids from ingested bacteria are used for synthesis of protozoal protein.

C. Protozoa may not be essential for ruminant digestion, but:

1) They do have a major influence on the overall microbial process!
2) Protozoa may account for as much as one-third of ruminal cellulolysis, and their presence may enhance the cellulolytic activity of bacteria.

8. **Manipulations of Ruminal Microbes**

A. Ruminal microbial protein:

1) May be adequate for maintenance and during periods of slow growth or early pregnancy.
2) When protein demand is high, animal productivity can be enhanced by increasing the amount of "rumen-escaped" protein.

B. Some attempts have been made to find ways to manipulate the microbial population to minimize the degradation of feed protein, e.g.:

1) Searches for chemicals that would inhibit the activity of microbial proteases or deaminases.
2) Treatment of feedstuffs that would inhibit ruminal proteolysis such as the use of various drying procedures, heat, or treatment with chemicals. An example of the effort? - The increased efficiency of growth with formaldehyde-treated feeds!

C. The use of some proteins to coat and protect fats from microbial attack to enhance yields of milk and to increase amounts of unsaturated fatty acids in milk or animal fat.

D. The use of various chemicals to inhibit methanogenesis. About 10 percent of dietary energy may be lost as methane.

E. The use of some compounds to increase the ratio of ruminal propionate to acetate.

☛ The best example of successful manipulation via dietary inclusion? - Ionophore, monensin, which inhibits microbial methane production, proteolysis, and amino acid degradation and causes an increase in the ruminal propionate/acetate ratio.

9. **Modification and Production of Toxic Substances in the Rumen**

A. Some poisonous plants are less toxic to ruminants because microbes can attack toxic compounds before being exposed to gastric digestion and absorption.

B. Substances detoxified in the rumen:

Substance	Source	Reactions	Organisms
Nitrite	Nitrate	Reduced to ammonia	Various bacteria and protozoa
Oxalate	Oxalis and halogeton	Decarboxylated to formate	*Oxalobacter formigenes*
Ochratoxin A	Moldy feeds	Hydrolysis	Unidentified microbes
3-Nitropropanol & 3-nitropropionic acid	Miserotoxin in many *Astragalus* sp.	Nitro-group reduction to amine	*Coprococcus, Megasphaera, Selenomonas*
Phytoestrogens	Subterranean clover and red clover	Degraded to p-ethylphenol	Unknown
Gossypol	Cottonseed meal	Bound to soluble protein	Unknown
Pyrrolizidine alkaloids heliotrine	*Heliotropium*	Reductive fission	*Peptococcus heliotrinreducans*
3-Hydroxy-4(1 H)-pyridone	Mimosine from leucaena	Unknown	*Synergi.stes jonesii*, *Clostridium* sp.

C. Toxic substances produced in the rumen:

Substance	Source	Organisms involved
3-Methylindole (skatole)	Tryptophan in feeds	Lactobacillus sp.
Nitrite	Reduction of nitrates in feed	Selenomonas ruminantium, Veillonella alcalescens
Lactic acid	Rapidly degraded carbohydrates (in high-concentrate diets)	Streptococcus spp., Lactobacillus spp.
3-Hydroxy-4(1 H)-pyridone	Degradation product of mimosine	Unidentified gram negative rod
Cyanide	Hydrolysis of cyanogenic glycosides	Gram-negative rods and gram-positive diplococci
Dimethyl disulfide	Degradation product of S-methyl-cysteine sulfoxide (Brassica anemia factor)	Lactobacillus spp., Veillonella alcalescens, Anaerovibrio lipolytica; Megasphaera elsdenii
Equol	Demethylation and reduction of formononetin (a phytoestrogen)	Unknown
Thiaminase	Microbial enzymes	Clostridium sporogenes; Bacillus spp. and various anaerobes
3-Nitropropanoic acid 3-nitropropanol	Hydrolysis of miserotoxins	Unknown
Goitrin	Hydrolysis of glucosinolates found in rapeseed meal and other crucifers	Unknown

10. Small- & Large-Intestine Microbes

A. Small intestine - Concentrations of viable bacteria in the small intestine content (10^4 to 10^6/g) are much lower vs. the rumen & large intestine, and most are transients and the impact on digestion might be minimal.

B. Large intestine:

1) Concentrations of anaerobic bacteria (10^{10} to 10^{11}/g) are comparable with the rumen.
2) The diversity in microbes among animal species and diets.
3) Microbial fermentation - A major component of digestion in the LI, and main products include CO_2, acetate, propionate, and butyrate (also, methane & H).
4) Genera of bacteria? - *Bacteroides, Fusobacterium, Streptococcus, Eubacterium, Ruminococcus*, and *Lactobacillus*. Also, *Treponema* & *Eschericia coli*.
5) Protozoa? - Similar (not identical though!) to rumen ciliates inhabit the LI of horses, rhinoceroses, tapirs, and elephants . . . but their roles - ???

11. **Common, Well-Known Disorders in Ruminants**

A. Bloat

1) Eructation-inhibition reflex is initiated when proprioreceptors in mucosa around the cardia are in contact with fluid or foam, thus gases cannot escape!
2) The buildup of pressure can be sufficient to interfere with movement of the diaphragm and also cause circulatory impairment, which can lead to death?
3) Causes? Rapid release of soluble proteins from the degradation of the forage (especially, legumes?) and rapid production of gas by the microbes:
4) Susceptibility differs, thus some research to control bloat include selection of plants that do not cause bloat, bloat-resistant animals, and the use of antifoaming agents.

B. Ruminal acidosis

1) Lactic acid accumulation in the rumen (& in the blood) if animals are overfed with, or are abruptly switched to grain or other readily fermented carbohydrate - Can be lethal!
2) A drastic shift in microbial populations from gram-negative predominance to gram-positive lactic acid producers (*Streptococcus bovis* and *Lactobacillus* sp.) in the rumen, cecum, and colon of overfed animals.
3) Ruminal pH may drop from more than 6 to 5 or less - Normal rumen microbes may not compete well with the pH less than about 5.5, and the resulting population is dominated by the more acid-tolerant lactobacilli.
4) Ruminal lactic acid concentrations may exceed 100 mM, which can increase the osmolarity of the rumen, thus water is drawn into the gastrointestinal tract from the systemic circulation, thus severe dehydration and circulatory collapse in l to 2 days?
5) Other toxic factors such as histamine or endotoxin, which is produced by lysis of the gram-negative anaerobes at low ruminal pH, may also be involved.
6) "Gradual adaptation" to high concentrate rations may occur without the above population shift, and several studies indicate that certain antibiotics, particularly those selective against *S. bovis*, may provide protection against lactic acidosis.

C. Acute pulmonary edema

1) Also called "foggage" or "fog fever" occurs naturally 2 to 10 days after mature cattle are switched suddenly from poor to lush pastures.
2) Animals suffer obvious respiratory distress. No effective treatment!
3) Avidly consumed lush pasture lead to abnormal ruminal fermentation - The significant feature being the conversion of Trp to 3-methylindole:

   a) Absorbed & reaches the lung where it is oxidized to an active compound.
   b) The compound binds to and kills alveolar & certain bronchial cells.
   c) The cells slough off, allowing the airways to fill with frothy edematous fluid. The lungs would be enlarged, heavy, and rubbery.

D. Ketosis

1) Ketosis - A generic term for any condition in which ketone bodies (acetone & acetoacetate) are readily detectable in the body fluids and the expired breath.
2) Formed in liver mitochondria when acetyl-coenzyme A is being formed at a greater rate than it can be metabolized in the citric acid cycle.
3) Cause? - The inadequate provision of oxaloacetate to prime the cycle, and occurs when either oxaloacetate precursors, predominantly propionate, are deficient or available oxaloacetate is preferentially channeled for gluconeogenesis.
4) "Pregnancy toxemia" or twin-lamb disease, which occurs just before parturition in ewes that are carrying more than one fetus. Often fetal?:

   a) The high metabolic demands of the twin-lamb pregnancy, which can be exacerbated by the cold and/or by a reduced availability of glucogenic fermentation products.
   b) If there is an added nutritional or metabolic stress (. . . feed restriction, colder weather, etc.), likely to occur.

5) Acetonemia, which occurs at peak lactation in high-yielding dairy cows:

   a) The demands for glucose as the precursor of lactose at peak lactation cause the available oxaloacetate to be used for gluconeogenesis at the expense of the needs of the citric acid cycle.
   b) Exacerbated when the cow loses its appetite for concentrates, which would provide a relatively greater proportion of propionate.
   c) As the disease progresses, the milk yield falls rapidly, so that the ketosis and its cause therefore decline.
   d) The disease is usually not fatal, but the slowness of the self-cure and the consequential loss of peak milk production make therapy worthwhile.

6) Therapies? Includes dosing with propionate, intravenous administration of glucose, and the injection of the gluconeogenic corticosteroid hormones.

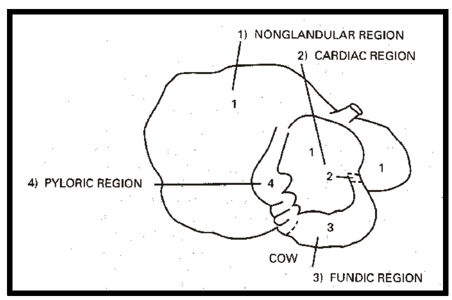
E. Ammonia toxicity

1) Arises most commonly when excessive amounts of urea are fed, especially at the time of low amylolytic fermentation. Ruminal urease rapidly convert urea to ammonia..
2) With cellulolytic fermentations, the VFA production rate is much lower, thus, less substrate for protein synthesis, and also microbial growth/division is much slower, thus less microbial protein synthesis.
3) The toxicity with ammonia arises after its absorption - Due in small part to a systemic metabolic alkalosis and in large part to central nervous system intoxication.
4) Toxicity is countered by oral administration of VFA and by feeding of grain.
5) The reduced ruminal acidity slows ammonia absorption, and the VFA provide carbon skeletons for microbial protein synthesis.

RUMINAL FERMENTATION IN GENERAL

1. **Functional Anatomy of the Ruminant Stomach**

A. Ruminants [so named because they ruminate (chew the cud)] have a stomach consists of a non-secretory forestomach and a secretory stomach (abomasum).
B Forestomach - Consists of three compartments, the reticulum, the rumen, and the omasum, and serves as a microbial fermentation vat of the ingesta mainly by hydrolysis and anaerobic oxidation.
C. Abomasum - Like the stomach of nonruminant species, largely concerned with the hydrolysis of protein by pepsin in an acid medium.
D. A schematic diagram (Kellems and Church, 1998):



1) Reticulum - Spherical, and the esophagus enters dorsomedially at the cardia. [The reticular groove (not shown) runs ventrally from the cardia to the reticuloomasal orifice.]
2) Rumen - Divided into dorsal and vetral sacs (not shown). (The ruminoreticulum occupies the entire left side of the addomen, and depending on the degree of filling, also extends ventrally on the right side.)
3) Omasum - A kidney-shaped structure and consists of many leaves (laminae; bear small papillae), which enhance the internal surface area/volume ratio of the omasum.
4) Abomasum - Consists of fundic, body, and pyloric regions.

E. The ruminant stomach is highly vascularized, and innervated by vagal and splanchnic nerves, both of which provide sensory (afferent) and motor (efferent) pathways.

2. **Benefits and Costs of Ruminant Digestion**

A. Benefits?

1) Because of a pre-gastric fermentation, can use feeds too fibrous for nonruminants.
2) Can use cellulose, the most abundant carbohydrate present, as a major nutrient.
3) Can synthesize high-quality microbial protein from low-quality protein, nonprotein N, and recycled nitrogenous end products.
4) Can provide all components of vitamin B complex, provided the presence of adequate Co for vitamin B_{12} synthesis.

☛ Thus, ruminants can compete successfully with nonruminant grass eaters, and also occupy niches where the grass quality would be too low to support nonruminants

B. Disadvantages?

1) Spend a large part of its day chewing, i.e., chewing food 4-7 hr/day or chewing the cud about 8 hours a day.
2) Need complicated mechanisms to keep the fermentation vat working efficiently, e.g.:

   a) Regular addition of large quantities of alkaline saliva.
   b) Powerful mixing movements in the forestomach.
   c) Mechanisms for the elimination of the gases of fermentation (eructation) for: (1) the regurgitation of the cud (rumination), (2) absorption of end products, and (3) onward passage of portions of the ferment to the omasum.

3) Pathways of intermediary metabolism must be geared toward the use of the peculiar end products of fermentation:

   a) In the case of all carbohydrates & some proteins - Volatile fatty acids (mainly acetic, propionic, and butyric acids).
   b) Propionic acid - Can be converted to glucose, which is needed during milk production and the later stages of fetal growth.

The Principal Components of Ruminant Feedstuffs

	C-1 linkage	Straw	Grasses	Grains	Legumes
Carbohydrates					
Nonstructural					
Starch	α	-	1	64	7
Other	α & β	7	13	2	8
Subtotal		***7***	***14***	***66***	***15***
Structural					
Cellulose	β	32	24	8	14
Hemicelluiose	β	31	20	4	7
Pectin	β	3	2	-	6
Subtotal		***66***	***46***	***12***	***27***
Other components					
Crude protein		4	14	12	24
Lipids		2	4	4	6
Lignin		10	7	2	5
Other		8	14	5	21
Subtotal		***24***	***39***	***23***	***56***

MICROBIAL FERMENTATION

1. **Dietary Substrates**

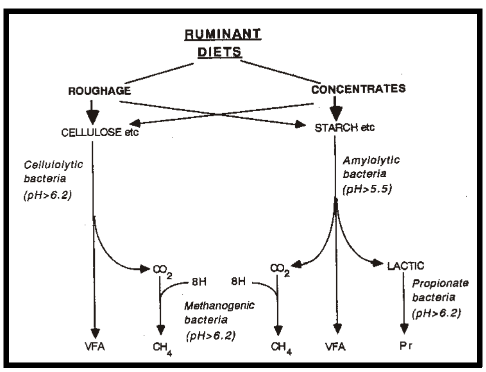
A.. The principal components of ruminant feedstuffs - See the table (Czerkawski, 1986).

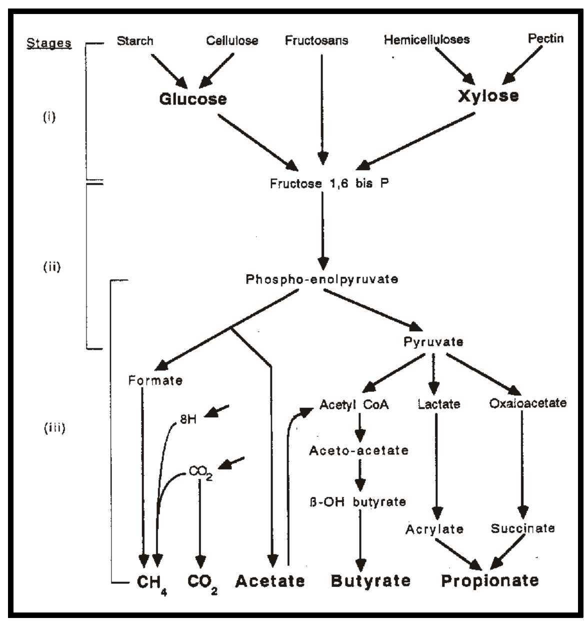
B. Nitrogen-fixing legumes are high in the protein content, but carbohydrates make up about 66% of the dry matter in non-leguminous plants & grains.
C. Grains - Most of the carbohydrate is nonstructural, and intracellular stored energy (starches and fructosans) or intermediaries (simple sugars).
D. Plant cell wall - Made up of cellulose fibers embedded in a hemicellulose matrix. The β-1 linkages are difficult to hydrolyze, and necessary emzymes (cellulase, hemicellualse, pectin lyase, and fructanase) are found only in microbes and plants.

2. **Fermenting Microbes & Fermentation**

A. Microbes:

1) Mainly of a mixed population of bacteria, but also yeast-like fungi and protozoa.
2) Primary bacteria - Degrade the diet constituents, and depending their preference for cellulose or starch, termed cellulolytic or amylolytic, respectively. (See the figure on the left: Leek, 1993))
3) Secondary bacteria - Use the end products of the primary bacteria, e.g., lactate-utilizing propionate bacteria.
4) Ruminal fungi - Little is known about the importance.
5). Protozoa - Feed on ruminal bacteria, plant starch granules & others, including perhaps PUFA, linoleic and linolenic acids.



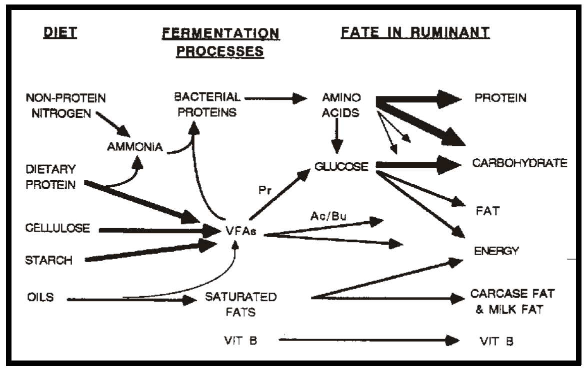


B. Fermentation

1) Three stages of a four-stage microbial process - See the figure on the right: Leek, 1993). The 4th stage of microbial activity being the synthesis of microbial compounds, especially amino acids, using intermediates from the stages 1 to 3, along with transamination.
2) Cellulose? - The degradation of the β-1 linked compounds (cellulose, hemicellulose, fructosans, pectin) by several species of cellulolytic bacteria.
3) Startch? - The degradation of the α-1 linked starches (amylose & amylopectin) and simple sugars by several species of primary amylolytic bacteria.

4) Protein? - Proteolytic bacteria represent only 12 to 38% of the total, and only about a half of the dietary protein is degraded in the rumen, thus the terms, "rumen-degradable protein & rumen-undegradable protein." Hydrolyzed to amino acids and(or) fermented to VFA, including branched-chain VFA from Leu, Ile, and Val.
5) Lipids? - Ruminal microbes rapidly hydrolyze dietary lipids, and, using unsaturated acids (oleic, linileic, and linolenic) as H acceptors, quickly convert most of them to stearic acid.
6) Other important ruminal reactions?

   a) Vitamin B complex - Adequate Co needed for vitamin B_{12} (required by both ruminants & some microbes) synthesis.
   b) S-containing amino acids - Adequate supply of S needed.
   c) Oxalates (toxic for nonruminants) - Converted to formate & CO_2.
   d) Dietary nitrate - Reduced to more toxic nitrite ion.



7) Overview/summary of the fermentation - See the figure (Leek, 1993).

CHANGES IN RUMINAL FUNCTION

1. **Protected Nutrients, Antibiotics, and Probiotics**

A. Protected nutrients:

1) Certain rumen undegradable protein (RUP) plants (e.g., corn) are poorly fermented in the forestomach, but readily digested in the abomasum and intestine.
2) Many denatured proteins also escape fermentation, which is being used commercially by subjecting, high-quality, rumen degradable protein (RDP) to denaturation (e.g., with formaldehyde) to increase RUP.
3) Lipids? Encapsulation by using a coating of protected protein, which prevents the saturation of polyunsaturated fatty acids & allows an increased lipid feeding.

B. Antibiotics

1) About 8% of total digestible dietary energy is lost as methane.
2) Thus, suppressing methane-producing bacteria would reduce the waste.
3) e.g., Monensin:

   a) Affects electrolyte transport across the cell walls of methanogenic & other bacteria, while not affecting, e.g., propionate-producing bacteria.

b) Also, inhibits some bacteria responsible for proteolysis and deamination.

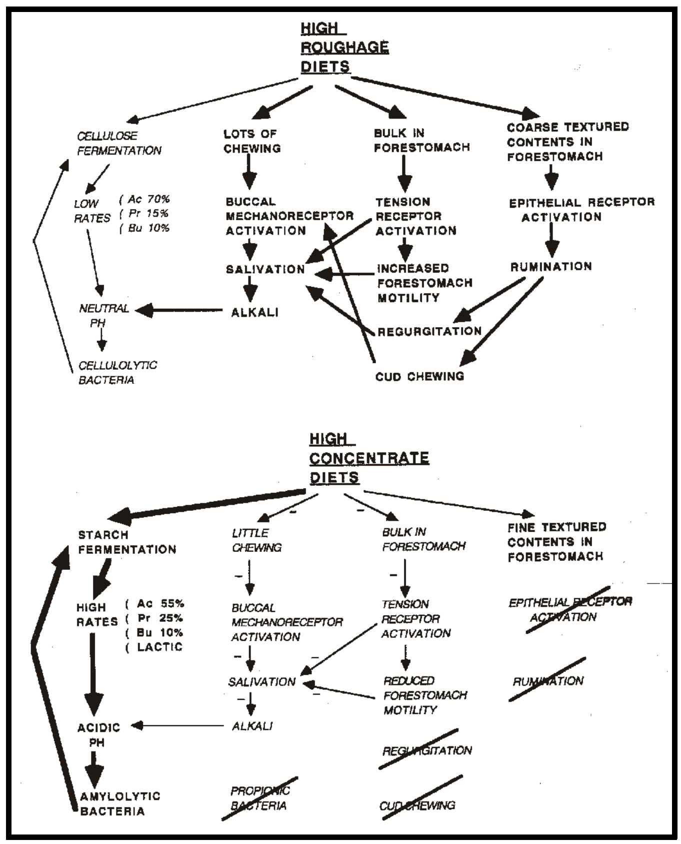
C. Probiotics:

1) Addition of selected, desirable active microbes. Undergo limited proliferation & cannot become established permanently, thus needed to add repeatedly.
2) Certain species of yeast:

a) Shown to be beneficial in concentrate-enriched roughage diets, perhaps, via less lactate production. Perhaps, pH effects & less H production, thus less methane?
b) Overall, the yeast supplementation increases the yield of VFA and microbial protein & decrease lactate & methane production.

2. **Concentrate-Enriched Diets**

A. High-roughage vs. high-concentrate diets - See the figure (Ac = acetate, Pr = propionate, and Bu = butyrate; Leek, 1993).



B. Increased energy and protein needs in ruminants (e.g., for lactation, pregnancy, & growth):

1) Part of the roughage component can be replaced by grain/grain-based concentrates.
2) The potential energy is lower for concentrates vs. roughages (5 & 7.5 mol VFA/kg DM digested, respectively), but can compensate by the greater digestibility (75 to 90% vs. 45 to 70%) & higher fermentation rates via the amylolytic vs. the cellulolytic pathways.
3) With adequate plant protein/NPN, expect a greater supply of VFA & a higher rate of microbial protein synthesis through microbial proliferation.
4) The amylolytic pathways can lead to the increased lactic acid, but will be converted by bacteria to propionic acid if the intraruminal conditions remain above pH 6.2.

C. On the other hand, grain and other concentrates undergo less chewing on ingesta than roughage diets, and their particle size is too small to evoke much rumination:

1) May lead to cessation of ruminoreticular motility (ruminal stasis), and may be sufficient to retard fermentation in some instance.
2) The high intraruminal osmolality may cause large movements of water into the forestomach, leading to tissue dehydration and diarrhea..
3) The high acidity gives rise to a systemic metabolic acidosis and also breaks down the integrity of the forestomach lining, e.g., multiple ulceration of the epithelium (rumenitis)?
4) The entry of largely anaerobic bacteria into the portal venous system:

   a) At best - Cause multiple liver abscesses.
   b) At worst - Swamp the animal's immune system & cause a fatal toxemia.

FATE OF THE END PRODUCTS OF FERMENTATION

1. **Volatile Fatty Acids**

A. End products:

1) Carbohydrates - Converted to mainly acetic, propionic, and butyric acids, with a significant increase in the proportion of propionic acid when starch-rich concentrates are fed.
2) Proteins - Converted to:

   a) Those acids mentioned for carbohydrates plus valeric acid (having a 5-carbon chain) and branched VFA (isoacids), isobutyric & isovaleric acid.
   b) Additional VFA account for less than 5% of the total, and may be more valuable to the microbes for protein synthesis using NPN than to the ruminant/host directly.

B. Absorption:

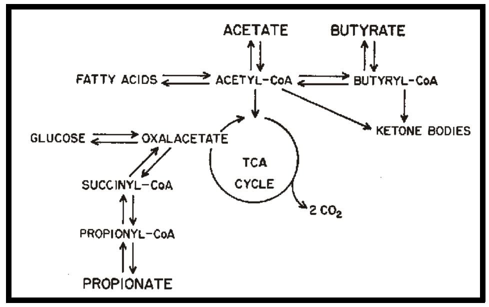
1) Most of the VFA produced are absorbed across the forestomach wall.
2) Absorption rates are higher:

   a) When ruminal pH is reduced, so that more compounds are present as "undissociated" acids.
   b) As the chain length increases, so that the rate of absorption is butyric acid > propionic acid > acetic acid.

3) About one-half of the VFA absorbed by passive diffusion are in the undissociated state, and the remainder are effectively absorbed as anions by facilitated diffusion in exchange for bicarbonate (hydrogen carbonate) ions.

C. Metabolism?

1) Major metabolic pathways for VFA - See the figure [propionate is glucogenic, whereas acetate and butyrate are ketogenic; TCA = Tricarboxylic acid; Bergman (1993) in Swenson and Reece (1993)].



2) Butyric acid:

   a) Most? - Metabolized/oxidized to ketone body, β-hydroxybutyrate, in sheep (less so in cattle).
   b) Remainder? - Carried to the liver and metabolized similarly, thus absorbed butyrate appears in the general circulation almost entirely as β-hydroxybutyrate.
   c) Readily metabolized by most tissues & used to provide the first four carbon for the synthesis of about ½ of the short- & medium-chain fatty acids (C4 - C14) in milk.

3) Propionic acid:

   a) About 30% of the propionate is metabolized by the forestomach wall to lactic acid, thus some lactic acid in portal venous originated as propionate in the rumen.
   b) The portal venous lactate and the remainder of propionate are almost completely removed by the liver.
   c) In the liver, converted to oxaloacetate & used in the Krebs' cycle or, together with lactic acid, converted to glucose, which is released into the circulation or stored in the liver as glycogen.
   d) Propionate is the only VFA that can be used for gluconeogenesis.

4) Acetate:

   a) The most abundant V FA in the general circulation and the prime metabolic substrate.
   b) A small amount of acetate is metabolized to CO_2 by the forestomach wall.
   c) Can be taken up by most body tissues to form acetyl Co-A for use in the citric acid cycle.
   d) In the mammary gland:

      (1) Used for the synthesis of the short- and medium-length fatty acids.
      (2) Account for about ½ of the first four carbon units in each fatty acid chain (i.e. , those not derived from β-OH butyrate) and all of the remaining carbon units in the chain.

2. **Lactic Acid**

A. Along with VFA, lactic acid is produced by certain amylolytic bacteria during the degradation of starch.
B. Normally, lactic acid is present transiently, and, therefore, only in low concentrations, as it is used by secondary bacteria to produce propionate.
C. Lactic acid is a stronger acid than the VFA, thus ruminal pH tends to fall very quickly.
D. Absorbed at only 10% of the rate for V FA, and the more common L(+) isomer is metabolized to pyruvate (en route to glucose and glycogen) by the liver faster than the D(-) isomer.
E. Unmetabolized acid will cause "metabolic acidosis."

3. **Gases**

A. Gases - Production reaches a peak of up to 40 L/h in cattle 2 to 4 hours after a meal when the fermentation rate is at its maximum. Eliminated almost entirely by eructation.
B. Principal gases? - CO_2 (60%), CH_4 (30 to 40%), and variable amounts of N_2, with traces of H_2S, H_2, and O_2:

1) Carbon dioxide - Arises from the decarboxylation of fermentation and neutralization of H^+ by HCO_3-ions entering the rumen in saliva & across the ruminal wall during VFA absorption.
2) Methane - Arises from the reduction of CO_2 and formate by the methanogenic bacteria. Methane is a high-energy compound and its elimination as a waste product represents the loss of about 8 percent of the total digestible energy of the diet.
3) Hydrogen sulfide - Arises from the reduction of sulfates and from sulfur-containing amino acids. A potentially toxic gas, even in small amounts.
4) H_2 - Usually present in traces.
5) Oxygen:

a) Via ingested food & water and also by diffusion from the blood.
b) Quickly used by the facultative anaerobic bacteria, so that ruminal concentrations are always low, which is essential because the majority of ruminal microbes are strict anaerobes.

4. **Ammonia**

A. Arises from the deamination of dietary proteins, NPN, and urea derived from saliva and, across the forestomach wall, from blood.
B. Feeding up to 30% total N as a urea supplement is usually well tolerated.
C. With adequate and suitable VFA, NH_3 is incorporated into microbial protein. If not, can be absorbed, especially if the ruminal pH is alkaline.
D. NH_3 (actually, NH_4^+) must be removed from the portal blood and converted to urea. If not, ammonia toxicity can develop.

5. **Other End Products**

A. Amino acids arising from fermentation are used by other microbes and are not immediately available to the ruminant.

B. Microbes that pass out of the forestomach are digested in the gastrointestinal tract:

1) Lysis of bacteria is started in the abomasum by the action of a lysozyme in the abomasal secretions.
2) Microbes yield protein of high biological value, lipids (including some PUFA), polysaccharides (as starch), and vitamins.
3) The protein content of the microbes is about 27 and 45% of the total DM in bacteria and protozoa, respectively.

C. Fatty acids:

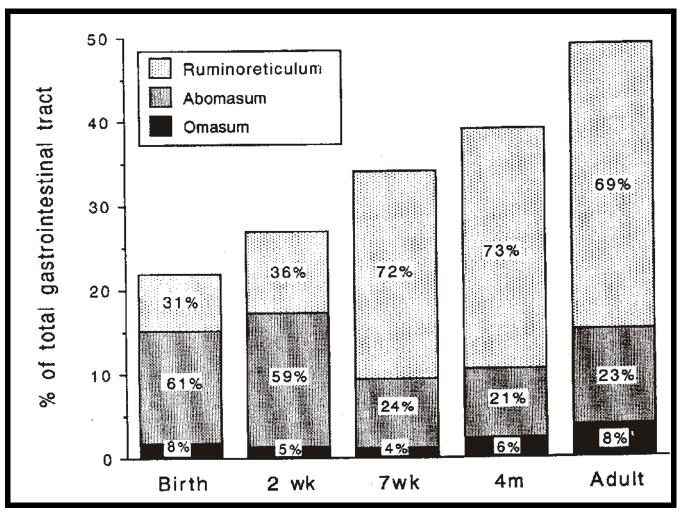
1) Long-chain fatty acids - Absorbed and taken up by the adipose tissue and by the lactating mammary gland.
2) Intraruminal hydrogenation of unsaturated fatty acids? - Causes ruminant carcass and milk fat to have a greater ratio of saturated to unsaturated fatty acids vs. nonruminants.

GASTRIC DIGESTION IN THE YOUNG RUMINANT

1, **General**

A. In the young ruminant, the development of gastric digestion can be considered to have four phases: 1) the newborn phase (0 to 24 hr), 2) the preruminant phase (1 d to 3 wk), 3) the transitional phase (3 to 8 wk), and 4) the preweaning and postweaning phase (8 wk to adulthood).

B. Changes in the proportion of the ruminant stomach - See the figure (Wardrop and Combe, 1960. J. Agric. Sci. 54:140-143)



2. **The Newborn Phase (0 to 24 hr)**

A. Forestomach at birth:

1) Nonfunctional, and represents a small proportion the total stomach.
2) Contains no microbes, and rudimentary ruminoreticular papillae and omasal leaves.

B. Diet? - Consists of colostrum, which is rich in immunoglobulins:

1) Abomasum - Secretes no acid or pepsinogen during the first day or so:

a) Thus, no gastric digestion, which prevents immunoglobulins (IgM antibodies, γ-globulins) from digestion/denaturation.
b) Also, the presence of trypsin inhibitors in the colostrum prevents the degradation of immunoglobulins in the intestine.

2) Subsequently, colostral antibodies are absorbed intact through the intestinal mucosa by endocytosis/exocytosis.
3) Ability to transport/absorb antibodies intact lasts only 24 to 48 hr after birth.
4) Colostrum can be a rich source of vitamins A, D, and E, Ca, and Mg.
5) Lactose is readily digested in the intestine to provide potential energy substrates, glucose & galactose.
6) Colostrum contains mammary gland microbes (mainly lactobacilli species), and they would gain access to the intestine with each sucking period.

C. Fecal contamination? - Provides a source of *Escherichia coli*, streptococci, and *Clostridium welchii*, which can be found in the intestine within 8 to 16 hr of birth.
D. With no or insufficient colostral antibodies, the newborns would be susceptible to acute infections ("joint-ill" and "navel-ill") and then to diarrhea/scours.

2. **The Preruminant Phase (1 d to 3 wk)**

A. The principal food is milk during this phase, but the young ruminant may start trying to taste solid foods during the latter half of this phase. Make only little contribution to its nutrient intake though!
B Compared with drinking from a bucket, sucking from a teat can lead to a greater secretion of saliva, and the saliva contains an esterase (pregastric esterase) that can start the hydrolysis of the milk lipids.
C. Milk passing through the pharynx:

1) Stimulates chemoreceptors with afferent pathways in the glossopharyngeal nerve (ninth cranial nerve).
2) The efferent vagal nerve output can cause the closure of the reticular groove and to relaxation of the reticuloomasal orifice and omasal canal.
3) Contraction of the spiral lips of the reticular groove causes their shortening and apposition to produce a temporary tube connecting the cardiac and reticuloomasal orifices.
4) Results? Milk can bypass the ruminoreticulum, and flow quickly through the relaxed rudimentary omasum, and end up in the abomasum.
5) Factors affecting the closure of the reticular groove?

a) The hunger drive seems to be the main determinant.

b) The closure is not consistently affected by other factors such as head position and whether feeding involves sucking from a teat or drinking from a bucket.

D. The act of sucking and the presence of milk in the abomasum can lead to abomasal secretions:

1) Rate? - Proportional to the number of sucks, thus teat feeding may be more effective vs. bucket feeding.
2) Consist of proteolytic enzyme, rennin/chymosin (no pepsinogen at this stage!), and HCl.
3) Rennin can act on milk at pH 6.5 for 3 to 4 min to produce a hard clot/curd, which consists of butterfat and milk protein precipitated as Ca caseinate.
4) Remaining fraction of the milk or whey? - Consists of whey proteins (albumins and globulins) and lactose, which enters the duodenum after each suck.
5) Hard curd - Very slow degradation over the next 12 to 18 hr:

a) Butterfat can be hydrolyzed to fatty acids and glycerol by lipase in milk (mammary origin) and pregastric esterase from saliva.
b) Precipitated Ca caseinate - Subjected to further proteolysis by rennin at an optimum pH of 3.5.

6) Curd & whey proteins are subjected to complete proteolysis in the intestine, and lactose is hydrolyzed by lactase to glucose and galactose.

3. **The Transitional Phase (3 to 8 wk)**

A. Ingested milk is handled as described before during this phase.
B. The animal starts to ingest progressively larger amounts of roughage, which can stimulate the development of salivary gland & ruminoreticulum:

1) Salivary glands (especially, parotid glands) increase the size and secretion volume, and the composition of secretion becomes alkaline.
2) Ruminoreticulum - Starts acquiring microbes:

a) "Early" microbes (at 1 wk after birth) are largely milk contaminants (lactobacilli), and give very low ruminoreticular pH values.
b) Transitional ruminants - Acquires normal microbes from the ingestion of food and water contaminated with some ruminal microbes.

C. Microbial fermentation of roughage:

1) Start producing VFA that is important for the development of the ruminoreticular papillae and omasal leaves.
2) "Gas production?" - Necessary to develop the mechanisms of eructation.

3) Bulk factor of the roughage - Responsible for the size & muscular development of the ruminoreticulum, onset of cyclic motility, and effective rumination.

D. This period is critical for establishing the ruminoreticulum:

1) The biggest changes occur during this period.
2) By the end of the period, the animal will have the ruminoreticulum with all the basic features.
3) Intermediary metabolism - Moving away from the glucose-based toward the VFA-based, and blood glucose becomes less insulin-sensitive.

4. **The Preweaning and Postweaning Phases (8 wk to Adulthood)**

A. The beginning of the preweaning phase? - Coincides with the natural decline in lactation. Progressively less milk would be available.
B. Reticular groove? - Closure becomes erratic & absent in older animals . . . unless feeding milk regularly.
C. The total empty stomach mass:empty gastrointestinal mass - Would become a progressively greater the animal approaches adulthood.
D. "Forestomach motility cycles" - Start resembling the characteristics of adult animals.
E. Pepsinogen/pepsin replaces rennin in the abomasal secretions.

WATER AND ELECTROLYTES (& IODINE)

WATER

1. **Introduction**

A. Water is the most abundant nutrient (≈ 273 liters/cm^2 of the earth's surface):

1) Sea water . . . . 268.45 liters
2) Continental ice . . . . 4.50 liters
3) Fresh water . . . . 0.10 liter
4) Water vapor . . . . 0.003 liter

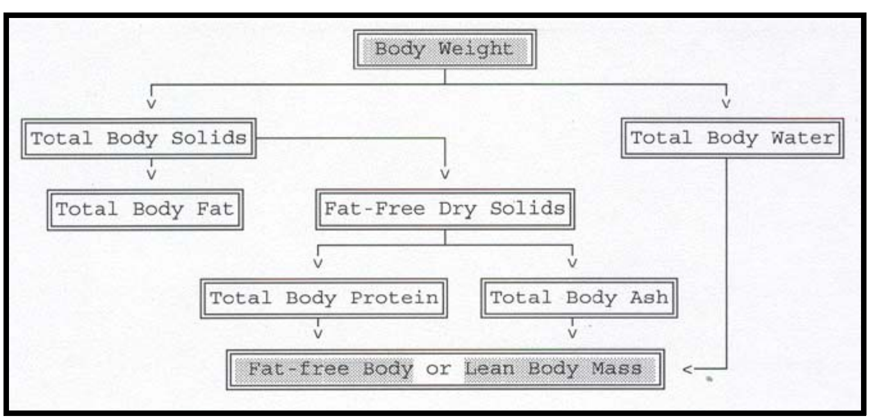
B. Water - 1) Required by animals in the largest amount, thus, 2) probably the most important nutrient, even though not enough attention is given!

2. **Body Water Content** (e.g., swine)

Stage/day	%
Embryo	95
At birth	≈75-80
7 d	*77*
15 d	*75*
30 d	*73*
60 d	*67*
90 d	*62*
120 d	*60*
Market weight	≈ 50

3. **Body Water and Body Composition**

A. The two-compartment model:



B. On the fat-free basis:

1) The proportion of body water, protein & ash stays relatively constant:

a) Moulton (1923; J. Biol. Chem. 57:79) postulated the concept of "chemical maturity," which he defined as "*the age at which concentrations of water, protein and mineral matters in the fat-free body mass become practically constant.*"

b) The age at which animals presumably reached chemically maturity (days):

(1) Rat, 50; guinea pig, 50; cat, 100; dog, 200; swine, 150-300; cattle, 50-300; man, 500-1,000. (Reid et al., 1955. J. Dairy Sci. 38:1344).

(2) Although various mammals become chemically mature at different ages, the proportion of the total life span expended prior to attaining it seems to be similar (3.9 to 4.6%; Moulton, 1923. J. Biol. Chem. 57:79).

2) Thus, the body composition can be determined if one of the three components can be estimated accurately.

☛ This is the basis for the "water concept" or "water dilution technique" to estimate the body composition!

C. If the body water content is known, then:

1) $\% \text{ fat} = 100 - \dfrac{\% \text{ water}}{0.732}$ or

$$\text{Total body fat} = \text{total body wt} - \frac{\text{total body water}}{0.732}$$

2) The remainder of body composition can be determined based on an another assumption that body protein & ash in fat-free, dry matters are practically constant.

Water Content (Fat-Free Basis)

Species	%
Mice	73.7
Rat	72.8
Chicken	74.2
Rabbit	72.6
Dog	75.2
Monkey	73.3
Sheep	73.3
Pig	73.5
Deer	75.0
Cattle	73.3
Man	72.2

4. **Starvation & Water Deprivation**

A. Starvation - Starving animals may lose nearly all of body fat, ½ of body protein & 40% of body weight, but they can still live!

B. Loss of body water:

1) Water deficiency generally impairs growth/development of young animals & reduces feed intake of all animals, thus ↓ productivity.

2) With a loss of 4-5%, animals become restless and lose appetite.

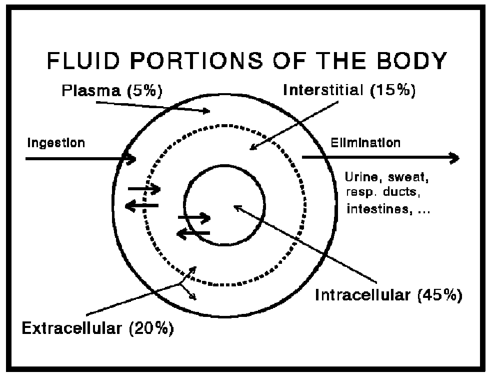
3) With a loss of 6-8%, disfunction of the central nervous system & metabolic disorders may be observed (due to ↑ viscosity of blood).
4) With a loss of 15-20%, death may occur!
☛ The animal can live up to 100 days without food (. . . perhaps, stretching a bit!), but only 5-6 days without water!

5. **Functions of Water**

A. Is involved in the body temperature regulation.
B. Is an universal solvent - e.g., nutrients must be solubilized for "absorption."
C. Has an ionizing power - important in all biochemical reactions.
D. Is involved in transporting nutrients & waste products.
E. Lubricates the body.
F. Provides a cushion to fetuses, nervous system, etc.
G. Is required for milk production in lactating animals.

6. **Absorption & Excretion**

A. Fluid fractions of the body (% of body wt) - Adapted & redrawn from Georgievskii et al., 1982. Mineral Nutrition of Animals.



◦ e.g., A Holstein cow consuming hey & lactating:

a) Intake - ≈ 53 L of drinking water/water in feed, and ≈ 3 L of metabolic water/day.
b) Elimination - ≈ 19 L of water in feces, 11 L in urine & 12 L in milk, and vaporize ≈ 14 L of water each day.

B. Water movement:

1) The gradient permeability of membranes to water (& also to electrolytes) declines almost linearly from the duodenum to ileum.
2) The movement of water molecules through cell membranes:

a) Is related to transfer of mineral elements, nutrients & waste products.
b) 1° function is to achieve "osmotic & hydrostatic equilibrium."

C. Loss of body water:

1) Through "respiration."
2) Through "evaporation" from the skin (but, very little loss via "sweat" in swine, dog & sheep).

Examples:

(1) A 75-kg pig given a water:feed ratio of 2.75:1 can lose ≈ 1 kg of water vapor/day (or .53 g/kg BW/h).
(2) A 182-kg lactating sow can lose ≈ 2.32 kg/day.

3) In the feces and urine - "Nitrogenous end products" influence the degree of water loss in the feces & urine among various species:

a) Mammals - Excrete N mostly as "urea" (which is toxic to tissues), ∴ water is required to dilute urea (which is soluble in water).
b) Birds - Excrete mostly as "uric acid:"

(1) Excreted in a nearly solid form, ∴ minimal loss of water.
(2) Also, catabolism of protein to uric acid produces/provides more metabolic water than its catabolism to urea.
(3) Thus, in general, birds: (a) have a lower water requirement, and (b) are less sensitive to a temporary water deprivation.

4) In the desert:

a) Small desert rodents:

(1) Lapse into a dormant state in "deep burrows," ∴ ↓ metabolic rate.
(2) Keep the body temperature below a critical point by heat conduction, ∴ less evaporation.

b) Camel: (Schmidt-Nielson, 1962. MO Agric. Exp. Sta. Special Rep. 21:1)

(1) Can ↓ body water loss - Lose only ≈ 1% of body weight/d vs 4.5% for a donkey & 7%/d for a man.
(2) Can vary body temperatures as much as 6°C (34.2 to 40.7) between the night & daytime.

7. **Source of Water**

A. Ingested water - Drinking water & water in feedstuffs.
B. Metabolic water - Originates from metabolism of CH_2O, protein and fat:

1) Glucose yields ≈ 55.5% of its weight.
2) Protein yields ≈ 41.5% of its weight.
3) Fat yields > 100% of its weight.

☛ "Poultry:" Conversion of feed into 1 Kcal yields 0.135 g water - e.g,, consumption of 300 Kcal/d yields ≈ 40 g water, which can be used to meet ≈ 15% of water requirement.

C. Hibernating animals:

1) Metabolic water is extremely important!
2) Metabolize reserves of CH_2O & fat as a source of energy for their vital processes.
3) Metabolic water generated may be enough to offset water lost via respiration & evaporation.

8. **Requirements**

☛ Vary according to species, physiological and environmental conditions!

A. Affected by: 1) Ambient temperatures, 2) Stage of growth and(or) body size, 3) Physiological state - e.g., dry or lactating, 4) Diarrhea, 5) Dietary salt & also protein, 6) Feed intake level, 7) Type of diets, 8) Stress, etc.

B. Water requirements: (Maynard et al., 1979)

Animal	Litters
Beef cow, lactating	60
Dairy cow	
Lactating	90
Maintenance	60
Horses	
Medium work	40
Lactating	50
Poultry, hen	0.5
Swine	
30 kg	6
60-100 kg	8
Lactating sow	14
Sheep	
Lactating ewe	6
Lamb	4

C. Swine & poultry:

1) Should be provided on *ad libitum* basis, and generally consume twice as much water as dry feed:

   a) 2:1 - Minimum, and wider ratios are needed for young & lactating swine.
   b) The ratio may increase to ≈ 5:1 during the summer or when environmental temperatures are high.

2) Broilers ↑ water consumption ≈ 7%/each 1°C ↑ the temperature above 21°C.
3) Swine - Daily feed intake is the best indicator of ad libitum water intake for ad libitum-fed pigs, and the relationship can be described by the following equations: (Brooks et al., 1984. Vet. Rec. 115:513)

a) Water (L/d) = 0.149 + (3.053 x kg dry feed) or
b) Water (L/d) = 0.788 + (2.23 x kg dry feed) + (0.367 x kg body wt$^{0.6}$)

9. **Nutrients & Toxic Elements in Water**

☛ Because of its property as an universal solvent, water may carry many essential elements, but at the same time it may contain toxic materials!

A. Composition of surface water[a]: (Maynard et al., 1979)

Substance	Mean	Maximum	Minimum
Phosphorus, mg/L	0.087	5.0	0.001
Calcium, mg/L	57.1	**173.0**	11.0
Magnesium, mg/L	14.3	**137.0**	8.5
Sodium, mg/L	55.1	**7,500.0**	0.2
Potassium, mg/L	4.3	370.0	0.06
Chloride, mg/L	478.0	19,000.0	0.0
Sulfate, mg/L	135.9	**3,383.0**	0.0
Copper, μg/L	13.8	280.0	0.8
Iron, μg/L	43.9	4,600.0	0.1
Manganese, μg/L	29.4	3,230.0	0.2
Zinc, μg/L	51.8	1,183.0	1.0
Selenium, μg/L	0.016	1.0	0.01
Iodine, μg/L	46.1	336.0	4.0
Cobalt, μg/L	1.0	5.0	0.0

[a]Based on more than 80,000 samples collected at 14,000 different locations over 12-yr period; "Sea water" (mg/l): Ca, 410; Mg, 1,303; Na, 10,813; sulfate, 2,713.

B. Water "hardness:"

1) Refers to a sum of Ca & Mg expressed in equivalent amounts of Ca carbonate.
2) Classification: Very soft, < 15, Soft, < 60, Hard, > 120, and Very hard, > 180 mg/liter.

C. Total dissolved solids (TDS) or "salinity:"

1) As a "drinking water, a total amount of mineral salts in water seems to be more important than the type of salts.
2) Safe TDS levels for livestock & poultry: (Adapted from Cunha, 1977)

mg/L or ppm	Comments
< 1,000	Safe for any species.
1,000-2,999	Generally safe for all species, but may cause temporary diarrhea.
3,000-4,999	Generally safe for livestock, but can cause temporary diarrhea or refusal. Poor for poultry - watery feces & may ↓ growth & ↑ mortality.
5,000-6,999	Reasonably safe for livestock, but avoid its use in pregnant or lactating animals.

	Not acceptable for poultry - almost always cause some problems.
7,000-10,000	Unfit for poultry and swine.
	Risky for pregnant, lactating, young or stressed cattle, sheep & horses.
	Some may tolerate, but better to avoid!
> 10,000	Unfit for all species.

3) Effects of TDS on pig performance:

a) TDS & digestibility coefficients (%; 30 to 55-kg pigs): (Adapted from Anderson, et al., 1994. Can. J. Anim. Sci. 74:141)

Water TDS, ppm	DM	GE	CP
Exp. 1 (H_2O with Na salts):			
0	83.7	81.6	82.0
370	83.6	81.3	81.3
1000	84.0	81.8	82.7
4000	82.4	80.0	80.6
6350	83.3	81.5	81.5
8000	81.9	79.4	80.2
Exp. 2 (H_2O with sulphates):			
0	79.8[a]	78.0	78.3[a]
450	80.1[a]	78.3	79.2[a]
1100	79.2[a]	77.4	78.3[a]
4000	78.4[a]	76.6	77.3[ab]
7000	78.1[a]	76.6	77.3[ab]
11700	75.3[b]	74.1	72.2[b]

[a,b]Means within a column with different superscripts differ ($P < .05$).

b) TDS & growth performance of 4-wk old weanling pigs* (Adapted from McLeese et al., 1992. Anim. Prod. 54:135):

Water TDS, ppm:	213	2350	4390
First Exp. (20-d study):			
Water, g/d (1st 5 d)	1144		1312
Feed, g/d	565		513
Weight gain, g/d	416		354
Gain:feed, g/kg	739[a]		685[b]
Second Exp. (5-d study):			
Water, g/d (1st 5 d)	2188[a]	1454[b]	1830[ab]
Feed, g/d	190	117	170
Weight gain, g/d	104	16	48

*Unmedicated & medicated diets were used in the first & second experiments, respectively;[a,b]Means within a row with different superscripts differ ($P < .05$).

D. Nitrate & nitrite:

1) Nitrate (NO_3^-):

   a) In general, pigs are not adversely affected by nitrate because there is no bacterial flora to convert nitrate to nitrite.

      (1) In one study, no death was observed with 9,000 ppm nitrate, even though performance was decreased!
      (2) Other research demonstrated that 330 ppm was completely safe.

   b) But, bacteria in water may convert nitrate to nitrite in some situations.

2) Nitrite (NO_2^-) - Rduced form of nitrate:

   a) Can combine with Hb to form Met-Hb, ∴ reducing the oxygen carrying capacity.
   b) Nitrite in water may indicate "bacterial contamination."

3) Recommended limits for livestock: (mg/L)

	Nitrate	Nitrite
NAS, 1974	440	33
CAST, 1974	1320	33

ELECTROLYTES IN GENERAL

1. **Body Fluids**

A. Electrolyte composition of body fluids (swine): [Crenshaw, 1991. In: Miller, Ullrey & Lewis (Ed.) Swine Nutrition]

Item ECF	ISF	ICF	
Cations, mEq/L:			
Sodium	142	145	10
Potassium	4	4	159
Magnesium	2	2	40
Calcium	5	3	1
Total	*153*	*154*	*210*
Anions:			
Chloride	103	117	3
Bicarbonate	28	31	10
Phosphates	4	4	75
Sulfate	1	1	2
Protein	17	-	45
Others	-	1	75
Total	*153*	*154*	*210*

1) Sodium - The major cation in the extracellular fluids.
2) Chlorine - The major anion in body fluids.
3) Potassium - Serves as the major intracellular cation.

☛ All three are extremely important for the "electrolyte balance!"

2. **Electrolytes**

A. A general definition - "*Substances that dissociate into ions when in solution & capable of conducting electricity.*"

B. Functions:

1) Osmotic pressure regulation & maintenance of water balance.
2) Nerve impulse conduction.
3) Muscle contraction.
4) Acid-base balance.
5) Enzymatic reactions - A component of enzymes or activate enzymes.

SODIUM AND CHLORINE (SALT)

1. **General**

A. The distribution of "population centers" was predicated by three factors, salt (NaCl), water & food in ancient times!

B. Salt is among the first specific nutrients recognized to be "essential."

C. Na & Cl are treated together because of their close relationships, and also it is a common practice to supplement together.

2. **Sodium**

A. The body contains ≈ 0.2% Na (≈ 75% in body fluids and 25% in bones).

B. Functions:

1) Involved in maintenance of osmotic pressure (chief cation of extracellular fluid).
2) Involved in maintenance of body fluid balance/hydration of tissues.
3) Involved in the action of heart & maintenance of membrane potential, i.e., nerve impulse transmission & conduction. (These functions are highly dependent on a proper proportion of Na & K!)
4) Involved in maintenance of blood pH (acid-base balance).
5) Involved in active transport system for sugars, amino acids, etc.

3. **Chlorine**

A. Closely related to Na - Usually 1 g Na & .812 g Cl in soft tissues (i.e., 1:.812 ratio).

B. The body contains 30-50 mEq/kg fat-free wt (15-20% bound to organic molecules).

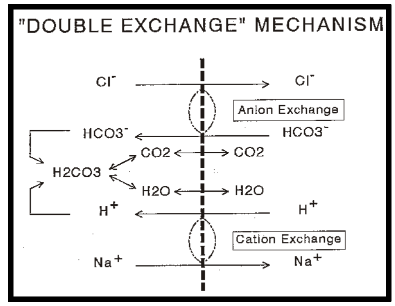
C. Functions - Mainly to ensure a proper fluid-electrolyte balance:

1) Acid-base balance (2/3 of acidic ions in the blood).
2) Osmolarity (1° anion in extracellular fluids).
3) Important component of gastric secretion (HCl).
4) Also, Cl^- may activate enzymes, especially α-amylase.

4. **Absorption and Excretion of Na & Cl**

A. Absorption:

1) Readily absorbed by the GI tract regardless of sources.
2) Absorbed against concentration gradient - "Double exchange mechanism?"



B. Excretion:

1) Na - 99% or more in the urine, and increase the loss via sweat with high temperatures.
2) Cl - 90-95% in the urine, 4-8% in the feces & 2% via the skin, and temperatures influence a proportion of loss via various routes.

5. **Homeostasis**

A. Deficit of Na:

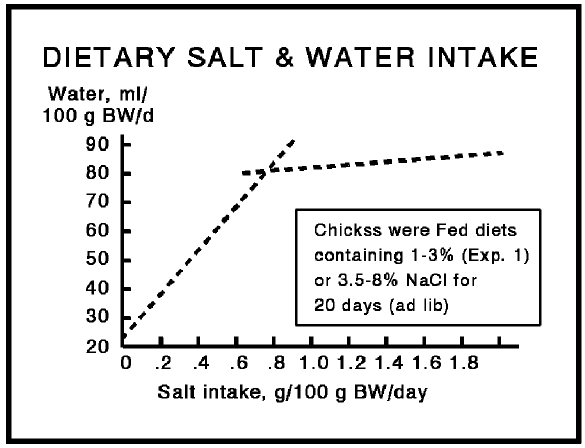
1) JG (Juxtaglomerular) cells: a) Can sense ↓ blood pressure of Na concentration, and b) A source of renin in kidneys and blood stream.
2) Functions of aldosterone? a) Increase permeability to Na?, b) ↑ ATP?, & c) ↑ activity of Na pump?

JG cells:
↓ BP/Na:
(Prorenin)
Angiotensinogen ↓ (kallikrein)
↓ <———— Renin
Angiotensin I
↓ (dipeptidyl-carboxypeptidase)
Angiotensin II
↓ (acts on adrenal cortex;
↓ also vasoconstriction)
Aldosterone
↓
↑ Na & water retention → ***↑ ECF volume***
(Also ↑ K excretion!)

B. Dietary salt & Na excretion: (Mason & Scott, 1974. Q. J. Exp. Physiol. 59:103)

	Excretion of Na			
Cl, % DM	Urine	Feces	Total	Urine, L/d
0.25	6	8	14	1.7
1.7	175	22	197	2.7
4.2	440	32	471	3.1
6.7	705	33	739	4.0
9.3	1042	40	1081	7.7
11.8	1182	47	1229	9.2
14.3	1335	159	1495	9.7

C. Salt & water intake in chicks - Redrawn from Paver et al., 1953. Cited by Mongin, 1980. In: Proc. IMC Conf.



B. Homeostasis:

1) Na - Maintained by adjusting the rate of excretion, i.e., simply ↑ excretion when consumed "excess" Na.
2) Cl - Affected by changes in concentrations of Na and K, i.e., its homeostasis is secondary to Na/K, and there seems to be no direct hormonal or CNS control.

☛ The availability of water is extremely important in animals' ability to tolerate diets containing high concentration of salt!

6. **Deficiency & Toxicity**

A. Deficiency:

1) General symptoms: a) "Salt craving," i.e., licking soils, rocks, woods & other objects, and b) Depressed appetite, consequently ↓ productivity.
2) Specific symptoms:

a) Na - ↓urinary & salivary Na, ↑renin secretion, and decreased kidney weight.
b) Cl - ↓blood & urinary Cl, and kidney damages (e.g., extensive general cell damage, hyperplasia, calcification, etc.).

B Toxicity (salt):

1) Swine: (Bohstedt & Grummer, 1954. J. Anim. Sci. 13:933)

a) Induce salt poisoning by feeding diets with 6-8% salt and restricting water?
b) Signs - Nervousness, staggering, weakness, paralysis, convulsion, blindness?

2) Fowl - Edema & ↑ mortality with about 4% or higher. (Tracor-Jitco, Inc., 1974)
3) Maximum tolerable levels: (NRC, 1980)

Lactating cows	4%
Cattle & sheep	9%
Swine	8%
Poultry	2%
Horses & rabbits	3%

7. **Requirements**

   A. For many years, it's a standard practice to add 0.5% salt to all swine diets, and also for other nonruminant species.
   B. For swine, renewed interest in reevaluating the requirement because of "Na build-up" in the cropland.
   C. Requirements - See "Nutrition & Feeding" section for each species.

POTASSIUM

1. **General**

   A. The third most abundant mineral in the body.
   B. The most abundant in muscle tissues.
   C. Functions:

      1) The major intracellular cation, ∴ important for "osmolarity" of body fluids and(or) water balance.
      2) Acts as available base, ∴ important for "acid-base equilibrium."
      3) Has an important function in excitability of nerves & muscles:

         a) Low levels can reduce frequency & amplitude of heart contractions.
         b) Excess levels can induce cardiac arrest. [For instance, saturated KCl has been used as an agent for "euthanasia(?)."]

      4) Activates enzymes or functions as a cofactor in several enzyme systems - e.g., involved in activation of ATPase or serving as a cofactor for K-dependent phosphatase.

2. **Absorption/Excretion & Homeostasis**

   A. Absorption - Mainly from the upper SI by simple diffusion, and the digestibility of most forms of K in typical diets is ≈ 95%, ∴ highly available.
   B. Excretion:

      1) Excrete excess K 1° via the urine (≈ 95%).
      2) Thermal stress ↑ the loss via sweat, and also 3) excreted in milk & eggs.

   C. Kidney is the main homeostatic mechanism to maintain a stable tissue level of K:

      1) ↓ BP → Renin → Angiotensinogen → Angiotensin I → Angiotensin II → Aldosterone.
      2) Net effects of aldosterone are to "↑ Na & ↓ K" in the extracellular fluid.

   D. The maintenance of K between intra- & extracellular fluids is controlled by the Na-K pump or Na-K ATPase, i.e., 3 Na pumped out of the cell & 2 K diffused into the cell.

E. Effects of "Na-K exchanges?" - e.g.

1) Transmission of nerve impulses.
2) Secondary transport of nutrients such as glucose.
3) Maintenance of osmotic pressure, water balance, acid-base balance, etc.

3. **Deficiency & Toxicity**

A. Deficiency:

1) Many symptoms/signs are results of impaired intracellular cation balance & malfunctions of nervous & muscle systems.
2) Not likely to observe the K deficiency under normal conditions, but K intake, diarrhea, vomiting, high NaCl intake, environmental temperatures & others may have effects on the K status.
3) Signs include: a) Reduced feed intake (usually the first sign) & depressed growth, b) Muscular weakness, nervous disorder & paralysis, and c) Degeneration of vital organs (e.g., heart).

B. Toxicity:

1) Not likely to occur under practical conditions.
2) A maximum tolerable level - Established to be ≈ 3% for cattle & sheep, and limited data on nonruminant species, but a 3% maximum seems to be satisfactory.

4. **Requirements/Factors Affecting Requirements**

A. Requirements - See "Nutrition & Feeding" section for each species.
B. The requirements are affected by the stress:

1) "Stress" → ↑ adrenal cortex activity → ↑ K excretion → "Deficiency!"
2) Thus, supplemental K may be beneficial or even necessary in some situations.

5. **The Effect of K Supplementation & Stress - e.g. With Feeder Pigs**

A. Dietary K & feeder pig performance: (Jesse et al., 1988. J. Anim. Sci. 66:1325)

Phase	Contr. (0.64% tot. K)	K Suppl. (1.00% tot. K)
Weight gain, kg/d		
0-14 d	0.65	0.65
14-28 d	0.56	0.60
28-42 d	0.59	0.66
0-42 d	0.60	0.64

☞ Improved weight gain, but no response in feed efficiency, and saw no response to K supplementation in other trials.

B. Dietary K supplementation and feeder pig performance: (Brumm and Schricker, 1989. J. Anim. Sci. 67:1411)

Added KCl, %[a]:	0	0.48	0.96	1.44
Feed intake, kg/d				
0 to 2 wk	0.88	0.93	0.87	0.95
0 to 12 wk	1.91	1.94	1.92	1.99
12 to final	2.66	2.78	2.71	2.80
Overall	2.09	2.14	2.11	2.18
Weight gain, kg/d				
0 to 2 wk	0.36	0.35	0.35	0.35
0 to 12 wk	0.60	0.59	0.60	0.60
12 to final	0.63	0.63	0.59	0.59
Overall	0.60	0.60	0.60	0.60
Feed:gain				
0 to 2 wk	2.50	2.76	2.60	2.76
0 to 12 wk	3.20	3.31	3.21	3.32
12 to final	4.33	4.46	4.64	4.78
Overall	3.46	3.59	3.53	3.66
No. of pigs dead or removed	5	4	3	6

[a]Added KCl during a 14-d receiving period & from d 84 to final period (d 110 & d 111 for Trial 1 & 2, respectively.)

☛ **The Bottom Line?** Corn-soy diets contain sufficient K for a period of stress associated with marketing and transport of feeder pigs.

6. Supplemental K has been shown to spare amino acids in poultry, but it has not been demonstrated in swine!

IODINE

1. **Introduction**

A. Present in the thyroid as mono-, di-, tri- and tetraiodothyronine.
B. Important in regulation of the metabolic rate.
C. "Hypothyroidism" can be a problem in the Northwestern and the Great Lakes regions because of a low iodine content of soils, ∴ "low-iodine" feeds.

☛ Unlike in the past, however, the problem may exist elsewhere in today's production system because of the extensive movement/transportation (. . . including international trades) of feed ingredients (. . . 1° concerned with grains).

D. Deficiency:

1) Enlarged thyroid or goiter.
2) Poor growth rate - Resulting from ↓ metabolic rate, cell differentiation/growth.

3) In severe cases, animals become lethargic, and pigs may be stunted.
4) Reduced reproductive performance (low conception rate, libido, etc.), and also ↓ milk production.

2. **Requirements**

A. Affected by the presence of goitrogenic substances in some feed ingredients such as rapeseed, linseed, peanuts & soybeans.
B. Typical corn-soy diets without iodine supplement contain sufficient goitrogens to ↑ the size of thyroid 5- to 6-fold.
C. The requirement (pigs) is estimated based on the amount of dietary iodine needed to prevent hypertrophy of thyroid in growing pigs fed a corn-soy diet.
D. Requirements (mg/kg):

1) Swine, all classes (NRC, 1998) 0.14
2) Chickens & broilers (NRC, 1994) 0.35
3) Laying hens (NRC, 1994) 0.33-0.35
4) Turkeys (NRC, 1994) 0.40
5) Horses (NRC, 1989) 0.10

3. **Sources**

A. Iodized salts (sodium or potassium iodide):

1) Contain 0.01% stabilized iodide or 0.0076% iodine.
2) Addition of 0.20% iodized salt to corn-soy diets supplies ≈ 0.15 ppm iodine.

B. Dicalcium phosphate contains ≈ 10 ppm iodine, ∴ addition of 1.5% dical to corn-soy diets supplies ≈ 0.15 ppm iodine.

ELECTROLYTE BALANCE

1. **General**

A. Traditionally, the interest of physiologists, chemists & biochemists.
B. During the last 15-20 years (especially, since early 80s), animal nutritionists started considering the "dietary electrolyte balance."
C. Electrolyte balance:

1) Dietary macromineral balance or dietary undetermined anion (dUA):

$$\text{dUA (mEq/kg)} = \sum(\mathbf{Na + K + Ca + Mg}) - \sum(\mathbf{Cl + P + S})$$

a) Represents in part "acidogenicity or alkalinogenicity" of diets.

b) If dietary mineral cations > mineral anions, there must be an equivalent excess of organic anions such as bicarbonate, citrate & acetate to preserve an "electrical neutrality."
c) The dietary content of individual minerals is irrelevant for this consideration, i.e., only interested in "charges."
d) Expressed in terms of milliequivalent per kg (mEq/kg):

(1) e.g., Conversion of % Na (.1%) to mEq/kg:

(a) % to mg/kg (x 10,000): 0.1 x 10,000 = 1,000 (or 0.1/100 x 1,000,000)
(b) Divide the result by MW: 1,000/23 = 43.5
(c) Multiply by the valence: 43.5 x 1 = 43.5 mEq/kg

(2) Or, use conversion factors:

Conversion table (% to mEq/kg)[a]

Mineral	MW	Valence	Conv. factor
Sodium (Na)	23.0	+1	+435
Potassium (K)	39.1	+1	+256
Calcium (Ca)	40.1	+2	+499
Magnesium (Mg)	24.3	+2	+823
Chloride (Cl)	35.5	-1	-282
Phosphorus (P)	31.0	-1.75	-565
Sulfur (S)	32.1	-2	-623

[a]mEq/kg = mineral (%) x conversion factor.

e.g. 0.1% Na = .1 x (+ 435) = + 44 mEq/kg,
0.5% K = .5 x (+ 256) = + 128 mEq/kg, and
0.15% Cl = .15 x (- 282) = - 42 mEq/kg. . . , etc.,
and use these values to estimate the dietary undetermined anion.

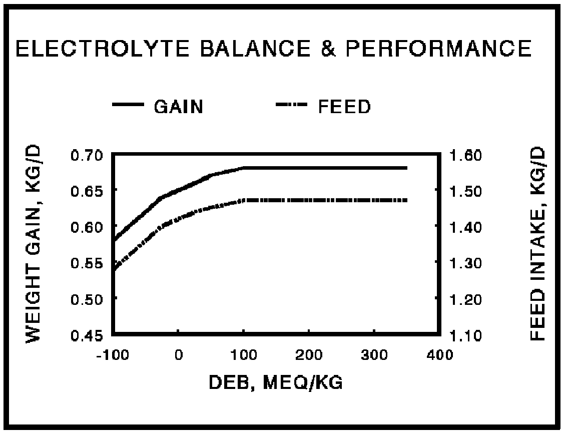
2) "Dietary electrolyte balance (dEB)" is a simplified version, and may be appropriate to use in most circumstances: dEB (mEq/kg) = **Na + K - Cl**

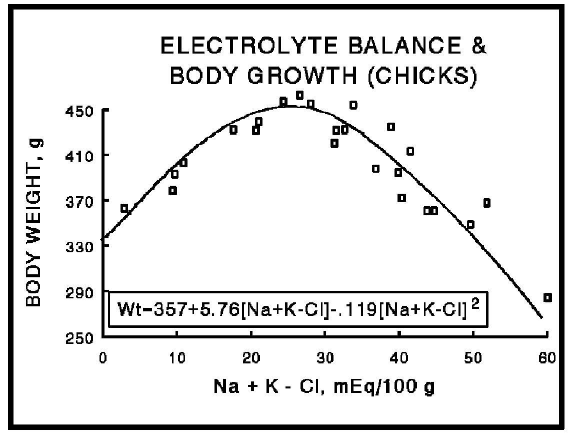
2. Dietary Electrolyte & Animal Performance?

A. Confounded by:

1) Deficiency/toxicity of each mineral.
2) Availability of each mineral.
3) Environmental conditions such as presence of diseases, ambient temperatures, availability of water, stress, etc.

B. Effect of electrolyte balance on performance of pigs (Patience et al., 1987. J. Anim. Sci. 64:457 - Left) and chicks (Mongin, 1980. Proc. 3rd. Annu. Int. Mineral Conf. - Right)





C. Electrolyte balance and nutrient digestibility (%) measured at the end of the small intestine of pigs: (Haydon & West, 1990. J. Anim. Sci. 68:3687)

dEB, mEq/kg:	-50	100	250	400
Nitrogen*	68.9	72.8	75.4	76.1
Gross energy*	63.3	68.4	69.6	72.3
Dry matter*	62.0	67.2	68.6	71.5
Indispensable amino acid:				
Arg*	84.3	85.6	86.8	87.0
His*	79.6	81.4	82.3	83.6
Ile*	80.2	80.9	82.5	83.0
Leu*	77.3	78.8	78.0	81.3
Lys*	79.4	82.2	83.6	83.6
Met	75.4	78.4	76.9	79.2
Phe*	78.8	80.1	81.3	82.5
Thr*	66.9	70.3	72.3	72.4
Val*	76.0	77.4	78.6	79.7

* Linear effect, $P = 0.01$ to 0.10. Also observed similar linear effects on all dispensable amino acids.

☛ The bottom line?

Electrolyte balance can influence the nutrient digestibility & performance of pigs. Practical swine diets contain ≈ 175 meq/kg, thus provide a margin of safety, but with ↑ use of lysine·HCl, may become a concern!

D. Effect of dietary chloride, sulfate, and phosphate on broiler chickens.

1) Chloride & sulfate: (Ruiz-López et al., 1993. Poult. Sci. 72:1693)

Diet	% of diet	14-d gain, g	14-d feed, g	Feed: gain
Basal	-	365[a]	537[ab]	1.47[b]
+80 meq Cl^-/kg	0.284% Cl¶	343[ab]	601[a]	1.76[ab]
+160 meq Cl^-/kg	0.567% Cl¶	355[ab]	537[ab]	1.52[ab]
+240 meq Cl^-/kg	0.850% Cl¶	307[b]	459[b]	1.51[b]
+80 meq SO_4^{2-}/kg	0.128% S§	349[ab]	579[a]	1.67[ab]
+160 meq SO_4^{2-}/kg	0.256% S§	362[a]	613[a]	1.71[ab]
+80 meq SO_4^{2-}/kg	0.128% S£	328[ab]	590[a]	1.83[a]
+160 meq SO_4^{2-}/kg	0.256% S£	365[a]	568[a]	1.54[ab]

¶ Cl from $CaCl_2{\cdot}2H_2O$; § S from Na_2SO_4 + K_2SO_4; £ S from $Ca_2SO_4{\cdot}2H_2O$; [a,b]Means within columns with no common superscripts differ, $P < 0.05$.

2) Chloride & phosphate: (Ruiz-López et al., 1993. Poult. Sci. 72:1693)

Diet	% of diet	13-d gain, g	13-d feed, g	Feed: gain
Basal	-	431[a]	662[ab]	1.55
+80 meq Cl^-/kg	0.284% Cl¶	437[a]	594[bc]	1.37
+160 meq Cl^-/kg	0.567% Cl¶	400[a]	607[bc]	1.52
+240 meq Cl^-/kg	0.850% Cl¶	338[b]	516[c]	1.52
+80 meq HPO_4^{2-}/kg	0.124% P§	455[a]	681[ab]	1.50
+160 meq HPO_4^{2-}/kg	0.248% P§	441[a]	620[ab]	1.41
+80 meq $H_2PO_4^{2-}$/kg	0.124% P£	461[a]	711[a]	1.54
+160 meq $H_2PO_4^{2-}$/kg	0.248% P£	419[a]	593[bc]	1.41

¶ Cl from $CaCl_2{\cdot}2H_2O$; § P from $CaHPO_4{\cdot}2H_2O$; £ P from $Ca(H_2PO_4)_2{\cdot}H_2O$; [a,b,c]Means within columns with no common superscripts differ, $P < 0.05$.

☛ Excess Cl can clearly depress the performance of broiler chickens, thus, perhaps, have to consider the amino acid requirement established by using amino acid·Cl!?

ELECTROLYTES AND IODINE FOR FISH

1. **Osmoregulation**

A. Osmotically active solutes:

1) Predominant minerals are Na, K & Cl.
2) Ca, Mg, bicarbonate & phosphate are not directly involved, but influence functions of the kidney.
2) Proteins play a small part but important in moving fluids across the cell membrane.

B. Ionic composition and osmolarity:
1) Fish maintain electrolyte levels significantly different from their environment.

2) Fresh water fish can maintain “hypertonic” blood vs external medium by:

    a) Active uptake of salts by the gill.
    b) Having low body surface permeability.
    c) Having high glomerular filtration rate of the kidney along with tubular & bladder reabsorption of filtered ions.

3) Marine fish can maintain “hypotonic” blood vs external medium by:

    a) Losing water via any permeable body surface, and gaining salts.
    b) Replacing lost water by drinking sea water.
    c) Absorbing monovalent ions & water into blood, and accumulating divalent ions in the intestine to maintain the same osmolarity as blood.
    d) Enhancing further water conservation by ↓ glomerular filtration (the kidney serving 1° as a divalent ion secretory organ).
    e) Excreting excess monovalent ions derived from swallowed seawater & passive uptake across the body surface 1° by the gill.

2. **Na, K & Cl**

    A. Na & Cl are 1° cation & anion, respectively, of the ECF, and K & Mg are 1° ICF cations.
    B. The osmotic pressure of the ICF & ECF is tightly controlled mostly by energy-dependent mechanism that determines/regulates the rate of absorption of Na & water by epithelial membranes of the gill, gut, integument & kidney.
    C. Deficiencies have not been produced in fish, even though they are necessary for osmoregulation, pH balance, nerve impulse, gastric juice, "chloride shift" in the transport of CO_2 & carbonate, etc.
    D. Most fresh & seawater fish environments contain adequate levels of these elements, ∴ can absorb via the gill in fresh water fish & the gut in seawater fish.
    E. Excrete "excesses" efficiently, ∴ 8-12% salt has no adverse effects.

3. **Iodine**

    A. Needed for the thyroid hormone synthesis along with Tyr - Thyroid hormones influence cellular oxidation, growth, other endocrine glands, neuromuscular functions, circulatory dynamics, and metabolism of major nutrients.
    B. Fish can obtain I from water via branchial pumps & feed sources:

        1) Rainbow trout obtain ≈ 80% from water, 19% from diets & 1% by recycling.
        2) With a low or absent of dietary uptake, they can maintain plasma I by absorbing environmental I & mobilizing I bound to plasma proteins & tissue I.
        3) ≈ 5% of I consumed is utilized by the thyroid.

    C. “Iodide” trapped in the thyroid gland:

1) Oxidized to iodine, which is probably mediated by peroxide enzyme(s).
2) Iodination of Tyr to form mono and diiodotyrosine.
3) Two iodotyrosine to form thyroxine (T_4).
4) One mono & one diiodotyrosine to form triiodothyronine (T_3).

D. Both T_3 & T_4 occur in blood.
E. T_3 binds more strongly to plasma protein vs T_4, ∴ T_3 turnover is slower.
F. Both are excreted extensively in the bile, but other routes (kidney & gills) may also be involved.
G. Factors affecting blood I:

1) Dietary & water I levels.
2) Elevated water temperature, which ↑ excretion rate.
3) Sexual maturation.
4) Ability of fish to bind I to plasma proteins.

H. Deficiency or hypothyroidism:

1) Insufficient dietary I is probably the most common cause.
2) Early 1910s, "carcinoma" in brook trout was diagnosed correctly as "thyroid hyperplasia," and demonstrated this disease could be controlled by I supplementation.

I. A minimum dietary requirement of most fish species has not been established, and requirements are likely to be influenced by growth rate, sex, age, physiological status, environmental stress, disease, I content of water & other factors.

4. **Requirements** - See "Fish, Dog, and Cat Nutrition & Feeding" section.

CARBOHYDRATES

INTRODUCTION

1. **General**

   A. Carbohydrates make up 75% of dry weight of many plants on which many animals primarily depend on.
   B. Carbohydrates make up 70-80% of swine diets (& also poultry diets), thus important from a nutritional standpoint as well as an economical standpoint.

2. **Classification**

- Based on the No. of sugar units & carbon atoms per sugar unit (Maynard et al., 1979):

I. Monosaccharides (single glycose unit):
Trioses ($C_3H_6O_3$)
Glyceraldehyde & Dihydroxyacetone
Tetrose ($C_4H_8O_4$)
Erythrose
Pentoses ($C_5H_{10}O_5$)
Ribose, Arabinose, Xylose, and Xylulose
Hexoses ($C_6H_{12}O_6$)
Glucose, Galactose, Mannose, and Fructose

II. Oligosaccharides (2 to 10 glycose units):
Disaccharides ($C_{12}H_{22}O_{11}$)
Sucrose, Maltose, Cellobiose, and Lactose
Trisaccharides ($C_{18}H_{32}O_{16}$)
Raffinose
Tetrasaccharides ($C_{24}H_{42}O_{21}$)
Stachyose
Pentasaccharides ($C_{30}H_{52}O_{26}$)
Verbascose

III. Polysaccharides (> 10 glycose units):
Homoglycan ("single glycose" units)

Pentosans $(C_5H_8O_4)n$	Arabans, and Xylans	
Hexosans $(C_6H_{10}O_5)n$	Glucans	Starch (α-linked), Dextrins (α-linked), Glycogen (α-linked), and Cellulose (β-linked)
	Fructans	Inulin, and Levan
	Galactans	
	Mannans	

Heteroglycan (2-6 different kinds of glycose units)
Pectins (α-linked), Hemicellulose (β-linked), Gums & Mucilages, and Mucopolysaccharides

Specialized compounds:
Chitin
Lignin (not a carbohydrate)

NUTRITIONALLY IMPORTANT SUGARS/CH_2O

1. **Monosaccharides**

A. Trioses, glyceraldehyde & dihydroxyacetone, are important intermediates in energy metabolism.

B. Pentoses:

1) Majority of pentoses:

a) Exist as polymers, pentosans, and only a small fraction as a free form.
b) Associated with cell walls (hemicellulose).
c) After fermentation by microbes, can contribute to "energy pool."

2) Ribose:

a) Occurs in a No. of compounds such as ATP, ADP, DNA, RNA, etc.
b) Can be synthesized by animals.

C. Hexoses:

☛ 16 stereoisomers (8 + 8 mirror images) are possible, but probably three are nutritionally important (i.e., in terms of a practical nutrition)!

1) Glucose (dextrose):

a) Found a free form in fresh fruits, plant fluids, etc.
b) 1° energy source, ∴ probably the most important sugar.
c) One of the sugar units of sucrose & lactose.
d) An end product of starch digestion, and produced commercially by hydrolyzing corn starch.

2) Galactose:

a) One of the sugar units in lactose.
b) No free form in the nature.
c) Converted to glucose in the liver:

(1) "Congenital galactosemia" - Some people lack the enzyme (phospho-galactose uridyl transferase), which results in accumulation of galactose, ∴ must restrict milk intake!
(2) Also, poultry lack this enzyme. (They can tolerate up to 10% galactose, but higher levels can cause convulsion & death.)

2) Fructose:

a) One of the sugar units of sucrose.
b) A ketose sugar.
c) Relative sweetness (sucrose = "1"): (Maynard et al., 1979)

Sugar	
D-fructose	**1.35**
D-glucose	0.74
Xylose	0.67
Sorbitol	0.54

Maltose	0.45
Galactose	0.32
Lactose	0.16
Saccharin	200-700

(1) The sweetest of sugars, and may be important in baby pig diets.
(2) Occurs free along with glucose & sucrose in fruits & honey.
(3) A polymer (inulin) is found in Jerusalem artichoke, dandelion, etc.
(4) Commercially produced by isomerization of glucose - Being used for soft drinks, canned food, etc.

2. **Disaccharides**

A. Maltose & isomaltose:

1) Two glucose molecules joined together by "α-1,4" and "α-1,6 linkages."
2) "Near-end" products of starch digestion - Hydrolysis (*amylase*) → maltose + isomaltose (*maltase/isomaltase*) → glucose (at the brush border).

B. Sucrose:

1) Glucose & fructose joined by an α-1,2 linkage.
2) Found in sugar cane & beets, fruits, tree sap, etc.
3) Molasses - A crude preparation of sucrose. Contains glucose, fructose, minerals, etc., and not commonly used in nonruminant diets because of its physical nature and a possibility of causing diarrhea at high levels (> 30%).

C. Lactose:

1) Galactose & glucose joined together by a β-1,4 linkage.
2) Synthesized by mammary gland.
3) Lactase?

a) Abundant in young animals.
b) Chickens have no lactase, but they can utilize at low levels of lactose via fermentation in the hind gut.
c) In humans? Tends to be low in people of Chinese and African descent.

3. **Tri-, Tetra- & Pentasaccharides**

A. Raffinose:

1) A combination of glucose, galactose & fructose.
2) Most widely distributed oligosaccharide in the nature except sucrose.

B. Stachyose - Raffinose + D-galactose.
C. Verbascose - Raffinose + 2 D-galactose.
D. Raffinose, stachyose & verbascose:

1) Galactose molecules are linked by an α-galactosidic linkage.
2) Found in substantial quantities in leguminous seeds.
3) No enzyme to split this linkage in animals:

a) Cannot be digested & too large to be absorbed, ∴ passed into hind guts.
b) Subjecto to microbial fermentation (especially, tetra- & pentasaccharides), which can result in production of a large amount of gas (1° H_2 & CO_2 gases).

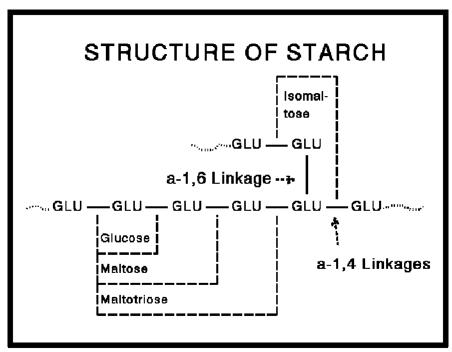
E. Soybean meal, which is a major source of supplemental protein for nonruminants:

1) Contains 1-2% raffinose & 2-3% stachyose.
2) May depress performance of pigs, especially young pigs.

F. Soy protein products (concentrate or isolate):

1) Complex carbohydrates are removed.
2) Primarily used by the food industry, but also being used as feed ingredients for baby pig diets in recent years.

4. **Polysaccharides**

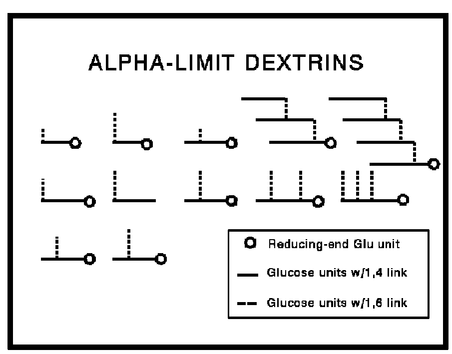


A. Starch:

1) Storage form of energy in seeds, tubers, etc.
2) Quantitatively, 1° source of energy for animals.
3) Structure of starch: (Adapted & redrawn from Davenport, 1982)

a) Amylose (α-1,4 linkage) - e.g., ≈ 20% of corn starch.
b) Amylopectin (α-1,4 & α-1,6 linkages) - e.g., ≈ 80% of corn starch.
☛ Both forms are utilized well by pigs!

B. Dextrins:



1) "α-limit dextrins:" (Adapted & redrawn from Kidder & Manners, 1978)
2) Called "α-limit" dextrins because of the inability of α-amylase to break α-1,6 bonds.
3) These intermediates are produced from hydrolysis of starch by enzymes (& heat).

4) Hydrolyzed at the brush boarder by α-dextranase.

C. Beta glucan:

1) Polymers of D-glucose with mixed linkages (β-1,3 & β-1,4).
2) Commonly found in barley (≈ 5-8%) - starch & protein are enclosed within endosperm cell walls, which consist 1° of β-glucans & arabinoxylans.
3) Forms a viscous solution in the GI tract, ∴ may interfere digestion process?
4) Dietary β-glucanase supplementation?

a) Has been shown to be beneficial in barley-based poultry diets.
b) For swine? - The results have been very inconsistent! One example:

Beta-glucanase supplementation (%) and apparent digestibilities (%) in weanling pigs (Li et al., 1996. Anim. Feed Sci. Technol. 59:223-231):

Grain	Response	0.00	0.05	0.10	0.20
Barley	DM*	84.7	87.1	86.0	88.3
	CP*	81.6	86.0	83.4	88.5
	Energy*	85.2	87.8	86.4	89.5
Corn	DM	85.6	84.1	83.7	85.2
	CP	84.4	82.5	81.3	82.7
	Energy	85.8	84.4	83.8	85.7

* Linear, $P < 0.05$. (Presented partial data.)

D. Glycogen:

1) Resembles starch in properties (& functions), and often called "animal starch."
2) Small amounts are found in animals as a reserve (1° in the liver & muscles - < .1% of the body wt).

E. Cellulose:

1) The most abundant carbohydrate in nature.
2) A structural component of cell walls.
3) A polymer of β-1,4-linked D-glucose, and 6 carbon atoms in the trans position.
4) Has an extensive H-bonding, which results in a tightly bound, crystalline structure.
5) Hydrolyzed only by microorganisms, and limited usage by nonruminant species.

F. Hemicellulose:

1) A complex, heterogenous mixture of different polymers of monosaccharides.
2) Found in cell walls.
3) Contains primarily xyloglucans, but also contains xylans, glucomannans & galactoglucomannans.

4) Less resistant to hydrolysis vs others, but more easily utilized than cellulose because of less H-bonding.

DIGESTION

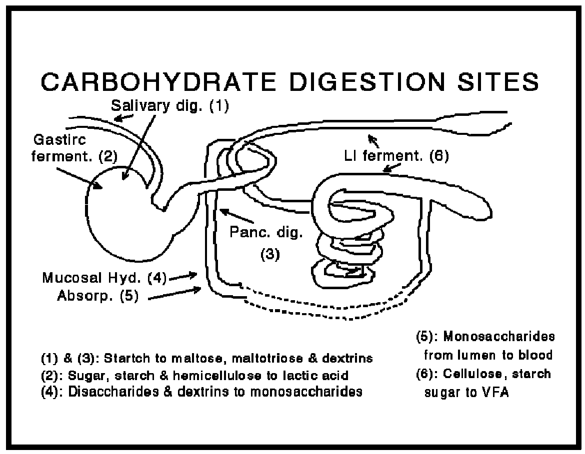
1. Introduction

A. Carbohydrates - Major sources of energy for the pig and poultry:

1) Lipids and protein contribute some energy, but starch & sugars are primarily sources.
2) Fermentation of fibers (largely hemicellulose) - In general, limited contributions to pigs & poultry.

B. Three basic factors that affect the "availability:"

1) Digestibility, absorption of end products of digestion, and Metabolism of absorbed products.
2) Digestibility is probably the most important factor in the efficiency of feed utilization, and it is an inherent feature of feedstuffs to a large extent.
3) Absorption & utilization are usually not a major problem, and may be influenced by animals (e.g., age, sex & physiological state) to some extent.



2. Digestion in General

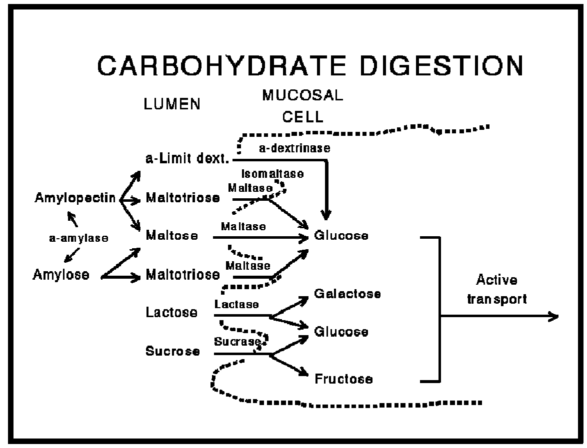
A. The sites of carbohydrate digestion: (Redrawn from Kidder & Manners, 1978)
B. Salivary digestion:

1) Fowl - Lacking amylase in saliva.
2) Swine - Pigs have "ptyalin:"

a) A weak α-amylase in saliva, which is similar to pancreatic amylase.
b) Can breakdown starch to a mixture of maltose, maltotriose & various dextrins.
c) Active over the pH range of 3.8 to 9.4 with an optimum pH of 6.9.

C. The GI tract digestion:

1) Carbohydrate digestion: (Redrawn from Gray, 1967. Fed. Proc. 26:1415)



3. **Digestion (Examples with Pigs)**

☞ A newly hatched chick has a full complement of enzymes to utilize complex CH_2O, which is different from a newborn pig!

A. Enzyme activities in intestinal homogenates (unit/ml): (Dahlqvist, 1961. Nature 190:31)

Enzyme[a]	Newborn	Adult
Invertase (sucrase)	0	78
Maltase I	0	55
Maltase II	1	248
Maltase III	7	66
Isomaltase	0	30
Amylase	26	1800
Lactase	**104**	**42**

[a]Maltase I is active against maltose, sucrose & maltosucrose, whereas maltase II & III are active against maltose & isomaltose.

B. Development of enzymes in young pigs:

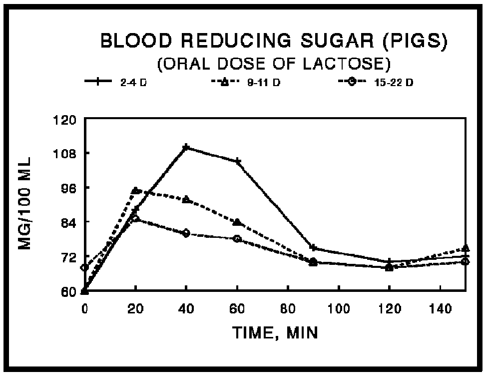
1) Enzymes for CH_2O digestion (except lactase) are very low until 4-5 wk of age.
2) Lactase - Concentrations/activities decrease over time regardless of a substrate (lactose) level in the diet, but older animals contain sufficient amounts to utilize whey (dried whey contains ≈ 65-70% lactose).

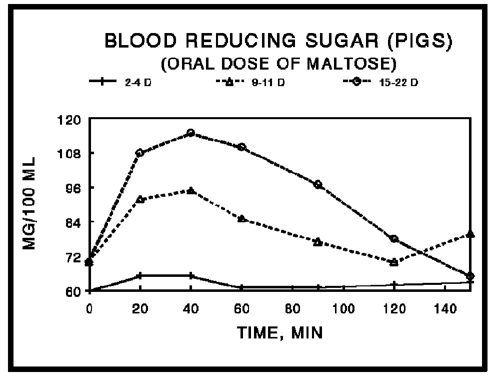
▸ Europe - Feeding a liquid whey to pigs is a common practice in some area:

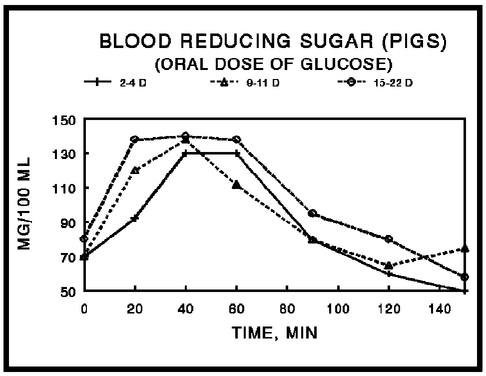
(1) "Remains" of cheese production contain ≈ 7% of DM, 90% of lactose, 20% of protein, 40% of Ca & 43% of P originally present in milk.
(2) A free-choice of liquid whey + grain fortified with vitamins & minerals can replace ≈ 1/2 of dry feed and(or) protein supplements in growing-finishing pigs and gestating sows.

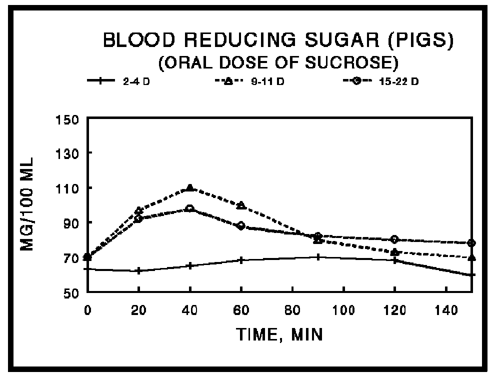
C. Baby pigs & utilization of various sugars:

1) Blood reducing sugar (glucose & galactose) concentrations after an oral dose of sugars (. . . fasted 3-7 h first). Dollar et al., 1957. Proc Nutr. Soc. 16:xii:"









a) Newborn pigs can utilize lactose and glucose, but not maltose or sucrose.
b) They can utilize some maltose and sucrose by 10 days of age & their ability to utilize those sugars continues to increase with age, but not completely ready for diets containing only "complex" carbohydrates at "normal" weaning time!

2) Pre- & starter diets may have to contain some milk products (i.e., dried skim milk, dried whey, etc.) to maximize performance - e.g.: Effect of lactose (14.4%) on baby pig performance: (Tokach et al., 1989. J. Anim. Sci. 67:1307)

Criteria		Control	Lactose
0-2 wk postweaning:			
Gain, g/d	229	289	
Feed, g/d	287	335	
F:G		1.24	1.15
0-5 wk postweaning:			
Gain, g/d	369	405	
Feed, g/d	565	605	
F:G		1.52	1.49

☞ Can expect similar response to dried whey!

D. Digestion coefficients (%) in swine fed diets based on various grains[a]: (Keys & DeBarthe, 1974. J. Anim. Sci. 39:57)

Item[b]	Wheat	Milo	Corn	Barley	CV, %

Starch					
Duodenum	75.72	63.27	71.83	45.11	15.2
Ileum	94.97	86.90	93.36	79.14	11.5
Feces	98.46	94.66	98.65	93.57	1.7
Amylose					
Duodenum	95.95	90.05	94.30	69.37	9.3
Ileum	97.53	91.43	96.61	85.28	9.5
Feces	98.62	94.49	98.44	93.59	1.8
Amylopectin					
Duodenum	70.45	52.20	66.52	40.24	26.7
Ileum	94.30	86.06	92.68	77.74	12.2
Feces	98.41	94.70	98.67	93.57	1.7
Sugar					
Duodenum	-86.04	-43.42	-405.79	41.14	167.2
Ileum	98.58	99.34	91.53	97.87	2.6
Feces	99.77	99.79	99.35	99.89	.2

[a]Mean of four values.
[b]Digestibility at duodenum or ileum was determined by the indicator method (Cr_2O_3), whereas fecal digestibility was determined by total collection method.

ABSORPTION

1. **General**

   A. The process of the absorption of sugars at the SI mucosa is similar for a wide range of species.
   B. Although small amounts of disaccharides may be absorbed from gut lumen, a bulk of dietary CH_2O is absorbed as monosaccharides.

2. **Absorption Rate of Some Monosaccharides** (Source, unknown)

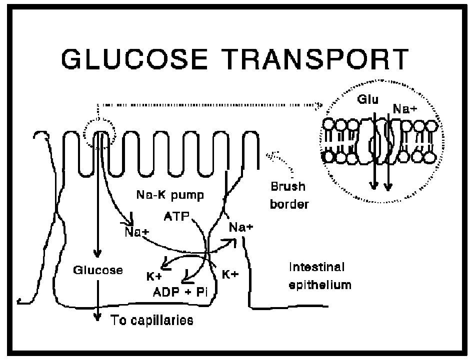
Sugar	Rat	Chick
Glucose	100	100
Galactose	110	108
Fructose	43	67
Mannose	19	42
Xylose	15	46
Arabinose	9	47

3. **Absorption Processes**

   A. Can be absorbed either by:

      1) Simple diffusion or active transport (absorbed against concentration gradient).
      2) The process is specific for an individual sugar or group of sugars.

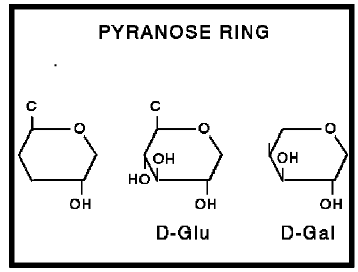
B. The important process is the one that involves Na: "Transport of glucose (& galactose) - Adapted & redrawn from Martin et al., 1983.



☛ Also transport others such as xylose, arabinose & mannose to some extent.

C. A minimum structure required for "active transport?"

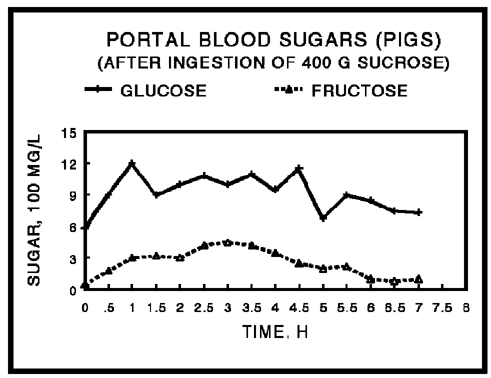
1) Important to have "OH" on carbon 2 (the same configuration as glucose).
2) Has a pyranose ring:
3) Both glucose & galactose meet these requirements, ∴ absorbed rapidly.



☛ But, fructose does not, ∴ suggesting a separate mechanism for fructose!

D. Fructose is generally absorbed slowly:

1) Example - "Portal blood glucose and fructose. Rérat et al., 1973. Cah. Nutr. Diet. 8:154. Cited by Kidder & Manners, 1978."
2) In some species such as hamster, guinea pig & dog, fructose can be partly converted to glucose within the mucosa.
3) But in pigs, not likely or not efficient vs other species.



METABOLISM

1. **General**

A. Absorbed CH_2O (sugar) is metabolized in three fundamental ways:

1) To be used as an immediate source of energy.
2) To serve as a precursor of liver & muscle glycogen.
3) To serve as a precursor of tissue triglycerides.

B. The metabolic pathways are similar for most animals.

2. **As a Source of Energy** [See Maynard et al. (1979) & others for details]

A. Glucose:

1) Glycolysis occurs in the cytoplasm.
2) Phosphorylation to Glu-6-P in the liver and other cells (catalyzed by *hexokinase*).
3) Isomerization (*isomerase*), and the second ATP to form Fru-1,6-diP (PFK).
4) Form 2 pyruvate (or 2 lactate in the anaerobic pathway).
5) Pyruvate can enter "mitochondria," then → acetyl-CoA → citric acid cycle.
6) Net results? - Generation of high-energy bonds (~Ⓟ) during the catabolism of glucose: (Martin et al., 1983)

Catalyzed by	~Ⓟ production	No. of ~Ⓟ
Glycolysis		
Glyceraldehyde-3-phosphate dehydrogenase	Resp. chain oxidation of 2 NADH	6[a]
Phosphoglycerate kinase	Oxidation at substrate level;	2
Pyruvate kinase	Oxidation at substrate level	2
		10
ATP consumption by hexokinase & phosphofructokinase		-2
		Net **8**
Citric acid cycle		
Pyruvate dehydrogenase	Resp. chain oxidation of 2 NADH	6
Isocitrate dehydrogenase	Resp. chain oxidation of 2 NADH	6
α-ketoglutarate dehydrogenase	Resp. chain oxidation of 2 NADH	6
Succinate thiokinase	Oxidation at substrate level;	2
Succinate dehydrogenase	Resp. chain oxidation of 2 $FADH_2$	4
Malate dehydrogenase	Resp. chain oxidation of 2 NADH	6
		Net **30**
Total per mol of glucose under aerobic conditions		**38**
Total per mol of glucose under anaerobic conditions		**2**

[a]Assuming that NADH formed in glycolysis is transported to mitochondria vis the malate shuttle. If the glycerophosphate shuttle is used, only 2 ~Ⓟ would be formed per mol of NADH, and a total net production being 36 instead of 38.

B. Galactose:

1) Can be converted to glucose readily in the liver - This ability may be used as a criterion for assessing the “hepatic function” in the galactose tolerance test.

2) Phosphorylated to Gal-1-P (by *galactokinase*) in the liver.

3) Converted to Glu-1-P in the liver, which is catalyzed by *galactose-1-P uridyl transferase*.

   a) Chicks and people with congenital galactosemia lack this enzyme (also, other enzymes?).
   b) Galactosemia - (1) Accumulation of Gal-1-P → deplete liver inorganic P, (2) Can result in the liver failure & mental retardation, & (3) Only treatment is a galactose-free diet!

3) Converted to Glu-6-P, and follows oxidative pathways or converted to glucose (by *Glu-6-P-tase*) in the liver.

C. Fructose:

1) May be phosphorylated to Fru-6-P by *hexokinase*, but the affinity of this enzyme for fructose is very low vs glucose, ∴ not a major pathway.
2) Phosphorylated to Fru-1-P by *fructokinase*.
3) Split into triose sugars, and metabolized accordingly.

3. **Conversion of Glucose to Glycogen**

A. Most animals consume food in excess of their immediate needs for energy, and an excess is stored as liver or muscle (. . . also others . . . but not much!) glycogen.

1) Liver - Maintain blood glucose between meals?
2) Muscle - Readily available source of glucose for glycolysis within the muscle.

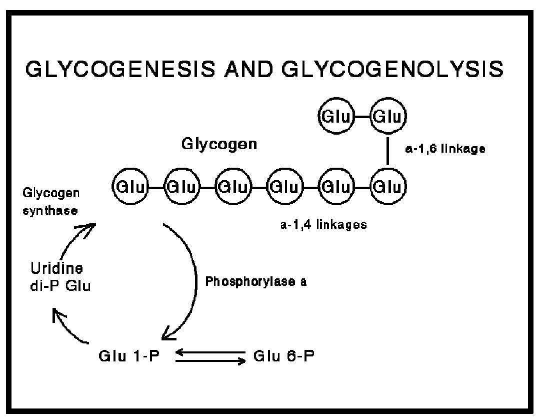
B. But, the energy stored as carbohydrates or glycogen is very small - e.g., in 70-kg man:

1) Stored carbohydrates = ≈1,900 Kcal (350 g muscle glycogen, 85 g liver glycogen, and 20 g glucose in ECF).
2) vs fat = 140,000 Kcal (. . . 80-85% of body fuel supplies stored as fat & the remainder in protein).

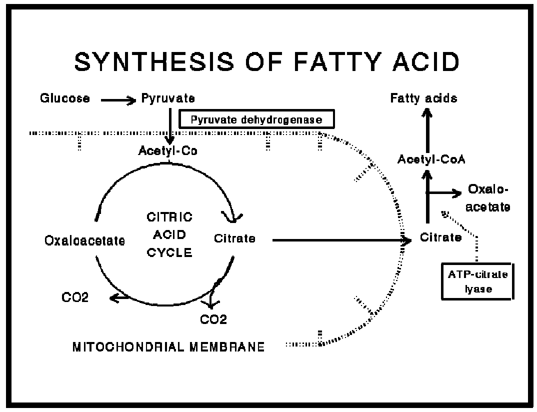
C. Glycogenesis & glycogenolysis: (Adapted & redrawn from Ganong, 1983)

◦ Need glucose?

“Cascade sequence” (i.e., epinephrine ⇒ adenylate cyclase . . . conversion of phophorylase b to phosphorylase a) can result in the cleavage of α-1,4 linkage!



4. **Conversion of Glucose to Fat**



A. Again, the storage of sugars as glycogen is rather limited, thus the excess is transformed into fats!
B. Synthesis of fatty acids from glucose: (Redrawn from Martin et al., 1983)
C. Factors affecting fatty acid synthesis:

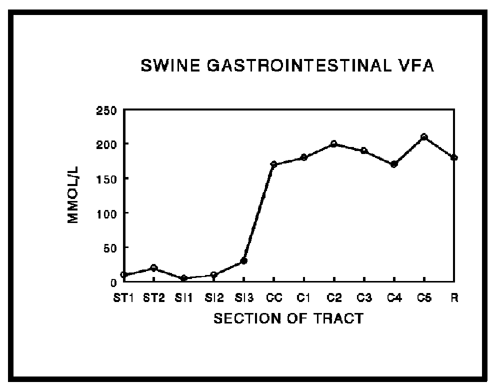
1) Insulin: a) can ↑ transport of glucose into cells, b) can activate pyruvate dehydrogenase & acetyl-CoA carboxylase, and c) can inhibit lipolysis.

2) Glucagon - Can inhibit acetyl-CoA carboxylase and lipogenesis in general.

D. Limiting step? - Acetyl-CoA carboxylase, which can be inhibited by acetyl-CoA, perhaps via negative feedback?!
E. Factors affecting acetyl-CoA?

1) Nutritional status - Inverse relationship between hepatic lipogenesis and serum fatty acids.
2) Dietary lipids can ↓ lipogenesis. With > 10% dietary lipids, a little conversion of carbohydrates to fatty acids.

5. **Fermentation in Nonruminant Species**



A. General:

1) Fermentation of starch can yield mostly lactate and propionate & not much acetate.
2) Fermentation that favors propionate production tends to be more efficient because propionate is "glucose former."
3) A reduction in acetate production can lead to ↓ in the milk fat content. (Precursors in blood? - Acetate, triglycerides, and β-hydroxybutyrate.)

B. Pigs:

1) Stomach - Some fermentation in the upper part (1° product being lactic acid).
2) The LI has more mixed flora, and produces acetic, propionic & butyric acids.
3) VFA concentrations - See the figure (Clemens et al., 1975. J. Nutr. 105:759).

4) Transport of VFA across the GI tract mucosa (μmol/cm^2): (Argenzio & Southworth, 1974. Am. J. Physiol. 228:454)

Mucosa	Loss from lumen side	Gain blood side	Tissue content
Gastric stratified squamous	15.2	1.0	2.8
Cardiac	20.8	2.8	2.0
Proper gastric	12.6	0.8	2.2
Pylorus	14.6	1.3	5.6
Cecum	25.8	10.7	2.8
Centripetal colon	20.1	9.3	2.8
Centrifugal colon	24.4	7.7	3.2

5) Once absorbed, VFA are metabolized accordingly:

a) Acetate/butylate → as a source of energy via acetyl CoA.
b) Propionate → as a source of energy via succinyl CoA.

C. Fowl:

1) Crop - Some microbial fermentation (1° product being lactic acid).
2) Colon - Likely to convey digesta rather than active fermentation & absorption.
3) Ceca - Produces most VFA (acetic, propionic and butyric acids), but only small contributions to the overall needs.

DIETARY FIBER

☛ *Excellent reviews: "Low, 1985. Role of dietary fiber in pig diets" & "Van Soest, 1985. Definition of fibre in animal feed" in W. Haresign and D.J.A. Cole (Ed.) Recent Advances in Animal Nutrition. Butterworths, London, and Fernández & Jørgensen. 1986. Livest. Prod. Sci. 15:53.*

1. **Definition of Fiber**

A. A widely accepted definition: "*A sum of lignin and the polysaccharides that are not digested by the endogenous secretions of the digestive tract.*" (Trowell et al., 1976. Lancet 1:967)
B. A practical definition (considers some attributes of fibers that can be analyzed easily by existing method): "*Non-starch polysaccharides and lignin.*" (Low, 1985)

2. **Analytical Methods** (Low, 1985; Fernández & Jørgensen, 1986)

◦ See "Analysis of Feed Ingredients and Diets" in Section 18 for the scheme to fractionate forage into various components (Van Soest, 1967. JAS 26:119).

A. Crude fiber - The fibrous, less digestible portion of a feed.:

1) Treat sequentially with petroleum ether, hot sulfuric acid, boiling water & alkali.
2) Insoluble residue contains mainly cellulose & lignin. (But the recovery is not always complete!)

B. Neutral detergent fiber - The fraction containing mostly cell wall constituents vs. cell contents.

1) Digestion by boiling in a neutral detergent solution.
2) Cellulose & lignin are completely recovered, but may lose some hemicellulose. [Water soluble CH_2O (e.g., gum & pectin) are completely lost.]

C. Acid detergent fiber - The fraction of a feedstuff not soluble by acid detergent & roughly correspond to a crude fiber plus lignin.

1) Digestion by boiling in an acid detergent solution.
2) The residue contains cellulose & lignin. (Almost all other components are lost/ excluded.)

D. Non-starch polysaccharides:

1) The removal of starch by enzymic hydrolysis.
2) The residue is separated into cellulose, non-cellulosic polysaccharides and lignin.
3) Acid hydrolysis & colorimetric or gas-liquid chromatographic measurement of component of sugars.

☛ The word "fiber" is a very generic term, and considerable variations/differences exist in terms of variety/complexity in the chemical component of plant cell walls, physical composition, and their metabolic effects on animals!

3. **Fiber Utilization by Ruminants & Nonruminant Species**

A. Composition of cell walls?

1) Typical cell wall? - 20 to 40% cellulose, 10 to 40% hemicellulose, 5-10% lignin, 1 to 10% pectin, & others.
2) Other major constituents of cell walls, i.e., other than cellulose & hemicellulose:

a) Pectin:

(1) Non-starch polysaccharide found primary in the spaces between cell walls, but also infiltrates the cell wall itself.
(2) Consists of α-1,4-linked D-galacturonic acid units interspersed with 1,2-linked rhamnose units.
(3) Can be extracted with hot or cold water and will form a gel.
(4) No mammalian enzyme to hydrolyze, but highly fermentable.

(5) Because of its water-holding (gel) capacity, often used to reduce diarrhea.

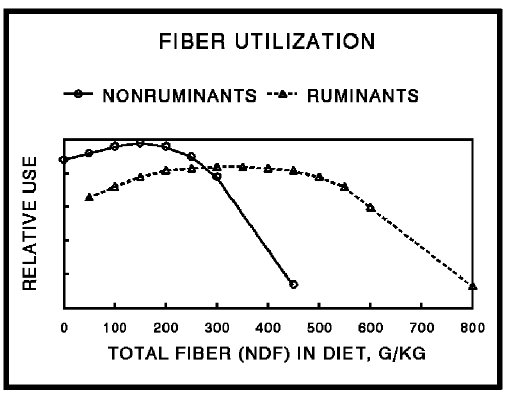
b) Plant gums:

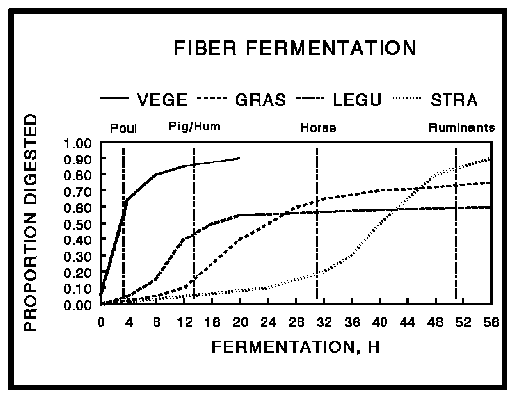
(1) Formed at the site of injury or by a deliberate incision, and are viscous fluids which become hard when dry.
(2) Complex, highly branched residues with D-glucuronic & D-galacturonic acids along with other simple sugars such as arabinose and rhamnose.

c) Lignin:

(1) A class of non-carbohydrate compounds, which provide structural support to plant cell walls.
(2) True lignin is a high molecular weight, amorphous polymer of phenyl-propane derivatives.
(3) Found in the woody parts of the plants such as cobs, hulls, and fiberous portion of roots, stems, and leaves.

B. Relative efficiency of fiber utilization (left) & fermentation curves for various species (right; Van Soest, 1985):





4. **Additional Benefits of Fiber?** - Laxative effect, stimulate the colonic growth, maintain "normal" microflora, buffering effects, reduction of energy intake, thus leaner carcass, etc.

5. **Dietary Fiber (e.g, in Pigs)**

A. General:

1) Nonruminant species (pigs & poultry) compete directly with humans for "high quality" feed ingredients (1° energy/CH_2O sources).
2) Successful animal production in the future? - ↑ the efficiency of feed utilization and also ↑ the use of alternative ingredients:

a) Alternative ingredients (by-products and forages) tend to be high in fiber.

b) Unfortunately, the information on fibers, the nutritive value of various types of fibers & their relationships with other nutrients, is inadequate at this time.

3) Negative aspects of using dietary fiber:

a) Dietary fiber & digestibility (%): (Kass et al., 1980. J. Anim. Sci. 50:175)

% Alfalfa:	0	20	40	60
Dry matter	77	61	52	28
Cell wall	62	34	27	8
ADF	56	10	11	1
Hemicellulose	67	54	49	22
Cellulose	58	20	9	7
Nitrogen	70	52	41	41

b) Also, there is an indication that the digestibility of minerals may be reduced with an increase in dietary fiber . . . Cations can be bound to fibers!

4) Fiber as a source of energy:

a) The age of pigs influences the efficiency of utilization:

(1) Cellulose may not be utilized by pigs weighing < 40-50 kg.
(2) Gestating sows can be fed up to 96-98% alfalfa & perform normally.
(3) There might be genotype differences in the ability to utilize fiber - e.g., Chinese pigs can thrive on high-fiber diets.
(4) According to some French data, growing pigs may be able to obtain ≈ 30% of DE from VFA (vs. commonly quoted value of 30% of maintenance energy).

PALATABILITY

1. **Palatability of CH_2O** - Important because CH_2O make up high percentages of diets.

2. **Most of high-CH_2O Ingredients** (e.g., corn & milo) - Fortunately, quite palatable!

3. **Young Pigs** - May prefer feed with a sweetener! Example - % of total diet consumed in the diet preference test: (Jensen et al., 1955. Cited by Cunha, 1977):

20% cane sugar 38%	15% cane sugar 20%	Dried skim milk 17%
10% cane sugar 13%	5% cane sugar 5%	0.05% saccharin 4%
0% cane sugar 2%		

LIPID METABOLISM & VITAMINS/MINERAL

INTRODUCTION

1. **General**

A. Lipids:

1) Include a group of substances that are insoluble in water, but soluble in ether, chloroform & benzene.
2) Include fats, waxes, glycolipids, phospholipids, steroids, prostaglandins, etc.
3) "Fats" are by far the most important lipids based on amounts present in the animal body & its food.
4) But others also play significant roles in nutrition & physiology - e.g., cholesterol is a precursor of vitamin D and sex hormones, and it is n infamous component of atheromatous plaques of cardiovascular diseases!

B. Lipids in diets for nonruminant species:

1) Baby pig's diet (milk) consists of 6-8% fat (30-40% on a DM basis). (Others - 80% water, 5-6% protein & 4.5-5% lactose.)
2) Lipid content in grains - Corn, ≈ 3.6%; milo, ≈ 2.8%; barley & wheat, less (< 2%).
3) Soybean & other oilseed meals (solvent extracted) are low in lipids (< 2-3%).
4) Animal protein sources (fish meal, meat meal, etc.) are relatively high (6-10%).
5) Corn-soy-based diets usually contain ≈ 2.5-3% fat.

C. Some reasons for using feed grade lipids in nonruminant diets:

1) To improve growth rate & feed efficiency.
2) To reduce dustiness of feed, and also in confinement buildings.
3) To ↑ energy content of sow's milk, ∴ increase the survival rate of baby pigs.
4) To reduce segregation of smaller particles.
5) To facilitate the pelleting process.
6) To reduce wear & tear on mixing and handling equipments,

2. **Classification of Lipids**

A. Based on the No. of carbon atoms and the degree of unsaturation:

1) Saturated fatty acid (SFA) - No double bonds.
2) Unsaturated fatty acid (UFA) - One or more double bonds.
3) Polyunsaturated fatty acids - Two or more double bonds.

B. Natural lipids (plant & animal origin):

1) Made up of triglycerides (glycerol + 3 FA).
2) Most FA have 8 to 24 C with 16 to 18 C being common for many feed lipids.
3) Short (< 10 C) or medium chain FA - FA with 14 C or less.

3. **Physical and Chemical Characteristics of Lipids** (Maynard et al., 1979)

	Corn	Soy	Saf-flower	Coco-nut	Past. grass	Butter	Tallow	Lard	Egg
Saturated acids, %									
Butyric C14:0						3.2			
Caproic C6:0				0.2		1.8			
Caprylic C8:0				8.2		0.8			
Capric C10:0				7.4		1.4			
Lauric C12:0				47.5		3.8			
Myristic C14:0			0.2	18.0	1.0	8.3	3.0		0.3
Palmitic C16:0	7.0	8.5	12.3	8.0	16.0	27.0	27.0	32.2	22.1
Stearic C18:0	2.4	3.5	1.8	2.8	2.0	12.5	21.0	7.8	7.7
Total	***9.4***	***12.0***	***14.3***	***92.8***	***21.1***	***58.8***	***51.0***	***40.0***	***30.1***
Unsaturated acids, %									
Palmitoleic C16:1					2.0				3.3
Oleic C18:1	45.6	17.0	11.2	5.6	3.0	35.0	40.0	48.0	36.6
Linoleic C18:2	45.0	54.4	74.3	1.6	13.0	3.0	2.0	11.0	11.1
Linolenic C18:3		7.1			61.0	0.8	0.5	0.6	0.3
Arachidonic C20:4									0.8
Total	***90.6***	***78.5***	***85.5***	***7.2***	***79.0***	***38.8***	***42.5***	***59.6***	***52.1***
Melting point, °C	< 20	< 20	< 20	20-35		28-36	36-45	35-45	
Iodine No.	105-125	130-137		8-10		26-38	46-66	40-70	
Saponification No.	87-93	190-194		250-260		220-241	193-200	193-220	

ESSENTIAL FATTY ACIDS

1. **Dietary Requirements**

A. "Essentiality" of fatty acids:

1) Evans & Burr (1926. Proc. Soc. Exp. Biol. Med. 24:740) indicated that "*a component of fat other than fat-soluble vitamins are dietary essential for rats!*"
2) Burr & Burr (1929. J. Biol. Chem. 82:345):

a) Feeding the diet almost devoid of fat to rats resulted in a poor growth, symptoms of dermatitis, necrosis of tails and death.
b) Also observed adverse effects on reproduction & lactation.
c) Small amounts of PUFA were effective in preventing/curing those conditions.

☛ Thus, they called the PUFA, "Essential Fatty Acids!"

B. Swine & chicks:

1) Demonstration of the essentiality of FA:

a) For chicks by Reiser in 1950 (J. Nutr. 42:319).
b) For swine by Whitz and Beeson in 1951 (J. Anim. Sci. 10:112).

2) Deficiency symptoms:

a) Swine - e.g., poor growth, skin lesions, retarded sexual maturity, underdeveloped GI systems, etc.
b) Birds - e.g., ↓ growth & disease resistance, dermal problems, faulty feathering, fatty livers, ↓ development of secondary sex characteristics, etc.

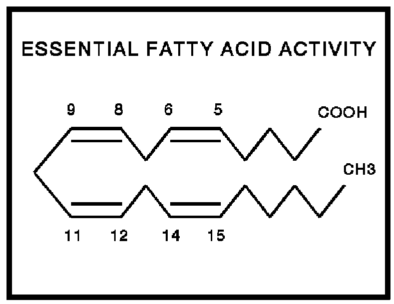
2. **Essential Fatty Acid Activity**

A. Essential FA "activity," NOT "essential FA?" - Possible reasons?

1) Interconversion among FA, i.e., FA provided in the diet may not be the one that is responsible for alleviating the deficiency symptom(s)!
2) Fatty acids are involved in a wide range of metabolic processes in animals:

a) May exhibit many manifestations of dietary essential FA deficiencies.
b) May respond differently to various FA depending on deficiency symptoms.

B. Fatty acids to be active:



1) Important to have unsaturated bonds between carbons 6-7 and 9-10 from the methyl end of FA chain [. . . known as omega (ω) carbon], which give FA the correct configuration!
2) Activity of various FA:

a) Linoleic acid (US bonds at 6-7 & 9-10 positions) - Has a 100% activity, and animals can synthesize arachidonic acid from linoleic acid.
b) Arachidonic acid (US bonds at 6-7, 9-10, 12-13 & 15-16 positions) has a 100% activity.
c) Oleic acid (an US bond at 9-10 position) has no activity because animals cannot unsaturate the 6-7 bond.
d) Linolenic acid (US bonds at 3-4, 6-7 & 9-10 positions) - Not effective because the "3-4" bond destroys a critical configuration, and although animals can saturate this bond, not efficiently, ∴ has a limited activity.

3) Essential FA:

a) From a metabolic standpoint, "arachidonic acid" is the essential FA.
b) From a dietary standpoint, "linoleic acid" is the essential FA because of:

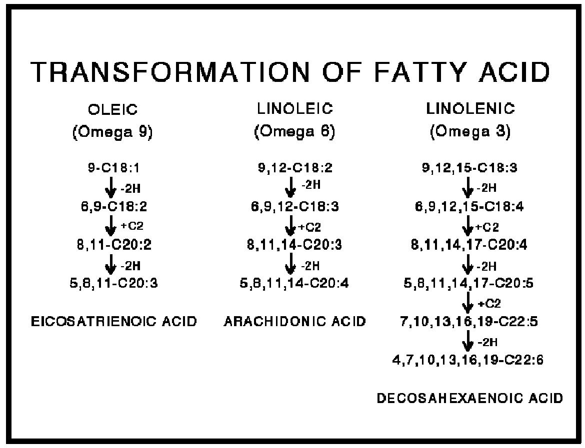
(1) Conversion of linoleic to arachidonic acid.

(2) Low arachidonic acid contents in feeds.

C. Metabolic transformation of FA:

1) Conversion by microsomal chain elongation or desaturase system.
2) Competition among series because of the use of the same enzyme systems:

   a) ω-3- & ω-6-family can suppress metabolism of each other.
   b) ω-6 family can suppress formation of PUFA from oleic acid.
   ☛ Affinity for enzymes? Linolenic (ω-3) > linoleic (ω-6) > oleic (ω-9)!



D. The cat family (e.g., cats & lions) - Unable to desaturate linoleic & linolenic acids (NRC, 1986), ∴ may require specific polyunsaturated FA of animal origin.

3. **Functions of Essential Fatty Acids**

A. Important components of cellular membranes and subcellular structures (e.g., mitochondria) - Present as phospholipids & provide "fluidity" to the membrane, which is essential for cellular functions.
B. Involved in the synthesis of arachidonic acid derivatives, which are synthesized and incorporated into the phospholipids of cell membranes - e.g.:

1) Prostaglandins - Involved in vasoconstriction/vasodilation, ♀ reproductive cycles, lipid metabolism, etc.
2) Prostacyclin - Involved in vasodilation, inhibition of platelet aggregation, etc.
3) Thromboxanes - Involved in vasoconstriction, stimulation of platelet aggregation (clotting), etc.
4) Leukotrienes - Mediators of allergic response & inflammation, also potent vasoconstrictors, etc.

4. **A Source of Linoleic Acid?**

A. Linoleic acid - Sources: [Stahly, 1984. In: Wiseman (Ed.); NRC, 1988]

Source	Percent	(NRC, 1988)
Safflower oil	78	
Sunflower oil	68	

Corn oil	55	(58.0%)
Soybean oil	50	(65.7%)
Cottonseed oil	50	
Peanut oil	27	
Poultry fat	25	(11.8%)
Lard	10	(18.3%)
Fish oil	2.7	
Beef tallow	1.5	(3.1%)
Milk fat	1.5	
Coconut oil	1.5	
Corn	1.8	
Oats	1.5	
Wheat	.6	
Barley	.2	
Soybean meal	.3	

B. Animal fats tend to be low in linoleic acid.

C. Plant oils tend to be high in linoleic acid, especially in forage lipids - e.g., pasture grasses contain ≈ 60% of lipids as linolenic acid.

D. The content and(or) type of animal fats can be influenced by the concentration and type of dietary lipids!

1) Effect of various "oils" on carcass fatty acids in pigs: (Maynard et al., 1979)

	Firm-ness	Melt. pt,°C	Iodine No.	Oleic	Lino-leic	Tot. SFA
Peanut, 4.1%	Medium	34.3	72	47.9	***13.8***	32.5
Cottonseed, 4.1%	Hard	45.3	64	35.9	15.7	***43.0***
Soybean, 4.1%	Medium	31.2	76	43.3	18.6	33.8
Corn, 4.1%	Medium	36.3	76	45.0	16.8	33.0
Corn, 11.5%	Oily	24.5	97	41.4	***31.4***	***23.1***

* Tot. SFA = total saturated fatty acids; Lard = ≈ 40% saturated FA & ≈ 11% linoleic acid.

2) "Soft" pork:

a) Oily & difficult to handle.

b) Fats are unstable, ∴ susceptible to rancidity. (Not a major problem today because of refrigeration! But, still . . .?!)

☛ ***The bottom line?*** If consumers demand meat products with "less saturated fat or more linoleic acid," can be done by dietary manipulations!

5. Fatty Acid Requirements

A. Birds (linoleic acid): (NRC, 1994)

1) Poultry (chickens, hens & broilers) - 0.83 (hens with 120 g of feed/day) to 1.25% (hens with 80 g of feed/day), with 1.00% for all others.
2) Turkeys - 0.8% (8-24 wk & breeders/holding), 1.0% (up to 8 wk), and 1.1% for laying hens.

B. Swine (linoleic acid):

1) ARC, 1981 - 3 & 1.5% of dietary DE for pigs up to 30 kg & from 30-90 kg, respectively.
2) NRC, 1998 - 0.10% for all classes of pigs.

☛ These levels are usually present in typical cereal-protein supplement-based diets (e.g., corn, 1.8% & soy, 0.30%).

C. Fish: (NRC, 1993)

1) Fresh water fish generally require either dietary linoleic acid or linolenic acid, or both - 0.5 to 2.5% depending on estimates/species.
2) Marine fish require dietary eicosapentaenoic acid [EPA; 20:5 (n-3)] and(or) docosahexaenoic acid [DHA; 22:6(n-3)] - 0.5 to 2% of EPA & DHA depending on estimates/species.

D. Factors that influence the "essential FA deficiency," ∴ the requirement:

1) Age & carryover effects (e.g., from the egg to chick).
2) Growth rate.
3) Sex - ♂ may need more (e.g. in rats, 10-20 mg for ♀ vs > 50 mg/d for ♂).
4) Humidity & water balance - Related to dermal conditions.

FATTY ACIDS AND HUMAN HEALTH

1. ω-3 Family (Linolenic) PUFA

A. Health benefits (based on epidemiological studies)?

1) A low death rate from a coronary heart disease (CHD) among Greenland Eskimos (subsist entirely on a marine diet high in ω-3 FA).
2) Lower death rate from CHD in Japan (higher fish consumption).

☞ The "relationship?" - Originally hypothesized to be via antithrombotic effects, i.e., ↓ platelet adhesion & aggregation!

B. The evidence? (e.g., Wallingford et al., 1991. Nutr. Rev. 49:323)

1) "Fish or fish oil?" (Most of fish in the Eskimo studies were not high in ω-3 FA!)

a) Positive or no response in some studies on fish/fish oil, and marginal effect in other studies.
b) Cannot distinguish between effects of fish consumption or fish oil consumption *per se* in studies with a positive response.

2) Primary endpoints should be myocardial infarction & death from CHD! - Only one 2-yr prevention study to date, in which reported the ↓death from CHD but no ↓ in non-fatal myocardial infarction. (Made no comparison of the effects of fish or fish oil consumption in that study, ∴ . . . ?)
3) Blood lipids:

a) A widespread agreement that fish oil ↓ TG & VLDL in subjects with high initial values.
b) The importance of TG level in CHD-risk is still a matter of debate!
c) In many studies, observed no effect of fish oil on a total serum cholesterol, LDL or HDL level. (One study with a positive response (i.e., ↓ total cholesterol by feeding 30-40% calories from fish oil) was confounded with PUFA.)

4. Blood pressure:

a) Observed ↓ BP with ω-3 FA in hypertensive persons.
b) Observed ↓ BP with fish oil in a large study with normal healthy subjects, but also observed comparable ↓ with "olive oil" placebo, thus the effect was not specific to fish oil?

5) Thrombosis:

a) Spontaneous platelet aggregation has been reported to be inversely related to an occurrence of myocardial infarction & CHD death in survivors of heat attacks.
b) Observed ↓ platelet adhesion & aggregation & ↑ bleeding time with fish oil consumption. (☞ This might be an important line of evidence that would support health claim/message for ω-3 FA.)
c) Prolonged bleeding time: (McDowell, 1989)

(1) May ↓ a platelet plug formation in damaged blood vessels.
(2) May inhibit vessel wall-induced clotting of plasma.

6) Vessel wall effects:

a) Observed ↓ production of superoxide, interleukin-1 & tumor necrosis factor from leukocytes among "fish oil-supplemented normal subjects."
b) Also, observed ↓ production of platelet dependent growth factor & endothelium-derived relaxation factor in rats supplemented with fish oil.

☛ All these effects may ↓ the progression of early stages of atherosclerosis!

2. **Linoleic Acid (ω-6)**

A. Suggested beneficial effects of linoleic acid? (Vergroesen, 1977. Nutr. Rev. 35:1)

1) ↓ blood cholesterol & TG levels,
2) ↓ thrombotic tendency of platelet,
3) Preventive & curative effects in a Na-induced hypertension, etc.

B. ↑ linoleic acid intake: (McDowell, 1989)

1) Mechanisms of these responses/beneficial effects summarized by Vergroesen (1977) are unknown, or not clearly established.
2) Prostaglandins:

a) Pharmacological data - Atherosclerosis-promoting factors (hypertension, ↑ thrombotic tendency of platelet) can be counteracted by arterial dilation, and ↑ water & Na diuresis induced by certain prostaglandins.
b) Preventive & curative effects of linoleic acid on atherosclerotic syndrome may be explained by ↑ prostaglandin synthesis.

DIGESTION AND ABSORPTION

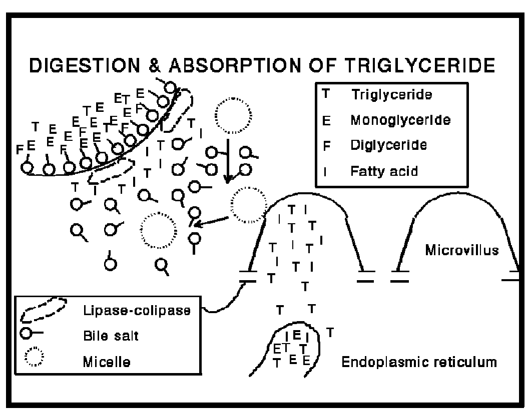
1. **Pre-Duodenal Digestion**

A. Intragastric lipolysis has been demonstrated in rats and humans.
B. Has not been described or demonstrated in the pig or chick, but probably exists.
C. It is likely that both oral and gastric lipases operate in the stomach, i.e., the initial modification of dietary lipids.
☛ Contribution(s) to the overall digestion - ???

2. **Digestion & Absorption of Triglyceride**

A. Triglyceride (TG) absorption - Redrawn from Maynard et al. (1979) [Should be: E = TG & T = monoglyceride!]
B. Brief Summary

1) A coarse emulsion enters the duodenum from the stomach or gizzard.
2) Bile salts interact with fat droplets to form emulsion droplets, and along with lipase & colipase, reduce lipids to finer emulsions.
3) Lipase and colipase:



a) Hydrolyze TG droplets into FA and monoglycerides.
b) Preferentially remove FA in 1 & 3 positions, leaving 2-monoglycerides.
c) Colipase & bile salt both needed for the lipase activity?

(1) Without colipase or bile, lipase is absorbed & denatured at the interface.
(2) With bile salt but no colipase, lipase remains in the aqueous phase.

d) Colipase is required for the attachment/function of lipase at the substrate-water interface.

C. Formation of micelles:

1) Consist of 2-monoglycerides, FFA & bile salts.
2) Outside, polar (hydrophilic) & center, non-polar (lipophilic).
☞ The rate of formation is a critical step in fat digestion/absorption!

D. Migration of micelles to the brush border (lower duodenum):

1) Micelles are disrupted.
2) FA & monoglycerides are absorbed.
3) Bile salts - Reused/eventually absorbed at the lower tract & recirculated via the liver.

E. Absorbed monoglycerides and FA are resynthesized into TG and phospholipids.
F. TG are combined with cholesterol & phospholipids to form chylomicron (pig) or very low density lipoprotein (fowl):

1) Apoprotein B:

a) Synthesized by the rough ER, and being incorporated into lipoproteins in the smooth ER, which is the primary synthetic site of TG.
b) Essential for the formation of chylomicron and VLDL.

2) Swine - Absorbed into the general circulation via the lymphatic system . . . The jejunum is a major site.
3) Chicks:

a) Via the portal system (the lymphatic system is poorly developed).
b) Also, absorbed at the duodenum & ileum.

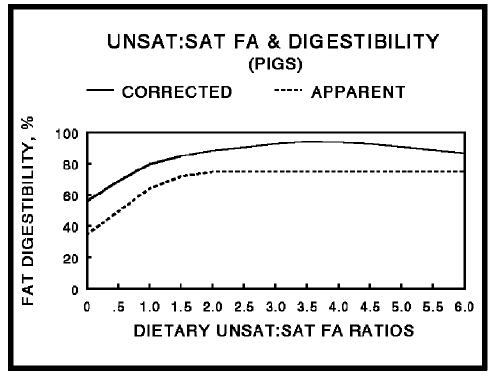
G. Glycerol is passively absorbed.
H. Short-chained FA (< 10 C), which are relatively soluble in water, are absorbed without micelle formation via the portal system.

3. **Factors Affecting Digestion & Absorption**

☞ The efficiency of digestion/absorption seems to be associated with the ability to form micelle . . perhaps, influencing the solubility in bile salt solution!?

A. Short & medium-chained FA (≤ 14 C) are utilized better vs long-chained FA.
B. Unsaturated FA are utilized better than saturated FA.
C. The degree of esterification:

   1) Removal of FA - > TG > DG > MG.
   2) Absorption - MG > FA.



D. The ratio of unsaturated/saturated FA:

   1) "UFA/SFA ratios" & digestibility - See the figure [Stahly, 1984. In: Wiseman (Ed.)].
   2) Effect of dietary fatty acid profile on fat digestion in pigs: [Stahly, 1984. In: Wiseman (Ed.)]

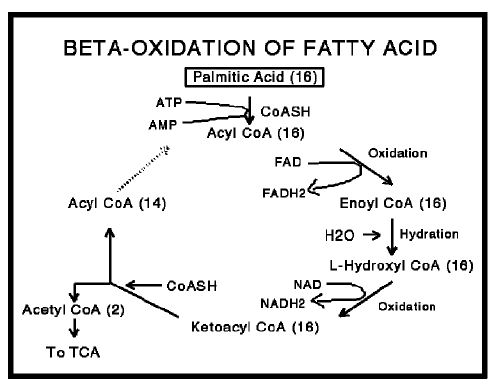
	Supple-mental fat	UFA: SFA ratio	Digesti-bility, %
Corn-soy	Tallow	1.5	85-92
Barley-soy	Tallow	1.0	70-85
Corn-soy	Soy oil	4.8	90-95
Barley-soy	Soy oil	4.0	90-95

☛ The bottom line? - When using animal fats, a source of grain may be important, whereas it may not be that important when using plant oils.

METABOLISM

1. **Post Absorption**

   A. Enter oxidative pathways for energy production, or
   B. Transported to adipose cells & incorporated into the body fats.



2. **β-Oxidation**

   A. β-Oxidation of palmitic acid - Redrawn from Maynard et al. (1979).
   B. Acyl CoA cannot pass into the inner mitochondria membrane alone, thus need a special carrier mechanism, "carnitine transport system (carnitine acyl transferase I & carnitine acyl transferase II).

B. Remove "2-C unit" at a time & 2-C units enter the citric acid cycle as acetyl CoA.
C. Glycerol enters the glycolysis pathway through triose sugar.

1) 2 glycerol → 2 glycerol-P (- 2 ATP).
2) 2 glycerol-P → 2 dihydroxyacetone-P (+ 4 ATP).
3) 2 dihydroxyacetone-P → 1 glucose (spontaneous).
4) 1 glucose → $6CO_2 + 6H_2O$ (+ 36 ATP)
☞ Net 38 ATP (or 19 ATP/mole of glycerol).

3. **The Energy Content of Lipids**

A. A complete oxidation of fat yields 2.25 x more energy vs carbohydrates!
B. e.g., Tripalmitin vs starch:

1) Tripalmitin (806 g/mole):

$C_{51}H_{98}O_6$ (+3 H_2O) + 72.5 O_2 → 51 CO_2 + 52 H_2O + 7,657 Kcal	
Glycerol	19 ATP
Palmitate	
Phosphorylation	- 2 ATP
7 cleavages x 5 ATP	+ 35 ATP
8 acetyl CoA x 12 ATP	+ 96 ATP
Net (129 ATP x 3)	387 ATP
Total	**406 ATP**

2) Starch (162 g/mole, glucose basis):

$C_6H_{10}O_5$ (+H_2O) + 6 O_2 → 6 CO_2 + 6 H_2O + 680 Kcal	
Glycolysis	10 ATP
Phosphorylation	- 2 ATP
NADH → mitochondria	- 2 ATP
Net	6 ATP
Oxidation of 2 pyruvate	6 ATP
2 acetyl CoA x 12	24 ATP
Total	**36 ATP**

3) Based on "gross energy:"

a) 7,657 Kcal ÷ 806 g = 9.5 Kcal/g of fat.
b) 680 Kcal ÷ 162 g = 4.20 Kcal/g of carbohydrate.
∴ 9.5 Kcal ÷ 4.20 Kcal = **2.26**

4) Based on "ATP production:"

a) 406 ATP ÷ 806 g = .504 ATP/g of fat.
b) 36 ATP ÷ 162 g = .222 ATP/g of carbohydrate.

∴ .504 ATP ÷ .222 ATP = **2.27**

4. **Fatty Acid Synthesis**

- *See some references on the subject [e.g., Martin et al. (1983) & Mayes (2000) in "Harper's Biochemistry"]*

A. Elongation pathways (2-C unit at a time):

1) Uses acetyl-CoA & NADH or NADPH for reduction in the mitochondria.
2) Uses malonyl-CoA & NADPH in the microsome.
☛ Both are modifications of the β-oxidation sequence. (Also, can go through shortening by a sequential removal of 2-C units!]

B. Some dietary lipids:

1) Are directly incorporated into the body fat with no loss of heat . . . Assuming adequate energy intake, i.e., dietary lipids are not necessary as a source of energy.
2) Thus, more efficient vs synthesis from CH_2O or others via acetyl-CoA, which results in a loss of some heat.

C. Extramitochondrial system for de novo synthesis:

1) Found in a soluble (cytosol) fraction of many tissues, e.g., liver, kidney, brain, lung, mammary gland, adipose tissue, etc.
2) Major products: a) Palmitic acid in liver & adipose tissues, and b) Short-chained FA in the mammary gland.

BROWN ADIPOSE TISSUE

1. **In General**

A.. A unique adipose tissue located near & around the spinal cord, thoracic organs and kidneys - Localized around some important/vital organs?!
B. Characteristics? - A reddish-brown in color & has a well developed blood supply & high contents of mitochondria and cytochromes.
C. Metabolized within the brown fat tissue itself:

1) A poor coupling of oxidative phosphorylation.
2) FA oxidation with little ATP formation, and much of energy is released as "heat."
3) e.g., "Exposure to cold environment? "- Nerve impulses can lead to release of norepinephrine → activate lipase present in adipose cells → hydrolyze TG to FA and glycerol → ↑oxygen consumption and ↑ the temperature of the tissue, and warming the blood passing through!

2. **Importance?**

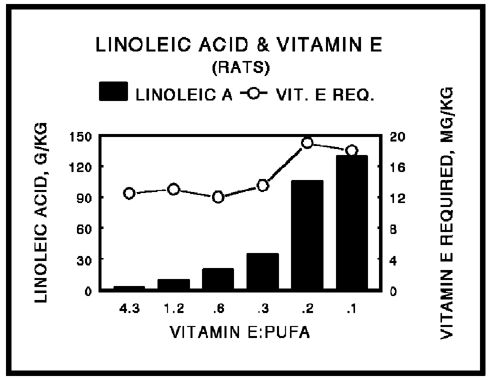
   A. May be important when generating heat is necessary/crucial.
   B. Examples? - Newborn animals, exposure to cold, arousal from hibernation, etc., i.e., the need for "Non-Shivering Thermogenesis!?"

VITAMIN E AND SELENIUM INTERRELATIONSHIPS

1. **Introduction**

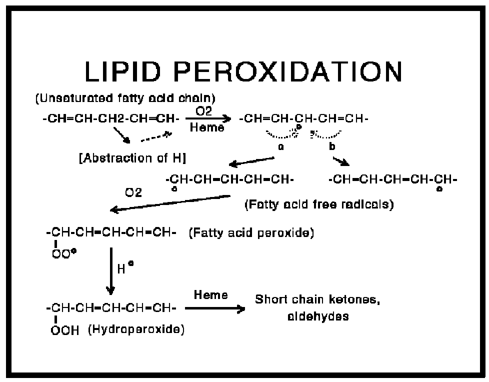
   A. Over the years, researchers observed a strong relationship between polyunsaturated FA & vitamin E, i.e., ↑ vitamin E requirement with ↑ dietary PUFA.

      ◦ e.g., Effect of linoleic acid intake on vitamin E requirement (rats) - Redrawn from Jagar, 1972. Ann. NY Acad. Sci. 203:199.



   B. Lipid peroxidation: (See the diagram)

      1) Polyunsaturated FA are highly susceptible to an attack by free radicals and others generated during the metabolic process!
      2) Lipid peroxidation either by abstraction of H or by addition of OH• (hydroxy radicals).
      3) Highly reactive intermediates can attack other fatty acids, leading to chain reactions!



   C. Polyunsaturated lipids can exacerbate many vitamin E deficiency symptoms.
   D. Selenium & synthetic antioxidants have been implicated in the "PUFA-vitamin E relationships:" (Mcdowell, 1989; AO = antioxidant)

			Prevented by			
Disease	Animal	Tissue	E	Se	AO	S-AA
Reproductive failure:						
Embryonic degeneration						
Type A	Rat, hamster, hen, mouse, turkey	Vascular system	X		X	
Type B	Cow, ewe		[a]	X[b]		
Sterility (♂)	Rat, guinea pig, hamster, dog, rabbit, monkey	♂ gonads	X			
Neuropathy	Chick, human	Brain	X		X	

Liver, blood, brain, capillaries, pancreas:						
Necrosis	Rat, pig	Liver	X	X		X
Fibrosis	Chick, mouse	Pancreas		X		
Erythrocyte hemolysis	Rat, chick, human, dog, monkey	Erythrocytes	X		X	
Plasma protein loss	Chick, turkey	Serum albumen	X	X		
Anemia	Monkey	Bone marrow	X		X	
Encephalomalacia	Chick	Cerebellum	X		X	
Exudative diathesis	Chick, turkey	Vascular system	X	X		
Kidney degeneration	Rat, mouse, mink monkey	Kidney tubular epithelium	X	X		
Steatitis (ceroid)	Mink, pig, chick	Adipose tissue	X		X	
Depigmentation	Rat	Incisors	X		X	
Nutritional myopathies						
Muscular dystrophy	Rabbit, monkey, guinea pig, duck, mouse, mink, dog	Skeletal muscle	X		?	
White muscle disease	Lamb, calf, kid, foal	Skeletal & heart muscles	[a]	X[b]		
Type C	Turkey	Gizzard, heart	[a]	X		
Type D	Chicken	Skeletal muscle	X			X
Retinopathy	Dog, monkey, rat	Epithelium	X			
Dermatosis	Dog	Skin				
Immunodeficiency	Dog, chick, pig mouse, sheep	Reticulo endo-thelial	X	X		

[a]Not effective if severely deficient in Se; [b]When added to diets low in vitamin E.

2. Vitamin E & Selenium as Biological Antioxidants

A. Vitamin E & Se are both important as biological antioxidants.

B. Oxidative metabolism produces highly reactive form of oxygen that are highly toxic to organisms. Examples? - Superoxide ion, hydroxy radical, hydrogen peroxide and lipid hydroperoxides (UFA + O_2).

C. Vitamin E prevents formation of free radicals, which stimulate production of highly-reactive products, within the membrane of cells and organelles. Thus, **the First line of defense** against peroxidation!

D. Glutathione peroxidase, which contains Se, eliminates and(or) and prevents formation of peroxides within the cellular interior or cytosol of cells. Thus, **the Second line of defense** (i.e., destroys peroxides after formation)!

3. Interdependence of Vitamin E & Selenium

A. Se spares Vitamin E at least in 3 ways:

1) Maintains the integrity of pancreas & allows normal lipid metabolism (including metabolism of vitamin E).
2) As an integral part of glutathione peroxidase, reduces vitamin E required to maintain the integrity of cell membranes.

3) May aid in retention of vitamin E in plasma (mechanism, unknown!).

B. Vitamin E reduces the Se requirement by:

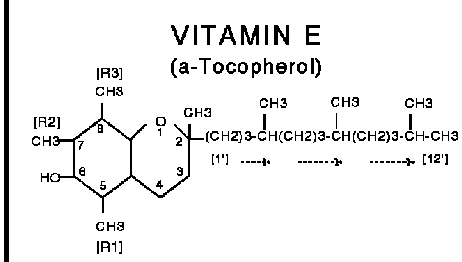
1) Maintaining body Se in an active form, or preventing its loss.
2) Preventing a chain-reactive autoxidation of the membrane, thus inhibiting formation of hydroperoxides, which ↓ the needs for Se-containing glutathione.

VITAMIN E

1. **General**

A. Alpha-tocopherol is the most widely distributed vitamin E-compounds in nature & has a greatest biological activity.
B. "Tocopherol" - Greek words *tokos* ("offspring/ childbirth") and *pherein* ("to bring forth")!
C. Unit of activity:

1) 1 IU of vitamin E = 1 mg of dl-α-tocopherol acetate (synthesized).
2) 1 IU of vitamin E = 0.67 mg of d-α-tocopherol acetate (extracted).



D. Natural vitamin E - Easily destroyed by oxidation, and oxidation is accelerated by heat, moisture, rancid fat & trace minerals (especially by Cu & Fe).
D. Chemical structures:

1) Structure: (Adapted & redrawn from McDowell, 1989)
2) Tocopherols: (McDowell, 1989)

Tocopherol	R_1 (5)	R_2 (7)	R_3 (8)
Alpha	CH_3	CH_3	CH_3
Beta	CH_3	H	CH_3
Gamma	H	CH_3	CH_3
Delta	H	H	CH_3
Alpha tocotrienol[a]	CH_3	CH_3	CH_3
Beta tocotrienol[a]	CH_3	H	CH_3
Gamma tocotrienol[a]	H	CH_3	CH_3
Delta tocotrienol[a]	H	H	CH_3

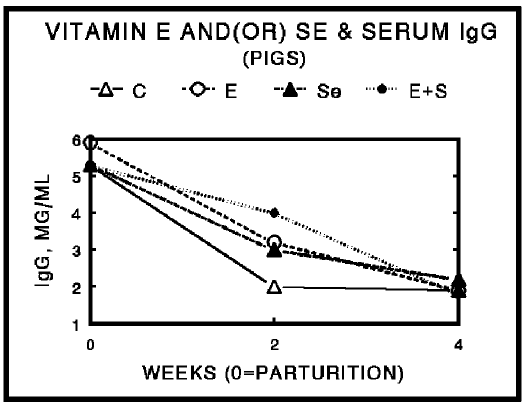
[a]Side chain double bonds at 3', 7' & 11' positions.

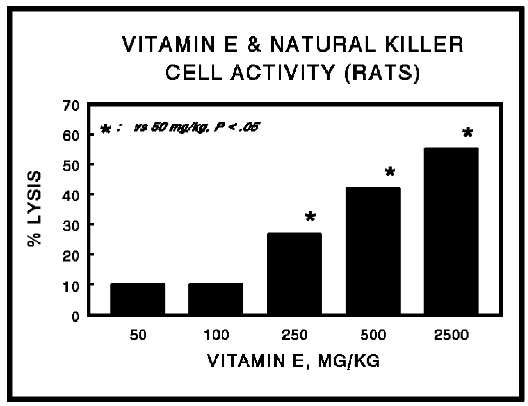
2. **Other Functions**

A. May be involved in formation of structural components of membranes, and perhaps increasing the stability.
B. May stimulate prostaglandin synthesis by increasing the conversion of linoleic to arachidonic acid, and preventing the peroxidation of arachidonic acid.
C. Inhibit platelet aggregation by increasing the synthesis of PGI_2. ("Platelet aggregation" & vascular diseases?)
D. May optimize the immune system:

1) Involved in the protection of leukocytes and macrophages during phagocytosis.
2) Stimulates antibody production.
3) Some examples?

a) Effects of vitamin E and(or) Se injections on serum IgG in piglets - Figure on the left: (Hayek et al., 1989. J. Anim. Sci. 67:1299)
b) Vitamin E natural killer cell activity in rats - Figure on the right: (Moriguchi et al., 1990. J. Nutr. 120:1096)





4) High-vitamin E:

a) ↑ activity of natural killer cells.
b) Augment responses of splenocytes to mitogens.
c) ↑ alveolar macrophage function via macrophage-activating factor produced by lymphocytes.
☛ Many investigations with other species demonstrated similar results, even though the magnitude & type of responses were different.

E. May be involved in oxidation-reduction reactions - Possibly a cofactor in cytochrome reductase portion of NAD oxidase & succinate oxidase systems?
F. May be involved in others such as:

1) Normal phosphorylation reactions.
2) Synthesis of ascorbic acid.
3) Sulfur AA metabolism.

3. **Effect of Vitamin E on Animal Performance?**

A. Example in pigs - Dietary vitamin E & sows/piglets[a] (Mahan, 1991. J. Anim. Sci. 69:2904.)

	Vitamin E, IU/kg				
Item	0	16	33	66	
No. of pigs/litter:					
Birth	9.85	10.87	11.20	10.04	NS
Weaning	6.73	7.00	7.88	8.14	NS
α-tocopherol, μg/ml:					
Sow serum (d 28)	.40	.78	1.45	1.83	Ln
Colostrum	2.72	4.34	7.75	7.01	Ln
Milk (d 28)	.44	.77	1.29	1.67	Ln
Pig serum (birth)	.05	.10	.15	.16	Ln
Pig serum (d 28)	.65	1.15	1.33	2.36	Ln
Post-weaning pig weight gain (0-28 d), g/d	375	346	332	329	

[a]NS = not significant; Ln = linear.

B. Their conclusions/implications:

1) < 16 IU/kg supplemental vitamin E is inadequate, which may result in a small litter size, sow agalactia, and also increase in pig mortality during the first week after birth.
2) Vitamin E can transverse placental tissue, but rate is low.

☛ 0.142, 0.224, 0.241 & 0.305 μg/g for 0, 16, 33 & 66 IU supplemental vitamin E/kg, respectively.

3) Mammary transfer, therefore, seems to be more effective means to provide α-tocopherol to nursing pigs, but, the importance of ↑ vitamin E status of the fetus before birth (or even after birth) has not been evaluated.

4. **Vitamin E Requirements** - Also, see an appropriate Nutrition & Feeding section!

Animal	Requirement, IU/kg
Swine: (NRC, 1998)	
3-10 kg	16
10-120 kg	11
Sows/boars	44
Poultry: (NRC, 1994)	
Immature chickens	4.7-10
Laying hens	4-6
Broilers	10
Turkeys, growing	10-12

Turkeys, breeding	25
Horses (NRC, 1978)	233 µg/kg BW
Fish: (NRC, 1993)	
Channel cat fish, rainbow trout, pacific salmon & tilapia	50
Common carp	100

5. **Sources** (McDowell, 1989)

Feedstuff	α, ppm	β, ppm	γ, ppm	δ, ppm
Barley	4	3	.5	.1
Corn	6	-	38	Trace
Oats	7	2	3	-
Rye	8	4	6	-
Wheat	10	9	-	.8
Corn oil	112	50	602	18
Cottonseed oil	389	-	387	-
Palm oil	256	-	316	70
Safflower oil	387	-	174	240
Soybean oil	101	-	593	264
Wheat germ oil	1330	710	260	271

6. **Possible Reasons for ↑ needs for Vitamin E (& also Se) in Recent Years**

◦ "Naturally occurring" vitamin E-Se deficiencies in swine were not reported until the late 60's, but became widespread in the 70's!

A. ↑ use of confinement facilities - no access to other sources of the vitamin.
B. Low-Se content of Midwestern feeds - Midwest is a major supplier of grains to many states/countries.
C. ↑ use of solvent-extracted protein supplements.
D. Limit feeding programs for sows during the gestation phase.
E. Loss of vitamin E & Se via processing/storage of grains (e.g., drying, high moisture grains, etc.)
F. Selection/production of meatier-type pigs.

☛ Some of these factors may be applicable to other species as well!

VITAMIN E AND HUMAN HEALTH

◦ *References - Various VERIS (Vitamin E Research & Information Service, LaGrange, IL) publications.*

1. **Antioxidants & Aging/Cancer**

A. "Free radicals" - Highly unstable substances produced via metabolism & also from exposure to certain environmental factors (dietary components, smog, radiation, etc.).
B. One suggestion for aging - Fee radicals damage body cells and cause pathological changes associated with aging, and this process is gradual & irreversible!?
C. Cancer:

1) "Cancer" - Probably the result of external factors combined with a hereditary disposition for cancer.
2) Normally, worn-out/injured tissues are replaced and(or) repaired.
3) Often, cells change to a precancerous stage, but body's immune system detects & destroys abnormal cells.
4) Occasionally, certain cells undergo changes without detection by the immune system, which can lead to "uncontrolled" growth & spread.
5) Vitamin & Se Recommendations?

Vitamin & Se Recommendations for Cancer Prevention

Antioxidant	*RDA*	*Recommen-dations*	*Toxic levels*	*Factors ↑ requirements*
Vitamin E	10-20 IU	200-800 IU	Negligible at < 1200 IU	High PUFA intake, smog, smoking
Vitamin A	5,000 IU	12,500 IU	Limited: 25,000 IU, chronic; > 300,000 IU, acute	Smoking
Vitamin C	60 mg	1,000 mg	Negligible at 1-2 g	Stress, oral contra-ceptives, smoking
Selenium	None	50-200 µg	Potentially toxic at > 200 µg	Aging, high PUFA intake, smog, heavy metal contamination

D. Free radical related damages:

1) Oxygen containing free radicals readily attack PUFA in cell membranes via peroxidation (a chain reaction).
2) Unless free radicals are neutralized, they can cause considerable damage to the structure & functions of cell membranes.

E. Vitamin E:

1) Inhibits accumulation of damaging free radicals. (Vitamin A, β-carotene & vitamin C are also antioxidants.)
2) Enhances the body's immune response (defense against cancer).
3) Protects vitamin A & spares Se.
4) Inhibits conversion of nitrites (present in smoked, pickled & cured food) to nitrosamines (strong tumor promoters) in the stomach.

2. **Protection Against Air Pollution Damages**

A. Nitrogen dioxide & ozone (most damaging!) can generate unstable free radicals.
B. Vitamin E traps & neutralizes free radicals more effectively than others in the lung.

3. **Optimal Immune System**

A. Immune response initiation is considered to take place at the cell membrane level.
B. Has stabilizing & regulatory effects on cell membranes to maintain optimal cell function. (via effects on free radicals!)
C. Vitamin E supplementation - ↑ immune response to antigen, stimulates production of antibody-producing lymphocytes, and ↑ antibody production.
D Modulates synthesis of prostaglandins - "PG" are important regulators of immune responses and other host defenses, i.e., ↑ PG is immunosuppressive, and vitamin E may prevent infection-induced ↑ in PG.

☛ Optimal concentrations for the immune function in most animal studies range from 180 to 360 mg/kg, which are at least 3 to 6 times higher than those concentrations found in animal diets!

4. **Neurological Role**

A. Detrimental effects of vitamin E deficiency on nervous & cardiac systems & skeletal muscle have been known for years.
B. Identification of a chronic deficiency in progressive neurological syndromes in children & adults is much more recent. (Mechanisms are unknown, but probably associated with free radical damages to cell membrane of nerve & muscle tissues.)
C. Beneficial effects of vitamin E supplementation on some neurological disorders - Tardive dyskinesia, Alzheimer-like dementia, Parkinson's disease, etc.

5. **Exercise**

A. The body takes in & utilize oxygen at a higher rate during exercise.
B. A higher rate of lipid peroxidation with higher degrees of exercise? Thus, vitamin E needed to prevent free radical-related tissue damage may increase during strenuous exercise!

SELENIUM

1. **Introduction**

A. The early interest in Se was in its role as a toxic element:

1) **Did You Know?**

"The battle of "Little Big Horn" in 1876. The U.S cavalry commanded by General George A. Custer had a 3-day forced march before reaching the Little Big Horn in Montana. Forages in that region contain toxic levels of Se. The horses were hungry since they had little grazing time during the march, so they avidly consumed the toxic plants and became sick. Obviously, they were unfit for ensuing battle, and thus were a factor in defeat. Also, a relief expedition failed to reach the beleaguered troops of General Custer in time to provide needed support. The officer in command of that expedition wrote in his official report that a peculiar sickness affected his horses, and was responsible for the delay." (McDowell, 1989)

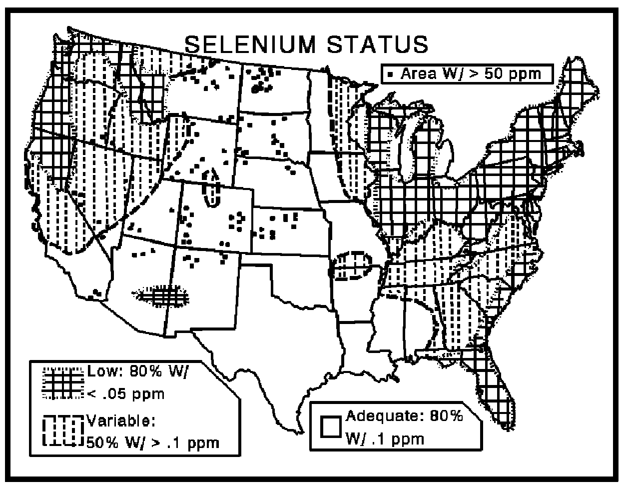
2) Marco Polo's journal:

"*. . . a poisonous plant . . . which if eaten by horses has the effect of causing the hoofs . . . to drop off . . .*"

3) An Army surgeon in the Nebraska Territory described similar signs in horses in 1857, and he termed it "Alkali" disease!
4) Three types of toxicity:

   a) Blind staggers type (with as low as 2-5 ppm?) - Wandering aimlessly, stumbling, impaired vision & signs of respiratory failure.
   b) Alkali disease type (with as low as 2-5 ppm?) - Lameness, hoof malformation, loss of hair & impaired reproduction.
   c) High levels (over 40 ppm) - Sudden death or severe distress (labored breathing, ataxia, abnormal posture, diarrhea, etc.).

B. Selenium as a nutrient:



1) Established as an essential nutrient in the late 1950's:

   a) Prevented liver necrosis in rats.
   b) Prevented exudative diathesis in chicks.
   c) Prevented white muscle disease in ruminants, etc.

2) In the early 70s, Rotruck et al. (1973; Science 179:588) discovered that Se was an integral part of glutathione peroxidase.

2. **Selenium Deficient Areas**

A. Selenium deficient areas of the US are much larger than those areas that are Se-toxic.
B. Selenium in crops in relation to animal needs: (Redrawn from Maynard et al., 1979 & McDowell, 1992)

3. **Other Functions?**

A. May play a role in electron transport - e.g., isolated a selenoprotein that resembles cytochrome C) in heart & muscle, which was absent in Se-deficient animals.
B. A specific selenoprotein in spermatozoa may serve as a structural protein for mitochondria, or as an enzyme.
C. May play a role in RNA because Se can be incorporated into purine or pyrimidine bases.
D. May have a role in prostaglandin synthesis & EFA metabolism.
E. May be involved in the immune response.

e.g., Effect of dietary Se on IgG concentration in yearling & older ponies (mg/100 ml): (Knight & Tyznik, 1990. J. Anim. Sci. 68:1311)

Week	0.02 ppm	0.22 ppm
0	1,170	1,250
1	1,420	1,475
2	1,280	1,740
3	1,700	2,365
4	1,380	2,090
5	1,310	1,915

* Observed similar responses in whole blood Se & GSH-Px activity.

4. **Absorption/Excretion**

A. Dietary concentrations/Se status of animals and the "form" affect the rate of absorption:

1) Greater absorption in a deficient state.
2) Organic compounds, selenide (- 2) & elemental Se (0) are absorbed less efficiently.
3) Selenite (+ 4), selenate (+ 6) & selenomethionine are highly available sources.

B. Absorption rate:

1) Swine - No absorption at the stomach and first part of the SI, and the greatest absorption at the last part of the SI, cecum & colon. About 77% of oral Se was retained in one study!
2) In rats, soluble Se compounds are efficiently absorbed from the GI tract (e.g., 92 & 91% for selenite & selenomethionine, respectively).
3) In humans, apparent absorption of dietary Se ranges from 55 to 70%.
4) Ruminants - Less efficient vs nonruminants (e.g., ≈ only 30% in sheep) because Se may be reduced to insoluble compounds in the rumen .

C. There seems to be no homeostatic control of Se absorption.
D Excretion:

1) Via urine, feces & exhalation (1° route in the Se toxicity).
2) Urinary excretion - 1° route in nonruminants & humans (excretion rate is closely related to dietary intake).

3) Fecal excretions - Contain unabsorbed dietary Se, small amounts of Se excreted via bile, pancreatic and intestinal secretions.
4) In general, ruminants excrete Se in the feces possibly because rumen microbes reduce Se to unavailable form, ∴ ↑ excretion in the feces.

5. **Deficiency**

A. A sudden death - A prominent feature of the deficiency).
B. Based on necropsy - e.g., Massive hepatic necrosis, edema in lungs, stomach submucosa, etc., paleness & dystrophy of the skeletal muscle (white muscle), and mottling and dystrophy of the myocardium (mulberry heart).
C. Impaired immune response.
D. Impaired reproductive performance & milk production.

6. **Assessing the Se Status** (Ullrey, 1987. J. Anim. Sci. 65:1712)

A. Analysis of plasma or serum Se - Plasma or serum Se ↑ directly with ↑ dietary inorganic Se from deficient to adequate (0.1 to 0.3 ppm), and from > 0.3 to 0.5 ppm, plasma or serum Se ↑ until reaching a dietary level that ↓ feed intake.
B. Analysis of whole blood Se:

1) Whole blood Se levels are ≈ 10 to 50% higher vs plasma or serum because of higher Se contents in erythrocytes.
2) Whole blood Se levels tend to follow a pattern in plasma or serum.
3) 1° difference? - A tendency for a lag period in the Se response in whole blood vs serum or plasma possibly because of a relatively long half-life of erythrocytes.
☛ Most of Se in red cells is incorporated during erythropoiesis.

C. Assay of plasma or serum GSH-Px activity:

1) Relatively low proportion of Se is associated with GSH-Px in rats.
2) A very low GSH-Px activity in plasma of sheep, thus usually not recommended to use as a response criterion!
3) The GSH-Px activity provides conclusions similar to plasma Se in a deficient to adequate region in rats.
4) Above adequate - Poor correlations with dietary or plasma Se in rats, swine & cattle.

D. Assay of whole blood GSH-Px activity:

1) The GSH-Px activity in erythrocytes is higher than plasma in all species examined, ∴ consistently measurable.
2) The GSH-Px activity has a high correlation with plasma Se in low-Se animals, but correlations may be poor in adequate to high dietary Se.

E. Measurement of urinary Se excretion - Urinary Se as a proportion of intake ↑ remarkably when dietary levels exceed an apparent requirement.

F. Analysis of Se in skeletal muscle:

1) Dietary & skeletal muscle Se levels are directly related in animals consuming diets that are low to adequate.
2) Samples obtained by biopsy, at necropsy or at slaughter can be used to assess Se status in cattle, sheep or swine.

G. Se contents in animals (wet basis):

1) Skeletal muscle (i animals apparently fed adequate diets) - Swine, 0.05 to 0.10 ppm; cattle, 0.04 to 0.14 ppm (0.50 ppm in one report); sheep, 0.06 to 0.24 ppm (0.85 & 1.56 ppm reported in two reports).
2) Poultry - Chicks & poults fed deficient diets = ≈ 0.05 ppm (Scott & Thompson, 1971: Poult. Sci. 50:1742) & whole egg = ≈ 0.3 ppm (Latshaw, 1975: J. Nutr. 105:32).
3) Plasma - 0.80 to 0.91 ppm in swine & 0.42 ppm in rats.

7. **Requirements**

A. Must consider:

1) Variations in the Se content of feedstuffs (i.e., geographic areas).
2) Antioxidant levels in the diet (including vitamin E).
3) In swine & poultry - Se status of dam influences the requirement for nursing/weanling pigs & chicks. (Se is readily transmissible through placental & mammary barriers, and also from hens to eggs!)
4. The amount of supplemental Se permissible is regulated in the US [maximum of .3 ppm (FDA, 1987)] and also in Canada.

B Se requirements - Plasma glutathione peroxidase level is a reliable index of the Se status of pigs (also for poultry?): (Also, see an appropriate "Nutrition & Feeding" section!)

Animal	mg/kg or ppm
Swine (NRC, 1998):	
3-10 kg	0.30
10-20 kg	0.25
20-120 kg	0.15
Sows/boars	0.15
Poultry (NRC, 1994):	
Immature chickens	0.10-0.15
Laying hens	0.05-0.08
Broilers	0.15
Turkeys	0.20
Horses, all classes (NRC,1989)	0.10

Fish (NRC, 1993):	
Channel catfish	0.25
Rainbow trout	0.30
Pacific salmon	Required, but not determined
Common carp & tilapia	Not tested

8. **Amelioration of Se Toxicity?**

A. e.g., Effects of arsenical & cysteine on chicks fed diets supplemented with a toxic level of inorganic Se: (Lowry & Baker, 1989. J. Anim. Sci. 67:959)

	Gain, g/d	Gain:feed, g/kg	Liver Se, µg/g DM
Basal	269	662	0.8
Basal + 15 mg/kg Se	109	458	14.9
Basal + Se + 14 mg/kg As	256	657	17.2
Basal + Se + 0.4% L-Cys	149	520	18.5
Basal + Se + As + Cys	254	671	17.4

B. L-Cys (& its derivatives, which are commonly used to treat heavy metal toxicity) showed ameliorative activity.

C. "As" compound totally corrected performance depressions, but it did not lower liver Se.

☛ Not in this research, but has been demonstrated in the earlier research that "As" increased biliary excretion of Se into the intestine.

CHOLINE

1. **Functions**

A. In lipid metabolism:

1) A component of phospholipids (important in the cell structure):

a) Phosphatidylcholine (lecithin) - A part of cell membrane, and also lipid transport moieties.

b) Sphingomyelin - Found in brain & nerve tissues.

2) Involved in phosphorylation and mobilization of long-chained FA from the liver, and in oxidation of FA in the liver - Hastening a removal of lipids or ↓ deposition of lipids in the liver, thus referred to as a "lipotropic" factor!

B. Other functions:

1) Involved in formation of acetylcholine, which is released at the termination of parasympathetic nerves.

2) Serving as a source of labile methyl groups, which are important in: (e.g.)

   a) Formation of methionine from homocystine.
   b) Formation of creatine from guanidoacetic acid.

2. **Is Choline Vitamin?**

A. Tentatively classified as a B-complex vitamin.
B. But, does not satisfy a strict definition of the vitamin, which is:

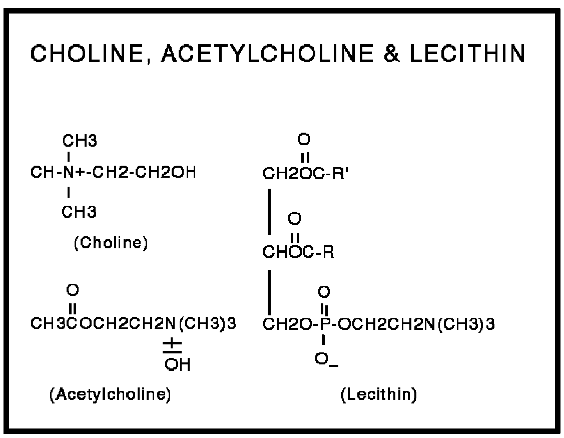
"*An organic substance of nutritional nature present in low concentration as a component of enzymes . . . and may be derived externally to the tissue or intrinsic biosynthesis.*"

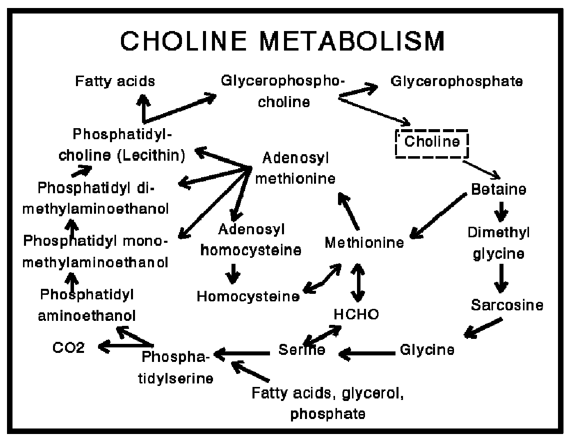
C. Choline:

1) Required by animals in greater amounts vs others.
2) Functions as a structural constituent rather than as a coenzyme.

3. **Structure and Metabolic Pathway**

A. Free choline, acetylcholine & lecithin - Figure on the left.
B Metabolic pathway - Figure on the right: (Adapted & redrawn from McDowell, 1989)





4 **Deficiency**

A. Signs in poultry:

1) Poor growth.
2) Perosis (slipped tendon) - Hemorrhages & puffiness of a hock joint, flattening of a joint, achilles tendon slips from its condyles and results in immobility.

3) Effect of choline on perosis in chicks? (Ketola & Nesheim, 1974. J. Nutr. 104:1484)

Choline, mg/kg	Incidence, %
0	54
300	0
600	0

- ▹ Perhaps, need phospholipids for a normal maturation of cartilage matrix of bones, thus choline has some beneficial effects?
- ▹ In mature birds, their synthetic rate might be sufficient to meet the requirement, but may have to supplement for a maximum egg production.

B. Signs in swine:

1) Poor growth & unthriftiness.
2) Poor conformation - Short-legged & pot bellied.
3) Lack of coordination - e.g., "Spraddled legs" in newborn pigs, which can be prevented by supplementation of choline to the sow diet. But, also genetics, folacin and(or) B_{12} may be involved!
4) Fatty infiltration of liver.

5. **Requirements**

A. In general:

1) Requirements can be met by: a) dietary supplemental choline or from typical feedstuffs, and b) choline synthesis in the body.
2) Affected by:

a) Dietary methionine (an other principal methyl donor) level.
b) Folacin level - Folacin in formation of a labile methyl group from a formate C.
c) Vitamin B_{12} level - B_{12} in transfer of a methyl group to tetrahydrofolate.
d) Others - Dietary protein, lipids & carbohydrate, sex, growth rate, etc.

B. The effect of dietary choline supplementation - Example in pigs:

1) Starter, grower and finisher pigs showed - No beneficial effect of supplementation?!
2) For sow diets - May or may not have beneficial effects:

a) Stockland & Blaylock, 1974. J. Anim. Sci. 39:1113:

Added choline (ppm):	0	400	800
Farrowing rate, %	62	80	76
No. born	9.3	10.4	9.8

Live pigs born	8.0	9.2	9.8
No. weaned	6.6	7.6	6.9
Piglets w/spraddled legs	17	7	10

b) Maxwell et al., 1987. J. Anim. Sci. 64:1044:

Item	No suppl	882 or 551 ppm
Litter size:		
At birth	10.65	10.69
At d 21	7.76	8.22
Litter weight (kg):		
At birth	13.17	13.33
At d 21	36.53	39.68
Spraddle legs:		
Litter w/one or more	8	10
No of pigs	11	12

* Total = 1,350 & 1,800 ppm for 551- & 882-ppm groups, respectively.

(1) Some improvements in sow performance with choline supplementation.
(2) No effect of choline on the incidence of spraddle legs.

3) No signs of toxicity reported in swine, but may reduce weight gain of pigs with 2,000 mg choline/kg - e.g., Southern et al., 1986. J. Anim. Sci. 62:992. (Weight gain data!)

Item	0	500	1,000	2,000	4,000	6,000
Weanling pigs:						
Exp. 1 & 2	721	696	720	684	-	-
Exp. 3	649	-	-	636	664	601
Weanling-finisher pigs:						
Exp. 4	757	-	-	701	-	-
Exp. 5	763	-	-	734	-	-
Grower-finisher pigs:						
Exp. 6	882	-	-	845	-	-
Exp. 7	777	-	-	802	-	-

C. Choline requirements: (Also, see an appropriate "Nutrition & Feeding " section!)

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	470-1,300
Laying hens	875-1,310
Broilers	750-1,300
Turkeys, growing	800-1,600
Turkeys, breeding	1,000

Swine (NRC, 1998):	
3-5 kg	600
5-10 kg	500
10-20 kg	400
20-120 kg	300
Gestating sow & boar	1,250
Lactating	1,300
Horses (NRC 1978)	Microbial synthesis
Fish (NRC, 1993):	
Channel catfish	400
Rainbow trout	1,000
Pacific salmon	800
Common carp	500
Tilapia	Not tested

6. **Sources**: (McDowell, 1989)

Source	ppm (dry basis)
Alfalfa, dehy	1,370
Barley	1,177
Corn, yellow	567
Cottonseed meal	2,965
Fish meal, anchovy	4,036
Oats	1,116
Milo	737
Soybean meal	2,916
Wheat	1,053

A. Not enough information on the availability of choline in natural feedstuffs, but based on a chick assay, soybean meal & whole soybeans may contain 60 to 75% available choline.

B. Supplemental choline:

1) Choline chloride contains 86.8% choline (a 70% liquid or 25-60% dry powder).
2) Choline bitartrate contains 48% choline.

SUPPLEMENTAL DIETARY LIPIDS

1. **Dietary Lipids in General**

A. High-energy diets for poultry:

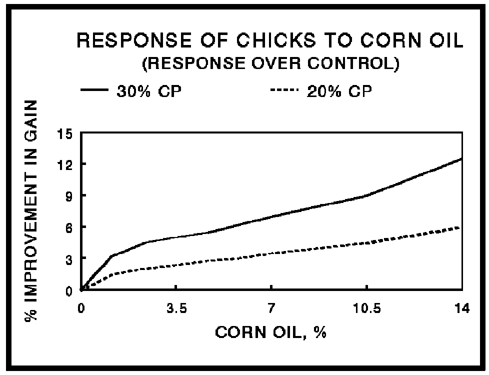
1) About 50-60 years ago, researchers (Univ. of Connecticut) observed that feed efficiency was improved by ↑ energy content of broiler diets.
2) Intensive research at many universities followed, and found that:

a) There is a limit to the level of dietary energy that can be ↑.
b) Beyond a certain level:

(1) Produced poor growth & feathering, and also reduced feed efficiency.

(2) Believed by many that high energy ingredients such as fats contained "toxic" factors.

3) Around mid 50's, researchers discovered an importance of "quality & quantity" of dietary protein:



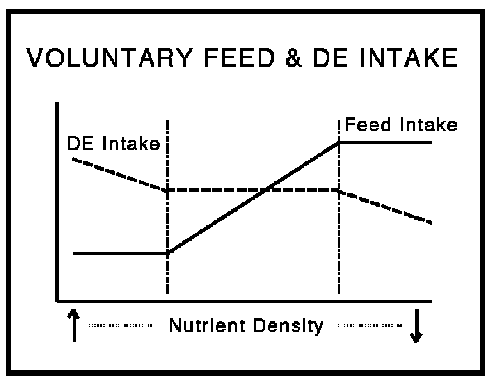
a) "Toxic effects" of high energy were overcome by simultaneous increase in dietary protein content (Donaldson et al., 1955, 1956, 1958. Poult. Sci. 34:1190, 35:1100, and 37:614.)
b) e.g., See Rand et al. (1958). Response of chicks to corn oil at two levels of protein. Poul. Sci. 37:1075.

☛ At the lower protein concentration, performance ↓ as dietary lipid ↑, but not at the higher protein concentration.

4) Subsequently, they found that growth rate, carcass fat, feed efficiency & feathering were influenced by manipulations of protein and energy ratios.

☛ Led to the concept of "**Calorie to Protein Ratio**!"

B. Energy density & energy intake:



1) Feed intake is largely determined by dietary energy content, i.e., animals generally adjust their voluntary feed intake to achieve a constant energy intake!
2) Voluntary feed and energy intakes with varying nutrient (energy) density: [Cole et al., 1972. In: Cole (Ed.) Pig Production]

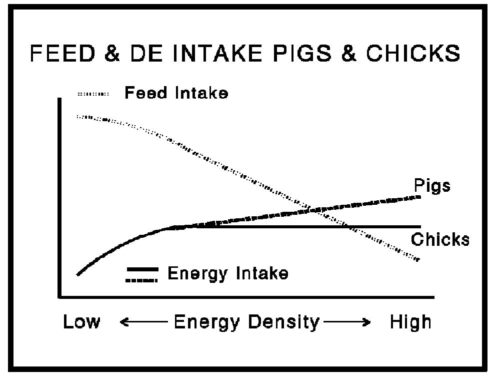
☛ The idea that "Animals eat to satisfy their energy needs?" The concept may work within a certain range of energy densities . . . But, outside of that range - ???

3) Feed and energy intakes in the pig and chick: (See the figure on "Feed & DE intake")

a) Chicks have a well controlled system for energy intake.
b) But energy intake tends to increase with dietary addition of lipids in pigs:

(1) This pig's propensity to over-consume energy may lead to its characteristic, "obesity?!" (The same is true for humans!?)

(2) Also, this contributes to an unclear energy-protein relationship in swine.



C. Dietary lipids? Example in pigs:

1) Addition of lipids to swine diets:

a) Extensively investigated over the years (started in the early 1950's).
b) Generally, improved feed efficiency, but inconsistent responses in weight gain and carcass fat.
c) The necessity of adjusting dietary protein in accordance with supplemental fat is still a matter of debate!

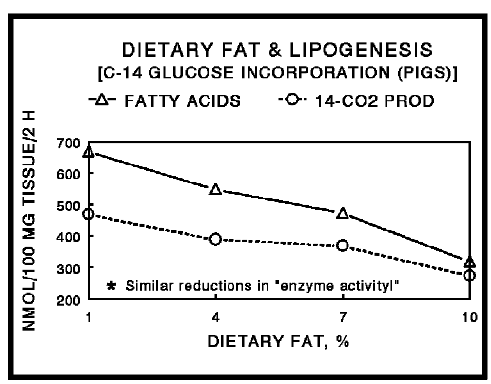
2) Possible reasons for conflicting results (. . . regarding the necessity of adjusting protein concentrations):

a) Differences in the age of pigs.
b) Differences in the type & levels of lipids used.
c) "Protein sparing effect" of dietary lipids:

(1) Lipids are highly available energy source, and have beneficial effects on protein metabolism.
(2) Thus, less deamination of protein as a source of energy, i.e., lipids (& CH_2O) may provide enough substrates for the TCA cycle.
(3) Greater release of insulin (anabolic), which has beneficial effects on protein metabolism, with dietary lipids?

d) Improve protein digestibility with dietary lipids.
e) "Quantity and quality of protein used.
f) Depressions in the rate of lipogenesis: (Allee et al., 1971. J. Nutr. 101:1415)

(1) Also, decrease the activity of malic enzyme, citrate cleavage enzyme, etc.
(2) A possible reason? - Free-FA or their CoA derivatives may inhibit acetyl CoA carboxylase, which is a limiting factor in lipogenesis!



g) Alterations in the body composition.

D. Extra caloric effect:

1) The addition of fat improves the utilization of energy, and this increase in efficiency is referred to as “extra caloric” effect.
2) Quite often, greatly exceed its gross energy value:

◦ e.g., Estimated ME value of fat: (Jensen et al., 1970. Poul. Sci. 49:1697)

Age, wk	ME, Mcal/kg
8-12	9.92
12-16	8.96
16-20	10.11
20-24	11.69

* vs. GE = 9.4 to 9.5 Mcal/kg & assumed ME value = 7.72 Mcal/kg.

3) May be explained partly by:

a) Synergism between saturated and unsaturated fatty acids.
b) Lower rate of passage of food, which may enhance nutrient digestion/ absorption.
c) ↓ energy expenditure for FA synthesis from CH_2O, i.e., direct deposition of lipids.
d) ↑ vitamin absorption (fat-soluble vitamins), which would have positive effects on digestive/metabolic processes of other nutrients.

2. **Supplemental Dietary Lipids? - Examples in Pigs**

A. Baby pigs:

1) For nursing piglets, diets mainly consist of sows' milk:

a) 18-20% solids & 6-8% fat (30-40% fat on DM basis).
b) Milk fat droplets are very small, i.e., relatively high in short- and medium-chained FA!
c) Highly digestible - Digestibility, 95-100%.

2) Weanling pigs:

a) One of the major interests in swine research over the years.
b) Early investigations indicated:

(1) Early weaned pigs can not utilize lipids efficiently.

(2) Investigations on a source of fats, emulsifying agents, form of diets (liquid vs dry), etc. had no effect on performance! - e.g., Frobish et al., 1969 & 1970. J. Anim. Sci. 29:320 & 30:197.

c) More recent data (based on weekly or daily performance) indicated that pigs are inefficient in utilization of lipids during the first 2 weeks or so after weaning - e.g., Effect of fat source and combinations on starter pig performance: (Li et al., 1990. J. Anim. Sci. 68:3694)

	None	Soy	Coconut	Soy+ Coconut	Grease	Grease + coconut
0-2 wk (10% fat)						
ADG, g	281	263	254	272	277	249
ADFI, g[a]	322	286	281	295	304	281
F:G	1.15	1.11	1.13	1.08	1.11	1.14
2-5 wk (5% fat)						
ADG, g[a]	450	490	481	522	490	499
ADFI, g	745	749	717	767	754	722
F:G[a]	1.68	1.52	1.50	1.47	1.55	1.46
0-5 wk						
ADG, g[b,c]	381	400	390	422	404	400
ADFI, g[c,d]	577	563	540	581	577	540
F:G[a]	1.52	1.41	1.39	1.37	1.43	1.37

[a]Control vs fat (*P* < .01); [b]Control vs fat (*P* = .06); [c]Soy + coconut vs coconut (*P* < .05); [d]Soy + coconut vs grease (*P* < .05).

d) Dried whey/corn oil & lipase activity: (Cera et al., 1990. J. Anim. Sci. 68:384)

Day	Whey, % Oil, %	0 0	0 6	25 0	25 6
Total lipase units					
7		1,440	1,445	1,787	1,658
14[a]		2,575	2,509	3,048	4,082
21[b]		7,542	5,577	6,149	5,294
28[b]		8,720	11,685	7,991	10,482
Lipase units/g pancreas					
7		193	196	201	204
14		200	224	210	255
21[b]		328	265	286	267
28		318	358	335	332

[a]Dried whey effect, *P* < .01; [b]Oil effect, *P* < .05.

e) Fat sources & apparent digestibility: (Cera et al., 1988; J. Anim. Sci. 66:1430)

Item[a]	Corn oil	Lard	Tallow
Apparent absorption, g/d			

Wk 1[b]	16.0	13.1	12.0
Wk 2	26.6	25.6	27.6
Wk 3[c]	47.0	43.8	50.7
Wk 4	63.0	60.7	61.6
Apparent digestibility, %			
Wk 1[d]	79.0	68.1	64.8
Wk 2[d]	80.5	71.8	72.4
Wk 3[d]	88.8	83.6	81.8
Wk 4[d]	88.8	84.9	82.5

[a]Linear response to week, $P < .01$ (all sources); [b]Corn oil vs animal fats, $P < .01$; [c]Lard vs tallow, $P < .05$; [d]Corn oil vs animal fats, $P < .05$.

f) Effects of medium- and short-chained fatty acids on apparent digestibility: (Cera et al., 1989. J. Anim. Sci. 67:2040)

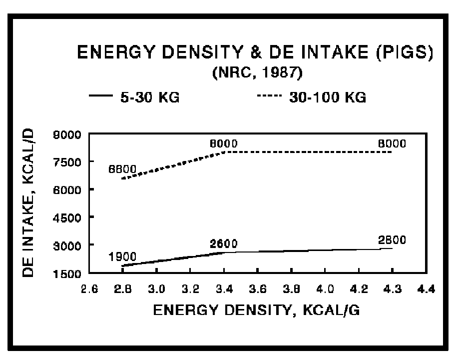
Item[a]	Tallow	Corn oil	Coconut oil
Apparent absorption, g/d			
Wk 1	17.7	22.2	18.6
Wk 2	34.7	39.7	38.8
Wk 3	54.0	52.3	64.9
Wk 4	75.8	72.9	77.4
Avg	45.5	46.8	49.9
Apparent digestibility, %			
Wk 1	75.4	76.5	81.7
Wk 2[b]	76.0	79.7	83.3
Wk 3[c,d]	81.5	86.3	89.2
Wk 4[c]	86.6	89.3	89.7
Avg[c,e]	81.8	84.8	87.3

[a]Linear response to week, $P < .01$ (all sources); [b]Animal vs vegetable, $P < .05$; [c]Animal vs vegetable, $P < .01$; [d]Corn vs coconut, $P < .01$; [e]Corn vs coconut, $P < .01$.

- ▹ Also, there were trends for improved weight gain and N utilization (↑ N retention & lower serum urea) with coconut oil.

☛ The bottom line (baby pigs):

a) First two wk or so after weaning, pigs can not utilize lipids efficiently possibly because of insufficient lipase concentrations or activity.
b) The ability of weanling pigs to utilize lipids improves with age.
c) Lipids containing higher proportions of short- and medium-chain FA (e.g., coconut oil) may be utilized better by young pigs.



B. Grower-finisher pig:

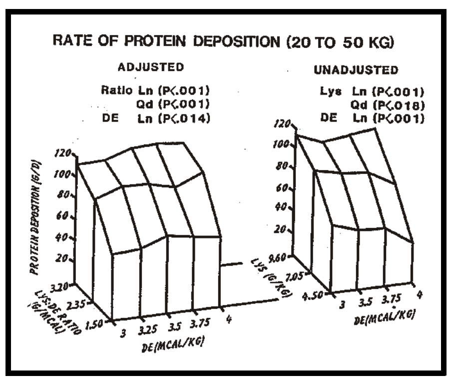
1) The relationship between energy density and feed intake is very important:

   a) Pigs generally consume feed to meet their energy requirements.
   b) With reduced energy density, animals increase feed intake.
   c) With increased energy density, animals reduce feed intake.
   d) Within a limit, energy intake remains relatively constant:

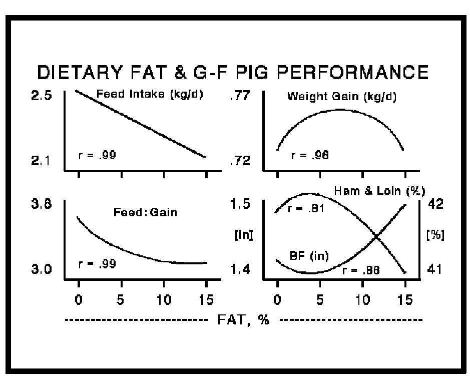
      (1) Energy density and DE intake: See NRC (1987).
      (2) Pigs fed graded levels of sand: (Baker et al., 1968. J. Anim. Sci. 27:1332)

Item	% Sand: 0	20	40
Gain, kg/d	.85	.84	.73
Feed, kg/d	2.89	3.46	4.13
Feed (- sand), kg/d	2.89	2.77	2.48
G:F .294	.243	.177	
G:F (- sand)	.294	.303	.294

2) Because of this relationship, need to balance other nutrients. If not, may see reduced performance: [Chiba et al. (1991a,b). J. Anim. Sci. 69:694 & 708.]



3) Typical responses to supplemental fat in growing-finishing pigs - "Effect of dietary lipids" [Moser (1977). Feedstuffs 49(15):20].



4) Dietary lipids/thermal environment & relative performance: [Stahly, 1984. In: Wiseman (Ed.)]

Temp (°C)	10			22.5			35		
Fat (%)	0	5	△	0	5	△	0	5	△
ME intake	114	112	-2	100	103	+3	72	77	+5
Gain	99	98	-1	100	109	+9	66	75	+9
ME:gain	116	116	0	100	94	-6	114	106	-8
backfat	93	97	+4	100	106	+6	85	92	+7

- Utilized better in warm/hot environments than in a cold environment!

5) Dietary lipids & apparent digestibility (%): [Stahly, 1984. In: Wiseman (Ed.)]

	Ileal			Fecal		
Fat (%)	4.5	17.0	26.8	4.5	17.0	26.8
CP	74	73	76	82	81	85
Amino acid:						
Lys	83	84	85	83	84	87
Trp	77	79	81	89	89	92
Thr	69	70	73	84	85	88
Met	83	82	84	83	85	86
Avg	***78***	***79***	***81***	***87***	***88***	***90***

- Dietary lipids generally improves digestibility of protein & amino acids!

☛ The bottom line (grower-finisher pigs):

a) To a degree, pigs can adjust feed intake to achieve a constant energy intake.
b) Because of this, nutrient levels (especially, amino acids) have to be adjusted in concert with dietary energy densities.
c) Dietary lipids - Improve feed efficiency, may or may not improve weight gain, and little adverse effects on carcass with ≈ ≤ 5%.
d) Lipids are utilized better in a warm or hot environment vs cold environment (associated with a low heat production rate in lipid metabolism).
e) Dietary lipids may improve nutrient digestibility.

C. Gestating & lactating sows:

1) On the average, producers lose about 25-30% of piglets born before weaning (. . . even though there has been some improvement in recent years):

a) Most of the losses? - During the first few days & ≈ ½ due to starvation & crushing!
b) Smaller, weaker pigs: [Speer, 1970. Unpublished data (based on 1948 litters)]

Birth wt., lb	Survival, %
Under 2.0	42
2.0-2.4	68
2.5-2.9	75
3.0-3.4	82
3.5-3.9	86
4.0 and over	88
Avg	*77*

c) Baby pigs:

(1) Only ≈ 2% body fat (mostly structural), ∴ low energy reserves.
(2) Liver glycogen depletes rapidly within 12-24 h.
(3) Develop a hypoglycemia → ↑ chance of being crushed.
(4) Little insulation (hair & fat).

☞ Because of all these factors (lack of insulation & low energy reserves), pigs cannot maintain a proper body temperature.

d) To increase survival rate of baby pigs:

(1) Must increase body reserves of pigs and(or)
(2) Improve the quality of their diet (i.e., milk).
(. . . + other management practices, obviously!)

2) Dietary lipids for sows - Dietary fat can improve the baby pig survival rate!

a) Summary of effects of dietary fat: [Based on 677-938 litters; Moser & Lewis, 1980. Feedstuffs 52(9):36]

Item	Contr.	Fat	Diff.
Born alive	10.0	9.9	-.1
No. weaned	8.1	8.4	.3
Survival, %	82.0	84.6	2.6

b) The degree of response to dietary lipids depends on the status of herds & birth weight of pigs: (Pettigrew, 1981. J. Anim. Sci. 53:107)

(1) Herds having < 80% survival rate - 4.1 % ↑.
(2) Herds having > 80% survival rate - .6% ↑.
(3) Pigs weighing < 1 kg at birth - 17.1% ↑.

3) Possible reasons for improved baby pig survivability:

a) Increased fat content of milk - "Effect of dietary fat on milk fat (%)[a]:"

	Fat in diet: -	+
Moser & Lewis, 1980	7.3	9.1
Coffey et al., 1987	5.14	6.07
Schoenherr et al, 1989	5.37	6.85
Newcomb et al., 1991 (DM basis)	20.6	23.6

[a]Moser & Lewis. Feedstuffs 52(9):36; Coffey et al. J. Anim. Sci. 65:1249; Schoenherr et al. J. Anim. Sci. 67:482; Newcomb et al. J. Anim. Sci. 69:230.

b) Increased milk production - "Effect of dietary fat on milk yield (kg/d)[a]:"

Reference	Contr.	Fat
Kruse et al., 1977	4.60	5.33
Pettigrew, 1978	3.82	4.48
Boyd, 1979	8.72	9.44
Coffey et al., 1987	8.93	11.06

[a]Kruse et al. Acta Agric. Scand. 27:289; Pettigrew. Proc. Pacific NW Pork Exposition, WSU; Boyd. Ph.D. Dissertation. Univ. of Nebraska; Coffey et al. J. Anim. Sci. 65:1249.

c) A slight increase in energy reserves of "newborn" piglets[a]:

Item	Contr.	Fat
Coffey et al. (1987):		
Blood FFA, mmol/l	3.23	4.12
Blood TG, mg/dl	31.1	33.9¶
Newcomb et al. (1991):		
Plasma FFA, μeq/l	120.0	136.4¶
Liver glycogen, % wet tissue	13.9	18.3¶

[a]Coffey et al. J. Anim. Sci. 65:1249; Newcomb et al. J. Anim. Sci. 69:230; ¶ = nonsignificant.

4) Effects of dietary fat at various phases[a]: [Moser, 1985. In: Cole & Haresign (Ed.)]

Item	Gestation	Lactation	Gest + Lact
Pigs weaned/sow	+.7 (3)	+.7 (2)	0 (17)
Survival (%)	+4.7 (4)	+1.2 (3)	+3.4 (22)

[a]( ): No. of experiments.

a) To observe beneficial effects of fat, sows may have to consume 1 kg of fat before parturition. (Pettigrew, 1981. J. Anim. Sci. 53:107)
b) Can be done by:

(1) Feeding a diet containing 10% fat for a week, or
(2) A diet containing 5% fat for 2 weeks before farrowing.

FEED GRADE LIPIDS

- *Also, see the composition of some lipid sources in the Section 18!*

1. **Terminology** (See AFIA, 1986. Proc. AFIA 46th Annu. Meeting)

A. Total fatty acids (TFA):

1) Include both free FA and those combined with glycerol.
2) In general, fats contain ≈ 90% FA (9.4 Cal/g) & 10% glycerol (4.2 Cal/g).
3) A good index of the potential energy value of fat.

B. Free fatty acids (FFA):

1) FA not attached to glycerol.
2) High levels of FFA were once thought undesirable:

a) High because of extensive bacterial & enzymatic actions, i.e., a reflection of careless handling prior to rendering.
b) Also, may be due to ↑ oxidation rate, ∴ ↑ rancidity?

3) But with the use of antioxidants, high levels pose no problem!

C. Moisture has adverse effects on fat - Corrosion of handling equipment/facilities → rust (a powerful promotor of rancidity).

D. Insoluble impurities:

1) Include minute particles of fiber, hair, hide, bones, minerals, etc. - insoluble in kerosene or petroleum ether.
2) Can cause problems in handling & storage (plus may ↓ nutritional quality).

E. Unsaponifiable matters:

1) Include fat soluble vitamins, pigments, sterols, fatty alcohols, etc., which are not split into glycerol and alkali salt of FA (soap) by alkaline hydrolysis (KOH).
2) All natural fats & oils contain small amounts.

F. Iodine value:

1) Measure the degree of unsaturation (each double bond takes up 2 atoms of iodine).
2) Expressed as grams of I absorbed/100 g of oil or fat.

G. Fat stability:

1) Oxidative rancidity:

a) Can lower the quality of fat.
b) Can destroy fat-soluble vitamins in feeds.

2) Measured by:

a) "Peroxide value" - Measures mEq of peroxide/kg lipids, and considered "not" rancid if < 5 meq/kg.
b) AOM test:

(1) A measure of peroxide value after 20 h of bubbling air through samples.
(2) Determine the ability of fat to resist oxidative rancidity.

H. Titer - An indication of the degree of hardness (or unsaturation):

1) Determined by melting FA after fat hydrolysis & cooling slowly, and measuring "congealing" temperature.
2) Titer - Over 40°C, classified as "tallow" & under 40°C, classified as "grease."

I. Color:

1) Variations - From pure white (refined beef tallow) & yellow color (grease) to very dark color (acidulated soapstock).
2) Generally, differences in color have no effect on the nutritional value of fat, but may be an important consideration in "pet" foods.

2. **Use of Feed Fats by Various Species** (million lb; 1990 = estimates; Rouse, 1987. Feed Management. Feb.):

Animal	1986	1990	% ↑
Veal	100	125	25
Pet	400	450	13
Hog	100	250	150
Cattle	200	225	13
Broiler	650	750	15
Turkey	500	700	40
Layer	30	50	67
Fish	30	50	67
Dairy	90	250	178
Total	***2,100***	***2,850***	***35***

3. **Production of Animal Fats** (Rouse Marketing Inc., 1983)

Source	Mil. lb.
Beef tallow	4,387
Restaurant grease	1,350
Pork grease	537
Dead stock	447
Poultry	253
Other	200
Total	***7,222***

4. **Feed Fat Categories**

A. "Animal fat:"

1) Mainly from packing house offal or supermarket trimmings.
2) "Tallow" - Titer = > 40°C & 4-20% FFA:

a) Fancy - Mainly for pet foods (maximum of 4% FFA).
b) No. 1 - Maximum of 15% FFA.
c) No. 2 - Maximum of 20% FFA.

3) "Grease" - Titer = < 40°C & 4-50% FFA:

a) Choice white - Maximum of 4% FFA.
b) Yellow - Maximum of 15% FFA.
c) Brown - Maximum of 50% FFA.

B. "Poultry fat" - From poultry offal, and mostly used by the poultry industry as a feed ingredient.
C. "Blended feed grade animal fats" - A blend of tallow, grease, poultry and restaurant grease.
D. "Blended animal and vegetable fats" - A blend of animal fats + vegetable fats.
E. "Feed grade vegetable fat" - Includes vegetable oils, acidulated vegetable soap stock and other refinery by-products.

5. **Rancidity** - lipids are subject to two types of rancidity:

A. Oxidative rancidity:

1) Light, heat & other factors can lead to formation of free radicals in unsaturated fats.
2) Free radicals react with oxygen to form peroxides.
3) Peroxides react with another unsaturated fat molecule.

. . . **Chain reaction**!

☛ Products? - Ketones, aldehydes, organic acids, etc. - have unpleasant odor/off-flavors!

B. Hydrolytic rancidity:

1) At high temperatures (with a presence of water), FA are hydrolyzed from TG (certain minerals can catalyze reactions), which lowers pH of fat.
2) Reduces the ME value of lipids.

☛ "High FFA" concentrations in a "low" grade tallow or grease are clear indication that they have undergone hydrolytic rancidity.

C. Antioxidants - e.g., Ethoxyquin (Santoquin), Butylated hydroxyanisole (BHA), Butylated hydroxytoluene (BHT), . . . , etc.

PROTEIN METABOLISM & VITAMINS/MINERALS

PROTEIN IN GENERAL

1. **General**

   A. Protein is a principal constituent of organs & soft structures of the animal body (& obviously others!).
   B. Includes an enormous number of closely related, yet physiologically distinct groups of substances.
   C. For animals, a liberal & continuous supply of protein is needed throughout the "life" for growth, repair of tissues & organs, and other functions.

2. **Functions**

   A. Enzymes - Almost all known enzymes are protein.
   B. Hormones - Insulin, growth hormone, etc.
   C Structural constituents - Collagen, keratin, membrane, etc.
   D. Transport - Hemoglobin, myoglobin, transferrin, etc.
   E. Protection - Antibodies.
   F. Coordination of the motion - Muscle (myosin, actin, etc.).
   G. Storage of energy - ?
   H. Storage - Casein, albumin, etc.
   . . . , etc.

3. **Composition (%) of Protein**

Carbon	51-55
Hydrogen	6.5-7.3
Nitrogen	15.5-18
Oxygen	21.5-23.5
Sulfur	.5-2.0
Phosphorus	0-1.5

4. **Determination of Protein - "Kjeldahl" Method**

   A. Estimate the protein content based on the nitrogen content.
   B. Advantages - Accurate & repeatable, can be used for liquid or solid samples, and requires no complex equipment.
   C. Disadvantages - Time consuming, involves the use of hazardous chemicals, and does not convert nitrate & nitrite N to NH_4SO_4.
   D. Calculation of the protein content from the N content?

1) Assumptions:

   a) All proteins contain "16% N."
   b) All N is present as proteins.
   ☛ % protein = % N x 100/16 or % N x 6.25

2) Assumption (a) is false, but . . .!?

   a) Factors for calculating the protein content from the N content of food:" (USDA Agric. Handbook No. 8 by Watt & Merrill)

Food	Factor	Food	Factor
Animal origin:		Navy	6.25
Eggs	6.25	Soybeans	5.71
Gelatin	6.25	Velvetbeans	6.25
Meat	6.25	Peanuts	5.46
Milk	6.38	***Nuts:***	
Grains & cereals:		Almonds	5.18
Barley	5.83	Brazil	5.46
Corn	6.25	Butternuts	5.30
Millets	5.83	Cashew	5.30
Oats	5.83	Chestnuts	5.30
Rice	5.95	Coconuts	5.30
Rye	5.83	Hazelnuts	5.30
Sorghums	6.25	Hickory	5.30
Wheat:		Pecans	5.30
Whole-kernel	5.83	Pinenuts	5.30
Bran	6.31	Pistachio	5.30
Embryo	5.80	Walnuts	5.30
Endosperm	5.70	***Seeds:***	
Legumes:		Cantaloup	5.30
Beans:		Cottonseed	5.30
Adzuki	6.25	Flaxseed	5.30
Castor	5.30	Hempseed	5.30
Jack	6.25	Pumpkin	5.30
Lima	6.25	Sesame	5.30
Mung	6.25	Sunflower	5.30

   b) True conversion factors range from 5.3 to 6.38.
   c) But, the use of a single factor works well because:

      (1) Normal diets contain a mixture of proteins.
      (2) Average true conversions are often close to 6.25.

   d) Special factors to be used? 5.70 for wheat products & 6.38 for milk products.

3) An assumption (b), "all N is present as proteins," is also false!?

a) "NPN" such as amides, amino acids, glycosides, alkaloids, ammonium salts & others are also present.
b) But, NPN compounds are present in large amounts in only a few feeds such as young grass, silage & immature root crops.

☛ Because of these unsound assumptions, the term "**crude protein**" is used?
☛ "True protein" can be determined by separating true proteins from NPN by precipitation, and then running the Kjeldahl procedure.

5. **Direct Determination - The Lowery method**

A. Widely used for the analysis of proteins in tissue samples.
B. Involves two steps:

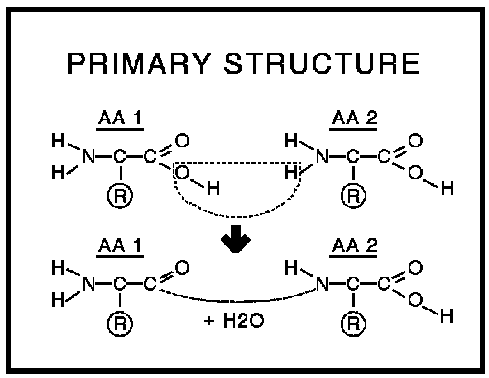
1) "Biuret reaction" - Add Cu to an alkaline solution, which chelates peptide bonds & produces a "blue-violet" color.
2) Add a "Folin-Ciocalteu phenol reagent" & measure a "blue color" spectrophotometrically.

PROTEIN AND AMINO ACIDS

1. **Protein Structure**

A. Primary structure:

◦ The linkage of individual amino acids into a long chain by "peptide bonds."



a) Peptides - 2 to 20 residues (e.g., growth hormone).
b) Polypeptides - 20 to 100 residues (e.g., insulin).
c) Many/most proteins contain at least AA 100 residues.

B. Secondary structure:

1) "Polypeptides" do not exist as straight chains, but they are folded into a specific "three-dimensional" conformation.
2) Most proteins are one of the three forms:

a) α-Helix - e.g., Found in horns, nails, skin, hair, wool & much of the skeletal muscle proteins (myosin & tropomyosin).

(1) 3.6 AA residues per turn.
(2) "R-group" of AA extend outward.

(3) Stabilized by H-bonds (NH-groups & CO-groups).

b) β-pleated sheet - e.g., Found in silk (β-keratin) & other insect fibers.

(1) Peptide chains are arranged side-by-side in sheets.
(2) Cross-linked by H-bonds.

c) Triple helix (or collagen helix) - Collagen is the most abundant protein in the body of higher animals - e.g., found in hide, tendons & other connective tissues.

(1) Consists of 3-polypeptide chains of the same size.
(2) Contains a high proportion of glycine and proline.
(3) Also contains OH-proline & OH-lysine, which provide a "rigidity" to protein.

C. Tertiary structure - e.g., Myoglobin:

1) "Polypeptides" are folded & tightly coiled into a globular form.
2) Stabilized by:

a) Disulfide linkages between two cysteine residues (-S-S-).
b) Salt linkages (i.e., basic AA, Arg & Lys + acidic AA, Asp & Glu).
c) Nonpolar ends of No. of AA become "hydrophobic centers" of polypeptide coils.
d) H-bonding.

☛ A tertiary structure is crucial to enzymatic activity of many proteins!

D. Quaternary structure - e.g., Hemoglobin:

1) Refers to alignment of several tertiary structures into one protein.
2) For instance, "Hb" consists of four single-strand tertiary forms of proteins that are compactly associated into a single globular protein.

2. **Classification of Protein**

A. Simple proteins - Refer to a protein that yields only AA and(or) its derivatives upon hydrolysis.
B. Conjugated proteins: (e.g.)

1) Nucleoproteins - e.g., Ribosomes/RNA.
2) Phosphoproteins - e.g., Casein/phosphate.
3) Metalloproteins - e.g., Cytochrome oxidase/Fe & Cu.
4) Lipoproteins - e.g., VLDL/phospholipid, fat, cholesterol.

5) Flavoproteins - e.g., succinic dehydrogenase/FAD.
6) Glycoproteins - e.g., γ-globulin/galactose, mannose, hexoamine.

C. Fibrous or globular proteins:

1) Fibrous proteins - Polypeptide chains are coiled into a helix & cross-linked by disulfide & H-bonds:

a) Collagen (in connective tissues) - Heating or treating with acid, yields gelatin.
b) Elastin (part of tendons, arteries & others) - Can stretch in two directions (poorly digested by animals).
c) Keratin - α-keratin is found in hair, horn and wool, whereas β-keratin is found in beaks of birds.
d) Myosin & tropomyosin - Muscle proteins.

2) Globular proteins:

a) Polypeptides are folded & coiled - very compact proteins!
b) Examples include enzymes, protein hormones & oxygen carrying proteins.

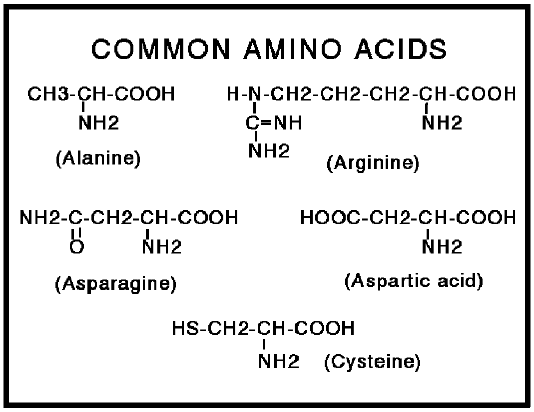
D. Classifications by solubility:

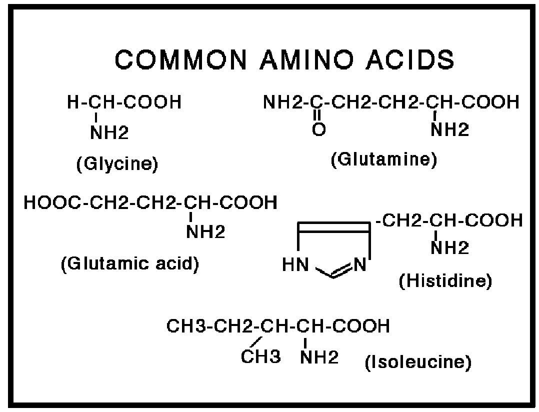
1) Albumins - Soluble in water and salt solutions.
2) Globulins - Insoluble in water, but can ↑ solubility by changing salt concentrations. (Many plant seeds contain globulins!)
3) Protamine - Soluble in a 70-80% ethanol, but insoluble in water & ethanol.
4) Histone - Soluble in salt solutions.
5) Scleroprotein - Insoluble in water or salt solutions.

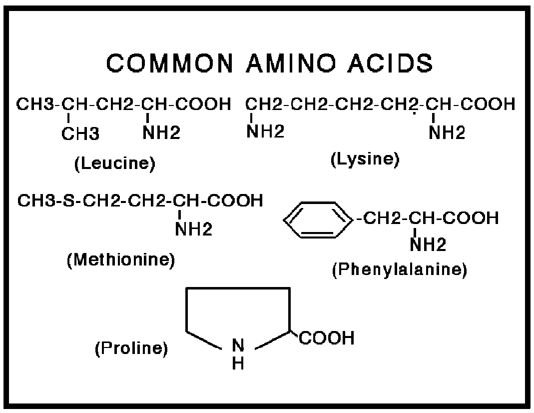
3. **Amino Acids**

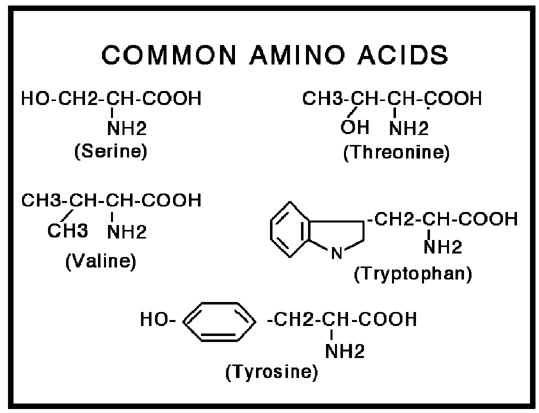
☛ *References - Nomenclature of α-Amino Acids. 1975. Biochemistry 14:449, Handbook of Chemistry & Physics. 1973-74, and The Merck Index. 1976.*

A. Structures of 20 common amino acids found in protein:









B. Name, systematic name, other name, symbol, formula, molecular weight, and composition of 20 common amino acids:

			Composition, %			
Symbol	Formula	MW	C	H	N	O
Alanine (2-aminopropionic acid)						
Ala	$C_3H_7NO_2$	89.09	40.44	7.92	15.72	35.92
Arginine (2-amino-5-guanidinovaleric acid or 2-amino-5-guanidopentanoic acid)						
Arg	$C_6H_{14}N_4O_2$	174.20	41.36	8.10	32.16	18.37
Asparagine (2-aminosuccinamic acid or aspartic acid β-amide)						
Asn	$C_4H_8N_2O_3$	132.12	36.36	6.10	21.20	36.33
Aspartic acid (aminosuccinic acid or 2-aminobutanedioic acid)						
Asp	$C_4H_7NO_4$	133.10	36.09	5.30	10.52	48.08
Cysteine (2-amino-3-mercaptopropionic acid or β-mercaptoalanine)						
Cys	$C_3H_7NO_2S$	121.16	29.74	5.82	11.56	26.41
Glutamic acid (2-aminoglutaric acid or 2-aminopentanedioic acid)						
Glu	$C_5H_9NO_4$	147.13	40.81	6.16	9.52	43.50
Glutamine (2-aminoglutaramic acid or glutamic acid 5-amide)						
Gln	$C_5H_{10}N_2O_3$	146.15	41.09	6.90	19.17	32.48
Glycine (aminacetic acid or aminoethanoic acid)						
Gly	$C_2H_5NO_2$	75.07	32.00	6.71	18.66	42.63
Histidine (α-amino-1H-imidazole-4-propionic acid or glyoxaline-5-alanine)						
His	$C_6H_9N_3O_2$	155.16	46.44	5.85	27.08	20.62

Isoleucine (2-amino-3-methylvaleric acid or 2-amino-3-methylpentanoic acid)						
Ile	$C_6H_{13}NO_2$	131.17	54.94	9.99	10.68	24.39
Leucine (2-amino-4-methylvaleric acid or α-aminoisocaproic acid)						
Leu	$C_6H_{13}NO_2$	131.17	54.94	9.99	10.68	24.39
Lysine (2,6-diaminohexanoic acid or α,ϵ-diaminocaproic acid)						
Lys	$C_6H_{14}N_2O_2$	146.19	49.29	9.65	19.16	21.89
Methionine (2-amino-4-(methylthio)butyric acid or α-amino-γ-methylmercaptobutyric acid)						
Met	$C_5H_{11}NO_2S$	149.21	40.25	7.43	9.39	21.45
Phenylalanine (2-amino-3-phenylpropionic acid or α-aminohydrocinnamic acid)						
Phe	$C_9H_{11}NO_2$	165.19	65.43	6.71	8.48	19.37
Proline (2-pyrrolidinecarboxylic acid)						
Pro	$C_5H_9NO_2$	115.13	52.16	7.88	12.17	27.79
Serine (2-amino-3-hydroxypropionic acid or β-hydroxyalanine)						
Ser	$C_3H_7NO_3$	105.09	34.28	6.71	13.33	45.67
Threonine (2-amino-3-hydroxybutyric acid or α-amino-β-hydroxybutanoic acid)						
Thr	$C_4H_9NO_3$	119.12	40.33	7.62	11.76	40.29
Tryptophan (2-amino-3-(3-indolyl)propionic acid or β-3-indolylalanine)						
Trp	$C_{11}H_{12}N_2O_2$	204.22	64.69	5.92	13.72	15.67
Tyrosine (2-amino-3-(4-hydroxyphenyl)propionic acid or 3-(4-hydroxyphenyl)alanine)						
Tyr	$C_9H_{11}NO_3$	181.19	59.66	6.12	7.73	26.49
Valine (2-amino-3-methylbutyric acid or α-aminoisovaleric acid)						
Val	$C_5H_{11}NO_2$	117.15	51.26	9.46	11.96	27.32

PROTEIN DIGESTION

1. Reasons for Protein Digestion?

A. To get through the membrane (i.e., uptake/absorption).
B. To resynthesize necessary proteins.
C. For the immune process/purpose.

2. Gastric Digestion

A. HCl & pepsin:

1) Are primarily responsible for gastric digestion.
2) Histamine, which is released in response to vagus nerve stimulation & gastrin, stimulates secretion of both.
3) Secretin inhibits acid secretion, but stimulates pepsin secretion.
4) GIP (gastric inhibitory polypeptide) inhibits pepsin secretion.

B. Pepsin:

1) At least four different types exist in both pigs & humans:

Other name?	Origin	Optimum pH

A	Pepsin	Fundal mucosa	2.0-2.2	3.5-3.9
D	Pepsin	Fundal mucosa	2.0-2.2	3.5-3.9
B	Parapepsin I	Pyloric mucosa	1.7-1.9	3.2-3.4
C	Parapepsin II	Pyloric mucosa	1.7-1.9	3.2-3.4.

2) Produced & released as inactive precursors (proenzymes or zymogens).
3) Pepsinogens are activated at < pH 5 (rapidly at 2 & slowly at 4), and the process is "autocatalytic" - Activation by hydrolysis of Glu-Ile bond with subsequent removal of a peptide from the N-terminal end of the molecule.
4) Has two pH optima, 2 & 3.5 - Usually, a full activity is not achieved because gastric content pH is 3.8 to 4.8 soon after consumption of feed/food.
5) Pepsin is a nonspecific endopeptidase, but the rate of hydrolysis differs according to the type of bonds (or AA) - e.g., bonds with aromatic AA > Glu > Cys . . . > Gly.

C. Importance of gastric digestion:

1) Conflicting results on overall contributions.
2) But, a total gastrectomy of pigs may decrease an apparent protein digestibility by 17-18%.

3. **Intestinal Digestion**

A. General:

1) 1° site is the duodenum, where feed/food is mixed with pancreatic & duodenal secretions.
2) pH of ingesta ↑ progressively, and reaches ≈ 7 by the time ingesta get to the end of ileum, ∴ digestion by pancreatic enzymes rather than pepsin.
3) Intestinal digestion consists of two phases: the intraluminal, and membrane & intracellular digestion.

B. Intraluminal digestion:

1) Mostly by pancreatic enzymes, but some microbial proteases may be involved.
2) Presence of acid & food in the upper SI results in:

a) Stimulation of pancreas by vagal nerves results in secretion of fluids, bicarbonate & pancreatic enzymes.
b) Release of peptide hormones:

(1) Secretin, which is released in response to "acid," stimulates secretion of fluids & bicarbonate.
(2) Cholecystokinin, which is released in response to the presence of "food," stimulates secretion of pancreatic enzymes.

3) Pancreatic juice contains:

a) Trypsin/trypsinogen:

(1) Trypsinogen is converted to trypsin by enterokinase (hydrolysis of Lys-Ile bond with subsequent removal of a peptide).
(2) Activation process is also "autocatalytic."
(3) Optimum pH are ≈ 8 to 9.
(4) Trypsin is an endopeptidase & highly specific - acts only on bonds where carboxyl group is contributed by either Lys or Arg.

b) Chymotrypsin/chymotrypsinogen:

(1) Three types, A, B & C, seem to complement each other.
(2) Chymotrypsinogen is activated by trypsin.
(3) Optimum pH is ≈ 8.
(4) Chymotrypsin is an endopeptidase & active against bonds where carboxyl group is contributed by Phe, Tyr, Trp or Leu.
☛ Other bonds maybe susceptible to chymotrypsin, but it's not active against Pro bonds.

c) Elastase(s):

(1) Proelastase is also activated by trypsin.
(2) Only enzyme active against elastin.
(3) Elastase is an endopeptidase, and acts especially on nonpolar AA (Val, Leu, Ser & Ala) & produces peptides.

▹ Elastase II - Acts on both typical chymotrypsin substrates and on elastin and other elastin substrates.

d) Carboxypeptidases:

(1) Procarboxypeptidases A & B (exopeptidases) are activated by trypsin.
(2) Optimum pH are ≈ 7.5 to 8.5.
(3) Carboxypeptidase A attacks peptides produced by chymotrypsin & elastase, and hydrolyze AA from the C-terminal end.
(4) Carboxypeptidase B attacks peptides produced by trypsin, and hydrolyze arginyl & lysyl residues from the C-terminal end.

☛ Also, there are pancreatic nucleases (nucleic acids → mononucleotides) - Ribonuclease & deoxyribonuclease.

4) Significance of pancreatic digestion:

a) A total pancreatectomy resulted in ≈ 70% normal N absorption rate in dogs (1 h after meal).

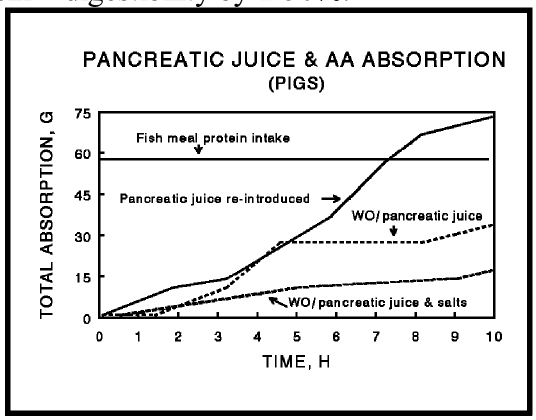
b) In pigs, it is affected by age & type of protein fed:

(1) e.g., Pancreatic juice & amino acid absorption in pigs [Rérat et al., 1976. In: Cole et al. (Ed.)] - Measured absorption rate during a 10-h period after ingestion of 500 g of a semisynthetic meal containing 58 g fish meal protein.

(2) Young pigs fed low-quality protein ↓ digestibility by ≥ 50%.

(3) The use of highly digestible protein or older pigs, ↓ in digestibility may be only 15-20%.

(4) Preventing pancreatic secretion is detrimental to digestion, but not fatal!

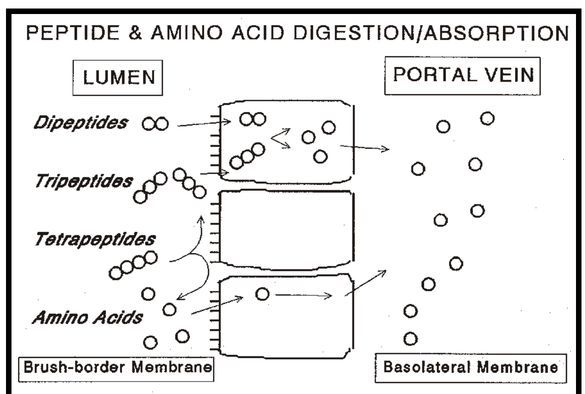


C. Membrane & intracellular digestion:

1) Final stages of protein digestion at the external membrane of intestinal mucosa (brush border) & within the SI columnar cell.

a) Mechanism(s) - Not completely understood.

b) The current view: [See, e.g., Grimble, 1994. Annu. Rev. Nutr. 14:419-447]



(Adapted & redrawn from Grimble, G.K. 1994. Annu. Rev. Nutr. 14:419-447)

(1) Larger peptides (3-6 AA residues) are split by aminopeptidases on the luminal surface at the mucosal brush border.

(2) Free amino acids and small peptides are absorbed from the lumen.

(3) Smaller peptides are hydrolyzed by aminopeptidases within mucosal cells.

(4) Metabolism of some absorbed amino acids, including some resynthesis of proteins.

2) Brush border (≈ 10 to 20% of total aminopeptidase activities):

a) Two oligopeptidases are active against di-, tri- and tetrapeptides.

b) Dipeptidase has a minimal specificity for larger oligopeptides.

c) All three are particularly active against glycyl-leucine & leucyl-glycine bonds.

3) Intracellular (≈ 80% of aminopeptidase activities) - Uncertain No. of peptidases, but four to eight may exit:

a) Leucine aminopeptidase - Active against all bonds adjacent to the N-terminal end, but has a wide range of activity.
b) Master dipeptidase (or Glycylleucine hydrolase) - Acts on many dipeptides (. . . demonstrated to be active against 65 out of 77 dipeptides tested in one experiment).

(1) Glycylglycine dipeptidase.
(2) Imidodipeptidase - Acts on the C-terminal of Pro or Hyp.
(3) Iminodipeptidase - Acts on the N-terminal of Pro or Hyp.
(4) Glycylhistidine dipeptidase.
(5) Arginyl dipeptidase.

D. Digestion at the large intestine:

1). A considerable microbial fermentation at the LI, and some AA may be absorbed?
2) AA not absorbed by the end of the SI are excreted in the feces, being absorbed but excreted in the urine and(or) metabolized within the mucosa, thus not likely to have any value to the pig. (Zebrowska, 1973. Roczniki Nauk Rolniczych 95B1:115)

4. **Digestibility**

☛ Proteins, like any other nutrients, are not completely digested and absorbed!

A. Apparent digestibility:

$$= \frac{\text{Feed protein - Fecal protein}}{\text{Feed protein}} \times 100$$

1) An assumption? - "All proteins in the feces are derived from undigested feed residues (i.e., from an exogenous source)."
2) But, the fecal protein consists of enzymes, cellular materials & others that are not reabsorbed (i.e., contains protein from endogenous sources), thus underestimate digestibility!

B. True digestibility:

$$= \frac{\text{Feed N - (Fecal N - Metabolic fecal N)}}{\text{Feed N}} \times 100$$

1) Makes an adjustment for endogenous sources by estimating metabolic fecal nitrogen (MFN).

   a) Considerable amounts of endogenous N are added in the form of digestive secretions and desquamated/sloughed off mucosal cells during the passage of food - e.g, 20 (e.g., fed a high-protein diet or a high-quality protein) to 30% (e.g., fed a low-protein diet or a low-quality protein) of dietary protein/N.
   b) Partly digested and absorbed but less digestible vs dietary sources.

2) Estimation of MFN is a very difficult task!

   a) Two common approaches:

      (1) Feed a N-free diet:

         (a) Since no N in the diet, all fecal N must be metabolic origin!?
         (b) But, a N-free diet is not palatable - Animals may not consume enough feed/day, and(or) may not be able to maintain a certain level of intake during the trial.

      (2) Regression method - Feed various levels of highly digestible protein, and extrapolate back to the zero N intake.

   b) Both methods underestimate MFN because:

      (1) Endogenous N ↑ when protein is fed.
      (2) The rate of endogenous N secretion varies with different protein sources.

C. Apparent or true digestibility?

1) The estimation of MFN is not precise.
2) The loss of MFN is inevitable, and must be taken into account when determining the value of feedstuffs to animals.

☛ Thus, "apparent" digestibility might be a more meaningful and realistic measure of the nutritional value of protein source(s) in question!?

D. Apparent fecal vs ileal digestibility:

1) e.g., Apparent ileal & fecal N digestibilities (%): (Knabe et al., 1989. J. Anim. Sci. 67:441)

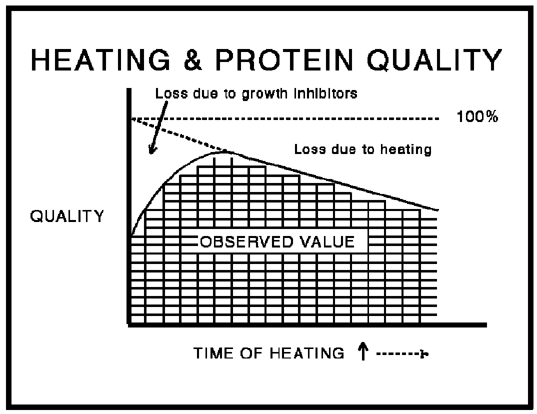
Source	Ileal	Fecal
Meat & bone meal	67	81
Canola meal	69	81

Poultry-by-product	79	87
Soybean meal	78	85
Blood meal	87	91
Corn gluten meal	88	92

2) Fecal digestibilities are usually higher than ileal values because of protein degradation by microbial fermentation (∴ less unaltered N in feces).
3) Differences are smaller for highly digestible sources because "less" undigested/ unabsorbed proteins are delivered to the LI for microbial fermentation.

☛ Thus, better to determine the N-digestibility at the terminal ileum!

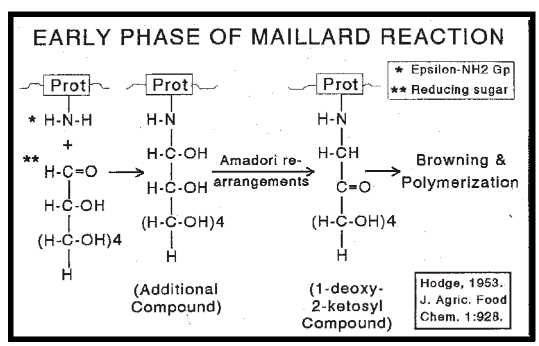
E. Some factors affecting protein digestibility:



1) Presence of enzyme inhibitors (e.g., trypsin inhibitors in soybeans).
2) Heat damage - Mainly due to "Maillard or browning reaction?" [See Hodge (1953)]

a) Reaction between the primary amine of peptide chain (often the ϵ-amino group of lysyl residue) and reducing sugars such as xylose (most reactive), glucose & galactose - "amino-sugar complex" → isomerization & polymerization.
b) Trypsin cannot work on "lysyl bonds," thus reducing the availability!

☛ FDNB (fluorodinitrobenzene)/Sanger's agent can bind to the ϵ-amino group, but not to the one combined with a sugar, thus can be used to assess the availability!



c) Reactions are affected by sugar concentrations, duration of heating, water activity & pH of reaction mixtures.
d) Under the influence of the intestinal microorganisms, a small portion may be released & absorbed, but usually excreted in the urine. (According to some data, some "intermediates" may be available to the animal!)

☛ For ruminant species, may be one way to protect proteins from microbial degradation in the rumen. (See Cleale et al., 1987a,b,c. J. Anim. Sci. 65:1312-1318,1319-1326 & 13-27-1335.)

3) Source of protein.
4) Amount of fibers in the diet.
5) Age and(or) development of digestive systems - Perhaps, related to 3) & 4)?

ABSORPTION OF AMINO ACIDS AND PEPTIDES

☛ *Good references on this topic:*

1) *Silk, D.B.A. 1980. Digestion and absorption of dietary protein in man. Proc. Nutr. Soc. 39:61.*
2) *Collarini, E.J. & D.L. Oxender. 1987. Mechanisms of transport of amino acids across membranes. Annu. Rev. Nutr. 7:75.*
3) *Christensen, H.N. 1990. Role of amino acid transport and countertransport in nutrition and metabolism. Physiol. Rev. 70:43.*
4) *Kilberg, M.S. et al., 1993. Recent advances in mammalian amino acid transport. Annu. Rev. Nutr. 13:137.*

1. Digestion of Protein - Any Exception?

A. Certain neonatal mammals:

1) Have the ability to absorb intact proteins, immunoglobulins (e.g., IgG), directly into the lymphatic system. ("IgA" may not be absorbed, but may be important in protecting the gut!)
2) Accomplished by "pinocytosis."
3) Colostrum contains powerful trypsin inhibitors (+ low acid secretion in baby pigs), ∴ suppressing proteolytic activity in the GI tract.

B. Closure - A loss of ability to absorb intact proteins:

1) Pigs - ≈ < 36 hours.
2) Cattle - < 2-3 days.
3) Humans - Perhaps, shorter than animals, or may not possess the ability to absorb intact proteins?

2. Mechanisms of Absorption

A. General:

1) Current knowledge/understandings on amino acid absorption were obtained mostly during 1950-1970, and little has been added in recent years.
2) Most amino acids are absorbed by the active process involving Na & membrane carriers (probably, protein).

B. In general, can be classified into four distinct amino acid transport systems?

1) Neutral system:

   a) Transports monoamino & monocarboxylic amino acids (Ala, Asn, Cys, Gln, His, Ile, Leu, Met, Phe, Ser, Thr, Trp, Tyr, Val).
   b) Active process (Na^+-dependent) & very rapid.
   c) Amino acids compete with each other for absorption.

2) Basic system:

   a) Transports diamino acids (Arg, Lys, Orn & cystine).
   b) Active (Na^+-dependent) & fairly rapid (but the rate is only about 10% of the neutral system).

3) Acid system:

   a) Transports dicarboxylic amino acids (Asp & Glu).
   b) Partially Na^+-dependent, and probably active.
   ☞ "Asp & Glu" - Both are rapidly removed by transamination process at the intestine after uptake, ∴ difficult to determine whether they are transported against concentration gradient!

4) Imino acid & glycine system:

   a) Transports two imino acids, Pro & Hyp (+ Gly).
   b) May not require Na^+, and the rate is slower than three other systems.

☛ There may be some interactions among these systems - e.g., some neutral AA use carrier(s) for basic AA, and neutral AA may stimulate transport of basic AA.

C. Absorption of peptides:

   ☛ Only ≈ 1/3 of total amino acids may exist as free-AA in the intestinal lumen, ∴ there must be some "peptide absorption!?"

1) Historical views:

   a) 19th century:

      (1) Physiologists conducted most of the work on this area.
      (2) Assumed that proteins are absorbed in the form of polypeptides.

   b) Early 1900's: (Actually, until 1950s!)

      (1) Assumed that proteins are completely hydrolyzed to amino acids at the intestinal lumen before being absorbed.

(2) This *classical view* persisted for a long time because:

(a) Extensive work on CH_2O demonstrated a complete hydrolysis before absorption, and assumed a similar mechanism for protein!?
(b) Isolated a considerable amount of AA in the portal blood, but failed to isolate a meaningful amount of peptides.
(c) Observed extensive hydrolytic activity at the brush border & mucosal cells, ∴ assumed a complete hydrolysis before absorption!?

c) In the mid 1950's and early 1960's, people started demonstrating that "peptides" can be absorbed.

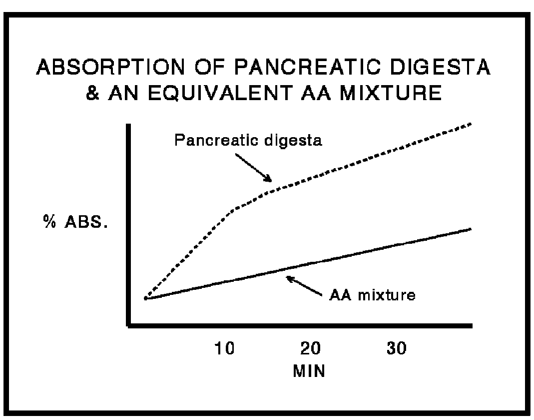
▹ e.g., Demonstration by one group that dipeptides can be absorbed by intact intestinal preparations (Newey & Smyth, 1962. J. Physiol. 164:527).

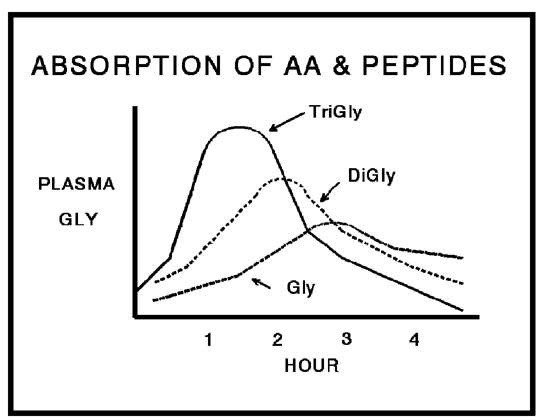
2) Absorption of peptides:

a) Little effect on absorption of free-amino acids, i.e., independent mechanisms for AA & peptides.
b) As in AA absorption, there are competitions among peptides for absorption.

3. **Rate of Absorption**

A. Absorption of pancreatic digesta (lactalbumin & peptides containing 2-6 AA residues) and an equivalent mixture of amino acids - Figure on the left (Unknown source).
B Absorption of amino acid & peptides - Figure on the right (Craft et al., 1968. Gut 9:425).





C. Absorption of peptides:

1) Dipeptides and tripeptides are absorbed faster than free amino acids at the intestinal epithelium.

2) Based on the evaluation with tetraglycine, has been no evidence of intact absorption of tetrapeptides, bu . . .?

   a) Probably, hydrolyzed to tri- & dipeptides before uptake/absorption?
   b) But considering a possible No. of tetrapeptides (20^4), the possibility of intact tetrapeptide absorption may exist!?

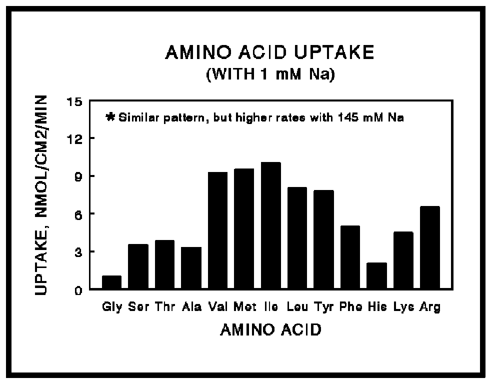
3) A possible mechanism(s)?

   a) Uptake of dipeptide is electrogenic and related to H^+ co-transport - Need inwardly directed H^+ gradient!?
   b) Protein (127 kDa) - Part of or the entire peptide transport system?

D. Nutritional significance of peptide transport:

1) ≈ 2/3 of total AA is absorbed as peptides!
2) Absorption of peptides can be very important in some instances of AA absorption defects (e.g., some congenital defects)!

   a) *Cystinuria* - Impaired absorption of Cys, Lys, Orn & Arg at the kidneys & intestines.
   b) *Hartnup disease* - Impaired absorption of e.g., Thr, Phe, Tyr, Trp, His, Gly, & Ser.



3) Advantages of peptide absorption?

   a) Because of competitions for absorption/transport:

      (1) After consumption of a meal, some AA may reach peak concentrations early, while others may lag behind.
      (2) Thus, may affect the efficiency of utilization of AA in protein synthesis.

   b) Amino acid uptake: [See Sepúlveda & Smith (1978). J. Physiol. (London) 282:73]
   c) If AA with slow absorption rate (e.g., Gly & Lys) are provided in the form of peptides instead of free AA, it may ↑ absorption rate of those AA!?

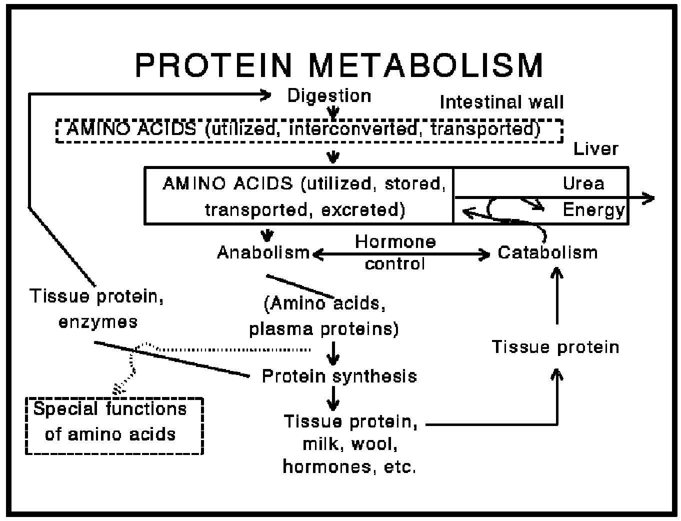
PROTEIN METABOLISM IN GENERAL

1. **Amino Acids**

A. Protein metabolism - Maynard et al. (1979).

B. Three major points?

1) Protein metabolism is a dynamic state, i.e., a continuous synthesis & breakdown of protein ("protein turnover")!
2) The liver is acting as a buffer or a focal point of regulating protein metabolism.
3) Amino acids have specialized functions.



2. **Fate of Absorbed Amino Acids**

☛ Amino acids consumed in excess of that needed for protein synthesis cannot be stored or excreted as such!

A. Anabolism - Protein synthesis (muscle, milk, egg, repair/maintenance, etc.).
B. Catabolism - Catabolized & used as a source of energy (C-skeletons), and N for urea synthesis.
C. Specific function(s) of each individual amino acid - AA are involved in the synthesis of various compounds.

PROTEIN SYNTHESIS AND TURNOVER

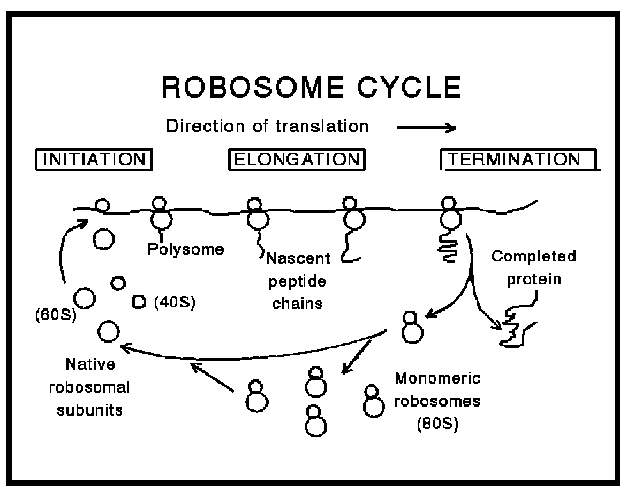
1. **Protein Synthesis**

◦ *A good reference - Pain, V. M. and M. J. Clemens. 1980. Mechanism and regulation of protein biosynthesis in eukaryotic cells. In: P.J. Buttery and D.B. Lindsay (Ed.) Protein Deposition in Animals. pp 1-20. Butterworths, London. (This is also an excellent reference book for the protein metabolism in general!)*

A. General:

1) Transcription - Formation of mRNA from DNA.
2) Translation - All amino acids (protein consists of 22 AA) must be available in adequate amounts simultaneously!

‣ See, e.g., Pain & Clemens (1980) for the "ribosome cycle."



a) Initiation - A ribosome & specific initiator tRNA (Met-$tRNA_f$) bind to the beginning of coding sequence of mRNA.
b) Elongation - A ribosome moves along mRNA, and a polypeptide chain is elaborated from AA in a specific sequence directed by mRNA.
c) Termination - A ribosome reaches the end of coding sequences, and being released together with a completed protein.

☛ The process of protein synthesis is not exact, i.e., many mistakes can be made during the process (∴ ↑ energy expenditures)!

B. Rate of protein synthesis:

1) Fractional rate of protein synthesis (rats): [Lewis (Pers. Comm.)]

Tissue	%/day	g/day	% of whole body
SI	136	0.41	9.8
Liver	87	0.55	13.0
Kidney	48	0.069	1.6
Heart	17	0.012	0.3
Brain	17	0.024	0.6
Skeletal muscle	13	0.79	18.7

a) Over 300 g protein synthesized/d vs requirement of ≈ 56 g/d in adult humans.
b) In one experiment, the protein synthetic rate was 713 mg/d vs deposition rate of 149 mg/d in a 100-g, rapidly growing rat.

2) The protein synthetic rate is much greater than the protein requirement or accretion rate.
3) Thus, a major focus of protein synthesis seems to be “replacement of old tissues” rather than deposition of new protein!

2. **Protein Turnover**

A. Possible reasons:

1) Metabolic adaptation - Enzymes, hormones, etc.
2) Restructuring for growth, etc. - e.g., collagen.
3) Repairing cells and tissues.
4) Mobilization/transport of protein - e.g., in the situation of "protein-deficiency."
5) Used as a source of energy.
6) Muscle growth.
7) Removal of faulty molecules or protein . . , etc.

B. Factors influencing the body protein turnover/metabolism:

1) Genetics & sex - species, breeds, lines/strains, etc.
2) Nutrition - Quantity & quality of protein sources (also energy sources).
3) Physiological state - lactation vs dry, pathological state, etc.
4) Age and(or) stage of development:

   e.g., Body protein turnover rate in pigs - 13% of body protein/day in a 20-kg pig, 10% in a 60-kg pig, 6% in a 100-kg pig, and 5% in a mature pig.

5) Hormones: Growth hormone - anabolic, insulin - anabolic, thyroid hormones - anabolic & catabolic, testosterone - anabolic, estrogen - anabolic in ruminants & catabolic in nonruminants, and corticosteroids - catabolic.

AMINO ACID AS A SOURCE OF ENERGY

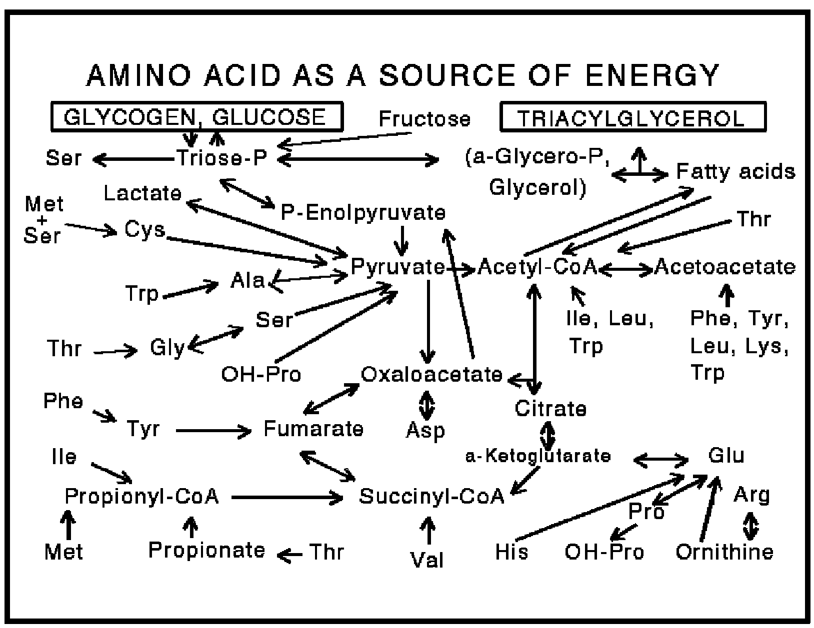
1. **General**

A. Often, a large part of protein consumed is used as a source of energy.
B. e.g., In human:

1) The RDA for protein (adult male weighing 70 kg) is 56 g/d in the U.S.
2) An average consumption is at least 100 g/d.
3) Excess protein is catabolized - Carbon skeletons are used as a source of energy, and a nitrogen component is converted to urea & excreted in the urine.

2. **Metabolic Pathways**

☛ Amino acids & entry points: (See Martin et al., 1983 & others)



A Unique for each amino acid.
B. Some amino acids share certain sections of the pathway.
C. All routes converge into a few terminal pathways leading to formation of: 1) pyruvate, 2) acetyl-CoA or 3) intermediates of TCA cycle.

3. **Classification of Amino Acids**

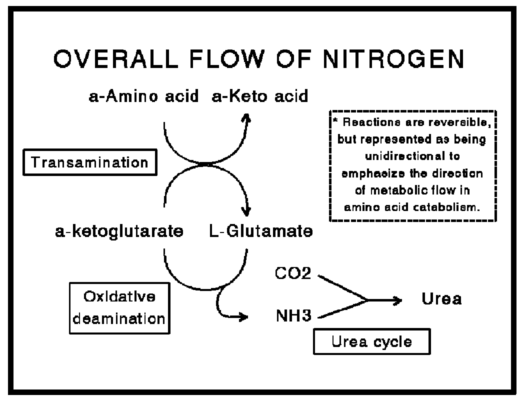
A. Glucogenic - Some or all C can be converted to glucose via pyruvate & intermediates of TCA cycle (Ala, Arg, Asn, Asp, Cys, Gln, Glu, Gly, His, Met, Pro, Ser, Thr & Val).
B. Ketogenic - Reactions lead to only acetoacetate & acetyl-CoA (Leu & Lys).
C. Glucogenic & ketogenic - Can be converted into both types of intermediates:

1) Ile - Succinyl-CoA & acetyl-CoA.
2) Phe & Tyr - Fumarate & acetoacetate.
3) Trp - Acetoacetate & pyruvate.

☛ Most of the AA are glucogenic, ∴ there is a potential for forming glucose from catabolized AA. But, experimental data indicate otherwise!

TRANSAMINATION AND DEAMINATION

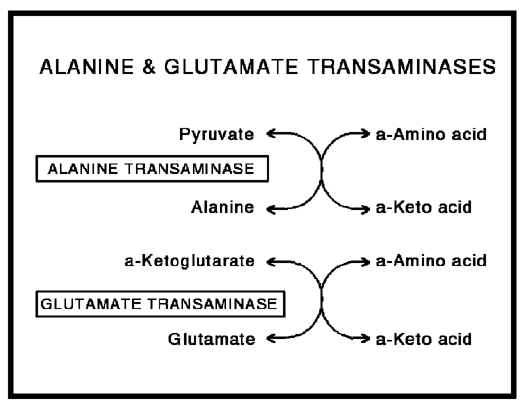
1. **General**



A. Overall flow of N in AA catabolism - See, e.g., Martin et al. (1983).
B. These processes are necessary:

1) To synthesize dispensable amino acids.
2) To oxidize excess amino acids.
3) For gluconeogenesis.

2. **Transamination**



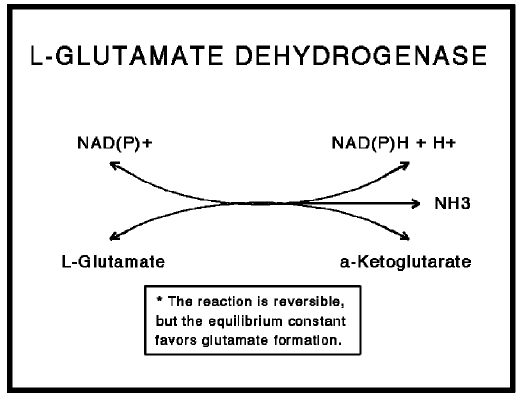
A. Exchange of ammonia between AA & α-keto acid (reversible reactions).
B. Occurs in the mitochondria & cytoplasm of most cells.
C. Vitamin B_6 is an essential component of these reactions.
D. Lys & Thr do not participate in transamination process (lacking means to add ammonia to their α-keto acids), thus, their analogs cannot be utilized by animals!
E. Catalyzed by transaminases:

1) Alanine & glutamate transaminases: (Adapted & redrawn from Martin et al., 1983)
2) Also, aspartate transaminase is involved:

Glutamate ⇔ α-ketoglutarate & oxaloacetate ⇔ aspartic acid.

3. **Deamination**

A. An amino group of most AA is transferred to α-ketoglutarate by transamination process, and a release of ammonia is catalyzed by L-glutamate dehydrogenase (oxidative):



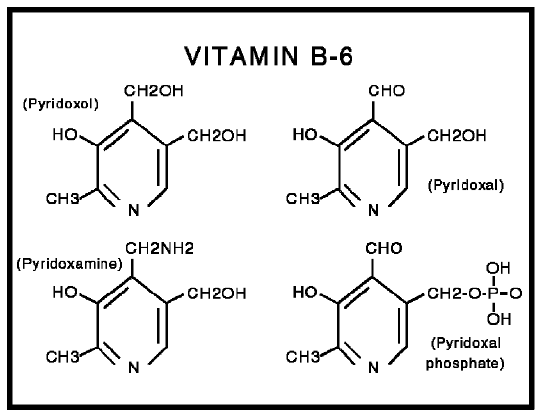
1) Reaction of L-glutamate dehydrogenase: (Redrawn from Martin et al., 1983)
2) Fate of the end products? Ammonia to urea cycle, and α-ketoglutarate to TCA cycle.

B. Nonoxidative deamination requires AA dehydratase & vitamin B_6:

1) Ser → pyruvate + NH_4^+.
2) Thr → α-ketobutyrate + NH_4^+.

VITAMIN B_6

1. **Chemical Structure**



A. Structure of vitamin B_6 compounds (McDowell, 1989).
B. The vitamin occurs in feedstuffs as:

1) Pyridoxine (or pyridoxol) - A predominant form in plants.
2) Pyridoxal & pyridoxamine - Generally in animal products.
3) Pyridoxal phosphate (PLP) - Metabolically active form of the vitamin.

2. **Functions**

A. PLP is a co-enzyme for many enzymes involved in amino acid metabolism:

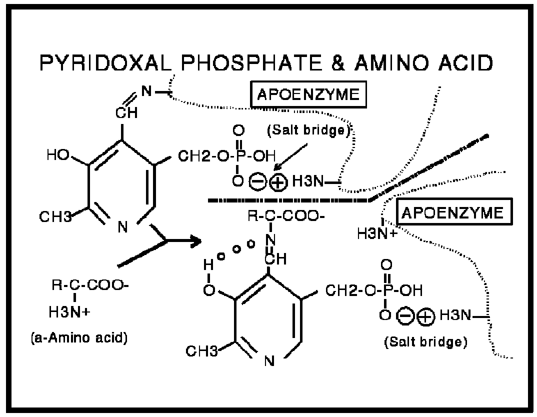
1) Over 50 enzymes depend on vitamin B_6 - e.g., Transaminases, deaminases, racemases (D-AA; yet to be detected in mammalian tissues), synthetases, decarboxylases, dehydrases, desulfhydrases, amino acid transport, etc.
2) PLP functions in practically all reactions involved in AA metabolism!
3) The initial step:

▹ Formation of an enzyme-bound Schiff base intermediate - Martin et al. (1983).

a) PLP binds to its apoenzyme.

b) When α-amino acid enters, it replaces ϵ-amino group of apoenzyme's lysyl residue & forms its own Schiff base with PLP.

c) After a series of rearrangements, substrate is oxidatively deaminated and PLP would be converted to PMP, and PMP can donate NH_2 to keto acids to form other AA.



B. Also involved in carbohydrate & FA metabolism - e.g., Breakdown of glycogen & conversion of linoleic acid to arachidonic acid.

C. Essential for formation of niacin from tryptophan.

3. **Deficiency**

- Involved in many biological functions, deficiency symptoms are very diverse!

A. Swine - ↓ appetite & growth, epileptic-like convulsions, rough hair coats, diarrhea, scaly skin, a brown exudate around the eye, disordered movement, etc.

B. Poultry - ↓ appetite & growth, abnormally excitable, nervous disorders, trembling & vibration of the tip of tails, convulsion, ↓ egg production & hatchability, etc.

C. Fish:

1) Expected to have higher vitamin B_6 requirement because of high-protein requirements.

2) Deficiency signs develop quickly - < 4-8 wk in channel catfish, salmonids & carp.

3) Signs include:

a) Nervous disorders - Hypersensitivity to disturbances, poor swimming coordination, convulsion & tetany.

b) A greenish-blue sheen to the skin in channel catfish.

c) Edema, exophthalmos & skin lesions in common carp.

4. **Requirements & Supplementation**

A. Requirements: (Also see an appropriate "Nutrition and Feeding" section.)

Animals	mg/kg
Swine: (NRC, 1998)	
Young (3-20 kg)	1.50-2.0
Growing (20-120 kg)	1.0
Adult	1.0
Poultry: (NRC, 1994)	
Immature chickens	2.8-3.0

Laying hens	2.1-3.1
Broilers	3.0-3.5
Turkeys	3.0-4.5
Horses (NRC, 1978)	Microbial synthesis
Fish: (NRC, 1993)	
Channel catfish	3
Rainbow trout	3 (10-15)
Pacific salmon	6 (10-20)
Common carp	6? (5-10)

( ) = previous estimates.

B. Supplementation:

1) Widely distributed in feeds & food.
2) The availability of corn (content, 5.3 mg/kg) & soybean meal (6.7 mg/kg) has been estimated to be 40 to 60% in chick assay, and probably similar availabilities in swine?
3) Swine - Probably not necessary to supplement in practical diets.
4) Birds - Unlikely to see deficiency in adults, but in young birds . . . ?
5) Fish - Most feedstuffs may contain adequate levels, but a common practice to supplement because of variations/uncertainty of the content (& availability?) in feedstuffs & also in processed and(or) stored feeds.

D-ISOMERS, α-KETO AND α-HYDROXY ANALOGS

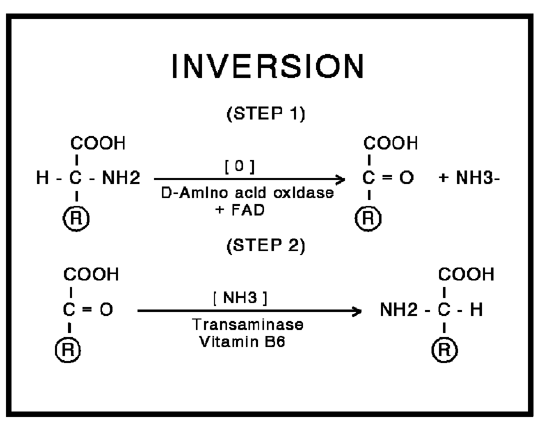
1. **General**

A. Reasons for the interest:

1) Can lower the N content of diets by using analogs - may be useful in various disorders associated with N metabolism.
2) May be able to reduce feed costs for animal production - Often, D-forms & analogs are inexpensive vs L-amino acids or intact proteins.

B. All natural proteins consist of L-form of amino acids. (Protein synthesized by certain MO “may” contain D-AA though!)

C. For the D-form to have activity or to be utilized, it must be converted to the L-form by the process called “inversion.”



2. **Inversion**

A Keto acids are intermediates of the inversion process, ∴ animals should be able to utilize those acids.

B. Hydroxy analogs - Simply have the OH group instead of amino group, thus animals should be able to utilize those analogs.

3. **Utilization**

A. Lys & Thr - No inversion for these AA because of the lack of D-AA oxidase & means to incorporate ammonia), thus the D-forms or analogs are not utilized by animals.

B. Met:

1) D- and L-Met have similar values in rats, mice, dogs & possibly in chicks.
2) α-Keto analog is readily utilized by animals.

C. Phe:

1) D-form is utilized well by species investigated (mice, rats, chicks & humans).
2) α-Keto & hydroxy analogs are utilized by rats and chicks.

D. For others such as Arg, Ile, Leu, Trp & Val, the efficiency of utilization may depend on species & type of AA intermediates, and likely to see considerable variations in their effectiveness.

EXCRETION OF NITROGEN

1. **General**

A. Mammals - 1° pathway is the urine, and major constituents of urine include: urea (60-80%), ammonia (2-10%), uric acid (2% in humans), amino acids, creatinine (3-10%), protein (< 1%), amino sugars, vitamin residues, etc.

B. Fowl:

1) Excrete N as uric acid - Almost “solid” (possibly because of limited water intake?).
2) Uric acid:

a) Synthesized from Gln, Gly and Asp in a very complicated manner. (Uric acid is also an end product of metabolism of purine bases.)
b) The synthetic process is under control of xanthine dehydrogenase or oxidase, which is produced in the liver & kidneys.

2. **Urea Cycle**

A. Reactions & intermediates of urea biosynthesis (Martin et al., 1983).

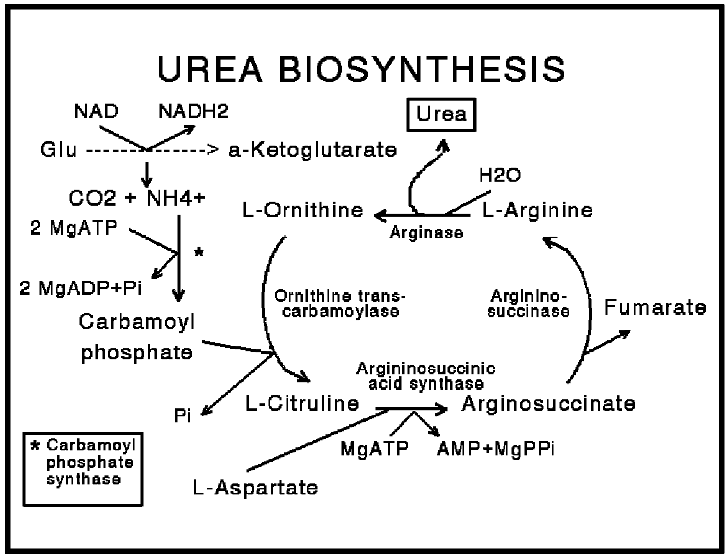
A. Presumably requires 3 ATP, but needs additional energy for:

1) Ornithine → mitochondria (crossing membranes).

2) Regeneration of aspartate & release of ammonia from AA.

C. The values determined via experiments range from 4.8 to 5.7 ATP/mole of urea produced (vs. theoretical value of 3 ATP), ∴ a costly process:

1) Account for ≈ 1% of ME intake in growing pigs?
2) Much larger for animals & people consuming large amounts of protein.



SPECIAL FUNCTIONS OF AMINO ACIDS

1. **Arginine**

A. A component of creatine, which plays important roles in the storage and transmission of phosphate-bond energy. (Also, Gly & Met are involved in creatine synthesis.)
B. A component of the urea cycle, ∴ involved in the conversion of ammonia to urea.

2. **Aspartic acid**

A. Involved in biosynthesis of purine - contributes the N atom labeled 1. (Also, Ser, Gln & Gly are involved in purine synthesis.)
B. Pyrimidine biosynthesis - contributes atoms 3 (N), 4, 5 & 6 (C) of the pyrimidine ring.

3. **Cysteine**

A. A component of tripeptide, glutathione.
B. Taurine is derived from Cys. (Taurine is a component of bile acids & excretory pathway for sulfur, and also may function as a neurotransmitter).

4. **Glutamic Acid**

A. A component of glutathione.
B. Decarboxylated to γ-aminobutyric acid (GABA), which may be involved in regulation of the CNS activity.
C. Involved in the transamination of amino acids.

5. **Glutamine** - Contributes two N atoms to the basic structure of purine.

6. **Glycine**

   A. Involved in the synthesis of glutathione, creatine & purine.
   B. Involved in conjugation in the liver - Combines with cholic acid to form glycocholic acid & with benzoic acid to form hippuric acid.
   C. Contributes the N atom of the pyrrole rings found in porphyrins such as heme.

7. **Histidine**

   A. Histamine (vasodilator & mediates release of HCl & pepsin) is formed by decarboxylation of His.
   B. Component of two dipeptides (carnosine & anserine) found in muscle tissues.

8. **Serine** - Involved in synthesis of purine, pyrimidine, sphingomyelin, ethanolamine & choline.

9. **Tryptophan**

   A. Involved in formation of serotonin, which is a vasoconstrictor & is found in significant amounts in the brain.
   B. Involved in formation of melatonin (by further metabolism of serotonin), which may play some role in the regulation of seasonal & diurnal rhythms.
   C. Involved in synthesis of niacin - Costly, but it is possible to meet the niacin requirement by providing sufficient Trp.

10. **Tyrosine**

   A. Involved in synthesis of catecholamines - Tyr → dihydroxy-Phe → dopamine → norepinephrine → epinephrine.
   B. Involved in synthesis of thyroid hormones - Try → mono-iodotyrosine (T_3) → diiodotyrosine (T_3 & T_4).
   C. Involved in synthesis of melanin (pigment of skin & hair).

11. **Methionine**

   A. Plays more than a casual role because it contains sulfur & labile methyl groups - may provide methyl groups to as many as 40 different methyl group acceptors.
   B. Involved in synthesis of Cys (∴ taurine), creatine & choline, in conversion of norepinephrine to epinephrine, and in many others.

FOLACIN, VITAMIN B_{12} AND COBALT (& SULFUR)

1. **Interrelationships in Metabolism of Methyl Groups**

   ◦ Metabolically, folacin, vitamin B_{12}/Co, choline and Met are closely related!

A. Folacin:

1) Indispensable in transferring single-carbon units such as **methyl**, formyl & methylene.
2) One-C units are generated primarily from AA metabolism - e.g., Metabolism of Met, Gly, Ser & His yields 1-C units. (Also, metabolism of nucleic acids.)

◦ *Folacin is involved in the synthesis of labile methyl groups from a formate carbon!*

B. Vitamin B_{12}:

1) Regulates a proportion of methyl- to nonmethyl-tetrahydrofolate (THF).
2) Necessary for the transport of methyl-THF across cell membranes, and also promotes folacin retention by tissues.

◦ *Vitamin B_{12} regulates a transfer of the methyl group!*

C. Cobalt is a component of vitamin B_{12} (1°/only biological effect of Co?).

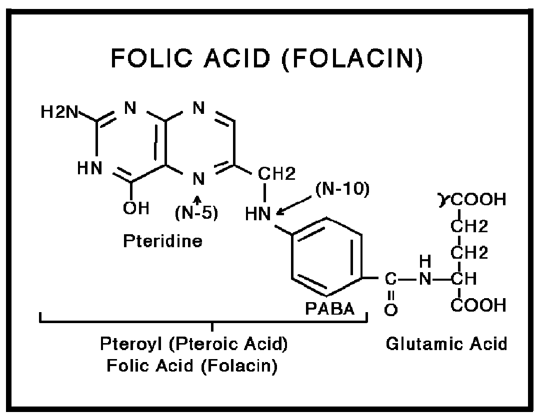
☛ Thus folacin, vitamin B_{12} and Co:

1) Are involved in the biosynthesis of Met from homocysteine.
2) Choline from ethanolamine.
3) Also, involved in biosynthesis of purine bases, adenine & guanine, and thymine, thus, deficiencies can ↓ nucleic acid synthesis, ∴ impair cell formation & functions.

2. **Folacin**

A. Structure of folic acid: (Adapted & redrawn from Martin et al., 1983)

◦ Active forms of folic acid may contain a formyl or methyl group attached to the N-5 or N-10, or a methylene group attached between N-5 & N-10.



B. Specific reactions/functions - Involved in metabolism of one-C units:

1) Purine & pyrimidine synthesis.
2) Interconversion of Ser & Gly.
3) Gly-α-C as a source of C units for many biosynthesis.
4) Degradation of His.
5) Synthesis of methyl groups for Met, choline, thymine, etc.

C. Deficiency:

1) Symptoms are mostly associated with reduced synthesis of purine & pyrimidine, thus the synthesis of nucleic acids.
2) Swine - Anemia (↓ hematopoiesis), ↓ feed intake & growth rate, poor reproductive performance, etc.
3) Poultry - Anemia, poor feathering & growth in young birds, poor hatchability, increased embryonic mortality, etc.
4) Fish:

a) Megablastic anemia (large, immature erythrocytes) in salmonids, and poor growth in eel & channel catfish.
b) No deficiency has been observed in common carp, possibly because of an adequate bacterial synthesis?
c) "No blood" disease in channel catfish:

(1) Characterized by very low erythrocyte concentrations in blood, kidneys, liver & gills, and also can expect signs associated with megaloblastic anemia.
(2) May be associated with folic acid degradation in diets:

(a) Bacteria degrade folic acid to glutamic acid & pteroic acid.
(b) Pteroic acid has no folic acid activity, and also it may be antagonistic to absorption & metabolism of folic acid (at least in warm blooded animals).

D. Sources:

1) Abundant in green leafy materials & organ meats.
2) Good sources include beans (seeds), some animal products & citrus fruits.
3) Poor sources include cereal grains, milk & eggs.

E. Folic acid requirements: (Also, see an appropriate "Nutrition & Feeding" section.)

Animal	mg/kg
Poultry: (NRC, 1994)	
Immature chickens	0.23–0.55
Laying hens	0.21-0.31
Broilers	0.50-0.55
Turkeys, growing	0.70-1.00
Turkeys, breeding	1.00
Swine: (NRC, 1998)	
Growing pigs	0.30
Sows & boars	1.30
Horses, adult (NRC, 1978; No established requirement, but responded to)	20 mg/d

Fish: (NRC, 1993)	
Channel catfish	1.5
Rainbow trout	1.0
Pacific salmon	2
Others	Not tested or determined

1) Folacin in common ingredients (corn, 0.30 & soybean meal, 0.70 mg/kg.) + microbial synthesis may be adequate to meet the requirements of animals fed practical diets.
2) Folic acid is presently added to most fish diets.
3) Factors affecting the requirement?

- Other vitamins (e.g., B_{12}, choline), use of antimicrobial agents & molds in feeds, dietary amino acids (Met, Gly & His), etc.

F. Folacin supplementation - Examples in pigs:

1) Effects of supplemental folic acid (FA) & sulfamethazine (S) on sow performance: (Lindemann & Kornegay, 1989. J. Anim. Sci. 67:459)

	0 ppm FA/ 0 ppm S	0 ppm FA/ 110 ppm S	1 ppm FA/ 0 ppm S	1 ppm FA/ 110 ppm S
Litter size:				
Total born[a]	9.76	10.70	11.04	11.31
Born alive[a]	9.51	10.22	10.64	10.93
At d 21	8.95	9.15	9.29	9.46
At weaning	8.92	9.10	9.24	9.44
Pig wt, kg:				
Birth, all	1.47	1.50	1.47	1.44
Birth, live	1.48	1.51	1.48	1.44
At d 21	5.82	5.69	5.68	5.52
At weaning	7.68	7.56	7.44	7.52
Breedings/litter farrowed[b]	1.17	1.16	1.10	1.04
Days to estrus after weaning	7.30	5.20	6.66	6.09

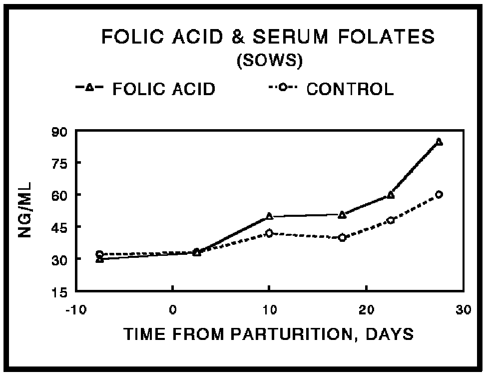
[a]Folic acid effect, $P < .05$ & [b]folic acid effect, $P = 0.12$.

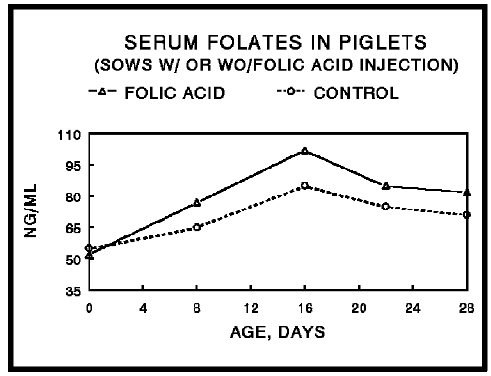
2) Effects of folic acid on litter criteria: (Thaler et al., 1989. J. Anim. Sci. 67:3360)

	Supplemental folacin, mg/kg		
Item	0	1.65	6.62
Total pigs born[a]	8.86	9.84	9.41
Pig born alive[a]	7.93	8.88	8.21
Pigs on d 21[b]	7.79	8.66	7.91
Birth wt, kg	1.54	1.52	1.51
21-d wt, kg[c]	5.96	5.63	5.88

[a]Quadratic effect, $P < .05$; [b]Quadratic effect, $P < .001$; [c]Quadratic effect, $P < .01$.

3) Effects of injection of folic acid (15 mg/wk from d 2 postpartum to weaning) to sows on serum folate: (Matte & Girard, 1989. J. Anim. Sci. 67:426)





- Had no effect on growth performance of piglets from birth to 8 wk of age.

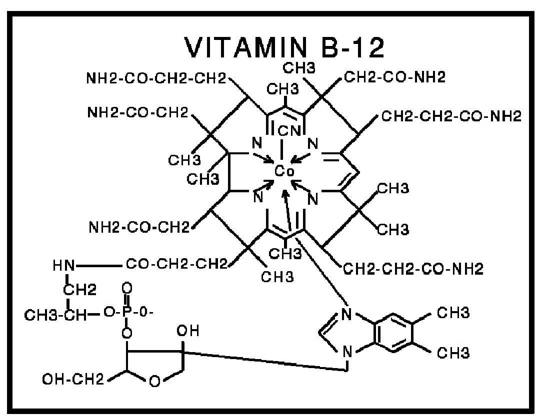
☛ The bottom line?

a) Folic acid supplementation to corn-soy diets can improve reproductive performance of sows. The 1988 NRC requirement for sows may be too low, but the optimum supplementation level has not been established.
b) Can enhance the folate status of piglets by treating sows, but had no effect on growth performance of piglets.
c) Dietary supplementation of baby pig diets may be unwarranted. (Also, folic acid supplementation of starter to finisher diets has been resulted in inconsistent responses!)

3. Vitamin B_{12}

A. General:

1) Formally known as a "chick growth factor" or "animal protein factor."
2) Synthesized in nature only by microorganisms, and usually not found in plant feedstuffs.
3) Cobalt is an integral part of this vitamin.
4) Vitamin B_{12} is a generic name for a group of compounds having B_{12} activity.



B. Structure: (Adapted & redrawn from NRC, 1987)

◦ Cyanide can be replaced by others such as OH (hydroxycobalamin), H_2O (aquacobalamin), NO_2 (nitrocobalamin) & CH_3 (methylcobalamin).

C. Functions:

1) Most vitamin B_{12} reactions involve a transfer or synthesis of one-C units (e.g., methyl groups).
2) A co-factor for methyl malonyl CoA isomerase (mutase) and homocysteine transmethylase.
3) Known enzymatic functions:

   a) Synthesis of methyl groups for Met & choline.
   b) Protein metabolism - Incorporation of AA.
   c) Transmethylation - Met ↔ homocysteine ↔ choline.
   d) Purine biosynthesis & nucleic acid formation.
   e) Conversion of carbohydrates to lipid.

D. Deficiency symptoms - Similar to the folacin deficiency.

E. Sources & requirements:

1) Sources:

   a) Synthesized at the hind gut by bacteria - Meet the needs partially by coprophagy/absorption in swine and by absorption in poultry.
   b) But, question/uncertainty about absorption/utilization, ∴ must be supplemented.
   c) Commercially, produced by fermentation & available as cyanocobalamin, which is very stable.

2) Requirements:

   a) Affected by dietary levels of choline, folacin, Met, etc.
   b) Requirements (animals need very small amounts, i.e., B_{12} is the most potent vitamin!): (Also, see an appropriate "Nutrition & Feeding" section.)

Animal	µg/kg
Poultry: (NRC, 1994)	
Immature chickens	3-9
Laying hens	4
Broilers	7-10
Turkeys	3
Swine: (NRC, 1998)	
3-20kg	15-20
20-120kg	5-10
Sows/boars	15
Horses (1978)	Microbial synthesis
Fish: (NRC, 1993)	
Channel catfish	Required, but not determined
Rainbow trout	.01 mg/kg (estimated)

Pacific salmon	Required, but not determined
Common carp & Tilapia	No dietary requirement

4. **Cobalt**

   A. Is a component of vitamin B_{12}, which is probably the only role of Co in animals.
   B. Vitamin B_{12} is synthesized by microbes, but absorption rate is low.
   C. Can substitute partly for Zn in carboxypeptidase and alkaline phosphatase.

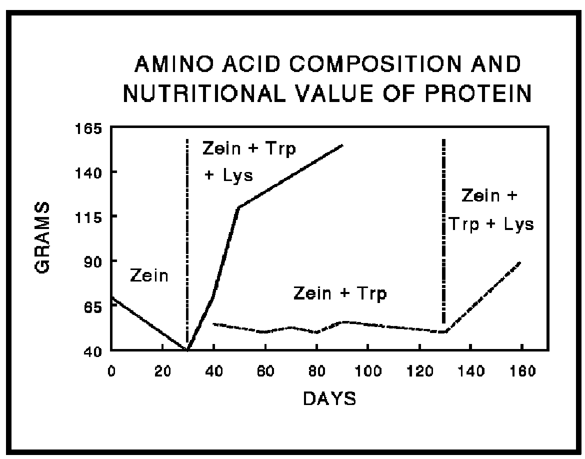
5. **Sulfur**

   A. A component of glutathione, taurocholic acid and chondroitin sulfate.
   B. Requirements can be met by sulfur released from catabolism of S-amino acids (even in low protein, ∴ low S-AA, diets).
   C. Sulfate can spare cystine in poultry, but it is unknown in pigs.

ESSENTIALITY OF AMINO ACIDS

1. **Brief History** [Please see Maynard et al. (1979) & others]

   A. Magendie (1816) fed diets of pure carbohydrates & fats to animals, and concluded that N is essential!
   B. Mulder (1839) used a term "protein," meaning the "first" or the most important.
   C. Kjeldahl (1883) developed the method for the nitrogen analysis.
   D. Identified 13 amino acids in 1900.
   E. Hopkins (1906) reported that feeding only zein (nothing more than the storage form of N or protein) to mice resulted in ↓ weight, but weight was maintained by adding Trp to the zein-based diet.
   F. Osborne & Mendel (1914) evaluated the effect of supplementing zein with Trp and Lys: See Maynard et al.(1979). "Amino acid composition and nutritional value of protein."



   ☛ The results indicated that the amino acid composition influences the nutritional value of protein, and animal body cannot synthesize many amino acids, which are present in its protein!

   G. Rose (1930) classified AA into essential or nonessential dietary constituents by using semipurified diets (AA as sole N sources) & investigating the effect of addition or deletion of each amino acid.

2. Essential or "Indispensable" Amino Acids

A. Definition:

1) Commonly used definition - "*One which can not be synthesized by the species in question from materials ordinarily available to the cells at a rate commensurate with the needs for the optimum growth!*"
2) The definition implies:

   a) Species involved.
   b) Optimum performance and(or) well-being of the animal.
   c) The stage of the life cycle.

B. Indispensable & dispensable amino acids (Lewis, A.J. Pers. Comm.): [(-) = dispensable & (+) = indispensable]

Species	Ala	Arg	Asn	Asp	Cys	Glu	Gln	Gly	His	Ile	Leu	Lys	Met	Phe	Pro	Ser	Thr	Trp	Tyr	Val
Salmon	-	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	+	+	-	+
Chick	-	+	-	-	-	-	-	+[a]	+	+	+	+	+	+	-	+[a]	+	+	-	+
Turkey	-	+	-	-	-	-	-	+[a]	+	+	+	+	+	+	-	+[a]	+	+	-	+
Mouse	-	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	+	+	-	+
Rat	-	+	+[b]	-	-	+[b]	-	-	+	+	+	+	+	+	+[b]	-	+	+	-	+
Rabbit	-	+	-	-	-	-	-	+[b]	+	+	+	+	+	+	-	-	+	+	-	+
Cat	-	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	+	+	-	+
Dog	-	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	+	+	-	+
Pig	-	+[c]	-	-	-	-	-	-	+	+	+	+	+	+	-	-	+	+	-	+
Human	-	+	-	-	-	-	-	-	+[d]	+	+	+	+	+	-	-	+	+	-	+

[a]Gly or Ser is indispensable; [b]Required for maximal growth; [c]Not required by adult animals; [d]May not be required by adults.

1) Ile, Leu, Lys, Met, Phe, Thr & Trp - Required by all species.
2) Arg, His & Val - Required by most. [(1) + (2) = "**PVT TIM HALL**"]
3) Chicks & turkeys - 10 AA + Gly or Ser.
4) Swine - Arg is not essential for adults.

3. Nonessential Amino Acids or Nonessential N?

◦ *May want to read "Harper, A.E. 1974. Nonessential amino acids. J. Nutr. 104:965.*

A. From physiological, biochemical & nutritional viewpoints:

1) Clearly, all of the AA that occur in proteins are essential to the animal.
2) Thus, the term, nonessential, might be a misnomer!
3) The term, dispensable, might be a better description.

B. The term, nonessential N or amino acids:

1) Nonessential (or dispensable) AA can be synthesized from a nonspecific source of N (Glu, Ala, diammonium citrate, etc.).
2) Nonessential N becomes essential or a limiting factor in certain situations:

a) A mixture of free indispensable AA (only source of N!) does not support a maximum growth of rats or chicks, and the diet can be improved by addition of a mixture of nonspecific N.
b) No single N-source is as effective as a mixture of AA that can be synthesized by the body.

3) The term, nonspecific N (nitrogen):

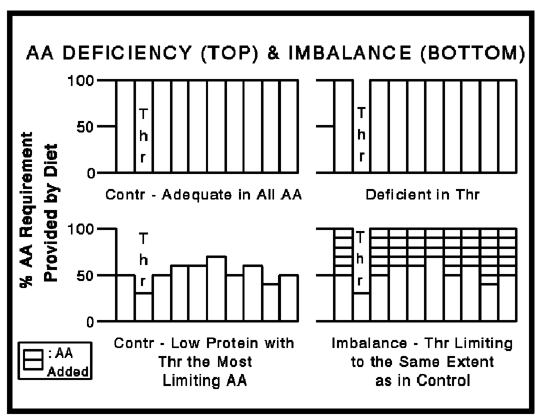
a) Does not imply essentiality or dispensability.
b) Thus, might be a better term to describe N that does not have to be provided by specific compounds.

AMINO ACID DISPROPORTION

☛ Because of an increased availability/use of crystalline AA (e.g., in addition to Met, feed grade Lys, Trp & Thr are currently available) in recent years, a chance of formulating diets containing disproportionate amounts of AA may increase in the future!

An excellent reference on the topic: "Harper, A.E., N.J. Benevenga and R.M. Wohlhueter. 1970. Effects of ingestion of disproportionate amounts of amino acids. Physiol. Rev. 50:428-558."

1. **Amino Acid Deficiency & Imbalance**



A. Difference between the "deficiency" & "imbalance" (Redrawn from Harper et al., 1970).
B. Deficiency:

1) Simply, a protein or diet is deficient in any one of the indispensable AA.
2) Animals can only utilize various AA for protein synthesis up to the level of the deficient AA in the diet/protein.
3) Observe a prompt reduction in feed intake.
◦ Can be referred to as a "naturally" unbalanced protein or diet.

C. Imbalance:

1) Caused by addition of one or more amino acids other than the one that is limiting the growth of animals.
2) Pigs & rats prefer a protein-free diet to an imbalanced-diet.
◦ Can be referred to as a "man-made" unbalance or disproportion.

☛ Both can be corrected by supplying the "growth-limiting" amino acid!

2. **Amino Acid Toxicity**

A. Caused by addition of a large amount of individual amino acid(s).
B. Depending on AA, may see specific gross or histopathological lesions.
C. Cannot be corrected by simply adding other amino acids.
D. Order of toxicity? - Met (most toxic) → Trp → His → Tyr → Phe → Cys → Leu → Ile → Val → Lys → Thr (least toxic). (Signs? - e.g., with 2% Met, may see liver & pancreas damages, darker spleen, etc.)

3. **Amino Acid Antagonism**

A. One AA can affect the requirement of another by interfering with the metabolism.
B. Example? Antagonisms among structurally similar AA - Between Lys and Arg (basic AA), and among Val, Leu & Ile (branched-chain AA).
C. Can be corrected/prevented by adding only a structurally similar AA(s).

4. **Amino Acid Interactions?**

A. e.g., Effects of amino acid interactions on chicks[a]:

	Ad libitum			Force fed		
Diet	Gain, g/d	Feed, g/d	F:G	Gain, g/d	Feed, g/d	F:G
Thr imbalance:						
Basal	9.1	18.8	2.05	9.3	17.8	1.91
+ 30 g Ser/kg	7.6*	16.2*	2.15	9.9	17.8	1.80
BCAA antagonism:						
Basal	9.8	21.7	2.67	9.6	21.5	2.23
+ 38 g Leu/kg	6.8*	18.4*	2.20*	8.7	21.5	2.47
Lys-Arg antagonism:						
Basal	9.9	18.4	1.86	8.6	17.4	2.02
+ 12 g Lys/kg	5.5*	15.2*	2.76*	7.4*	17.5	2.37*

[a]Data compiled by Austic, 1986. Biochemical description of nutrient effects. In: C. Fisher & K.N. Boorman (Ed.). Nutrient Requirements of Poultry and Nutritional Research. pp 59-77. Butterworths, London.

B. Most amino acid interactions can cause a reduced feed intake! - Perhaps, ↓ limiting AA in plasma may be a biochemical signal leading to ↓ feed intake because the infusion of small amounts of some AA prevented feed intake depression associated with the imbalance.

C. Imbalances:

1) "Force-feeding" generally results in normal growth rate & body composition?
2) Thus, "poor" performance associated with the imbalance seems to be due almost exclusively to the reduced feed intake?

(3) Antagonisms - The biochemical basis for BCAA antagonism is not known, but it seems to have specific effects in addition to effects on feed intake:

1) Excess Leu:

a) ↑ the activity of muscle BCAA amino transferase in chicks, hepatic BC α-ketoacid dehydrogenase in rats.
b) ↑ the oxidation of Ile & Val in chicks & Ile in rats.
☛ A possible loss of significant amounts of Ile & Val via catabolism may explain the failure of force-feeding to prevent the adverse effects!?

2) Lys-Arg antagonism in chicks:

a) Signs? ↓ creatine synthesis, ↑ activity of kidney arginase & urea excretion, and ↑ urinary excretion of Arg when Lys levels are highly excessive.
b) Lys & Arg share a membrane-bound carrier, and excess Lys inhibits the binding of Arg to the carrier, ∴ ↓ reabsorption (kidneys) & ↑ excretion. (But, a moderate excess of Lys may not ↑ Arg excretion!)
c) ↑ urea excretion is probably due to Arg degradation via kidney arginase because the chick lacks a functional urea cycle.

5. **Factors Affecting Amino Acid Disproportion?**

A. Degree of disproportion:

1) Imbalance - Caused by as little as 1/5 of the requirement?
2) Antagonism & toxicity - With at least twice the requirememnt?

B. Age - Older animals can tolerate better.
C. Adaptation - Some can show some adaptation, but can be dependent on the degree of amino acid disproportion.

PROTEIN QUALITY

◦ *A good reference: "Hackler, L.R. 1977. Methods of measuring protein quality: A review of bioassay procedures. Cereal Chem. 54:984. Also, see Maynard et al. (1979) & Jurgens (2002)."*

1. **Protein Quality**

A. Simply refers to the amount and ratio of indispensable amino acids present in a protein.
B. Protein quality & satisfying the requirement

Protein quality	Requirement[a]
100	1 x
50	2 x
25	4 x
12.5	8 x
0	Infinite

[a]The amount of protein needed to satisfy the requirement.

☛ Low- to med-quality protein sources would have a significant impact on the amount needed to satisfy the requirement!

2. **Protein Quality is not Synonymous with Efficiency of Utilization**

A. Protein quality is "inherent" feature of protein, and Protein quality determined by one set of conditions/situations may be different from the one determined by others. Thus, important to state conditions of the test!
B. On the other hand, the efficiency of utilization can be affected by many factors such as: 1) protein quality & intake, 2) dietary energy content, and other nutrient concentrations, 3) environment, 4) species, breeds, strains & sex, 5) previous nutrition, 6) age, 7) health status, etc.

3. **Some Methods to Assess the Protein Quality - Examples**

A. Choosing an Assay?

1) Need to consider validity, precision, proportionality, costs, simplicity, etc.
2) An assay has no value unless it can relate back to the target species!

B. Biological value (BV):

1) A measure of the relationship of protein/N retention to protein/N/ absorption.
2) $$\text{BV (\%)} = \frac{\text{N intake - (Fecal N - Metabolic fecal N) - (Urinary N - endogenous urinary N)}}{\text{N intake - (Fecal N - Metabolic fecal N)}} \times 100$$
3) Egg protein is considered to have the highest BV of natural sources (94% +).
4) Generally, BV is higher for animal sources (60 to 80% +) vs plant sources (40 to 65%).

C. Net protein value (NPV):

1) BV does not take into account differences in digestibility from one protein to another.
2) When digestibility as well as BY data are used, a NPV can be computed, "NPV = BV x Digestion coefficient."
3) NPV is corrected for a very low or very high digestibility and is a more useful!?

D. Net protein utilization (NPU):

1) Similar to BV (i.e., NPU = Retained N/Food N), but measures by comparing body N contents - Feed a test protein to one group & a protein-free diet to other group.
2) $$\text{NPU} = \frac{\text{(Body N with test group) - (Body N of non-protein group)}}{\text{N intake by test group}}$$
3) An advantage? - A brief test period (7 to 10 days) with a minimum of measurements. (But, measuring body N can be a problem for some!)

E. Protein efficiency ratio (PER)

1) Use a feeding trial to compare protein sources in terms of gain in animal body weight per gram of protein or nitrogen fed.
2) $$\text{PER} = \frac{\text{Body weight gain, g}}{\text{Protein consumed, g}}$$
3) Problem? Does not make an allowance for maintenance - A protein may meet the maintenance needs, but may not promote growth?

F. Net protein ratio (NPR):

1) Simply the weight loss of a negative control group added to the weight of gain of the test group, divided by the protein consumed by the latter - Similar to PER.
2) $$\text{NPR} = \frac{\text{Weight gain on test group + Weight loss of non-protein group}}{\text{Weight of test protein group}}$$
3) Problem? Among others, feeding a protein-free diet!?

G. Slope ratio assay (Relative Protein Value, RPV):

1) Feed several concentrations protein or N from the test & standard/reference protein sources & measure response criterion/criteria.
2) Only use the linear portion a curve in computation of the slope assay value, i.e., b (Test source) ÷ b (Standard/reference source).
3) Problems? Perhaps, the use of many diets/animals & may not have a common intercept would be the main ones, but it is a very reliable method.

4. **Assessing Protein Quality for Ruminants**

A. Assuming for years that protein leaving the rumen and entering the lower digestive tract was of good quality and adequate to meet the essential amino acid needs.
B. But, a feedstuff protein of good quality may be reduced via microbial protein degradation and synthesis.
C. Some instances, protein leaving the rumen could be inadequate to meet the amino acid needs of the high producing ruminant.
E. Dietary protein:

1) Either degraded in the rumen with partial or total conversion to microbial protein, or escape breakdown as undegraded protein - "Bypass" or "undegraded" protein.
2) Toe major factors influencing the rate of protein degradation in the rumen, "solubility of feedstuff protein" and the "rate of passage through the rumen."
3) Approximately 60% of the various feed proteins are broken down in the rumen by microbes their component amino acids and then to ammonia (NH3), and the other 40% passes on to the omasum.

4) Methods to protect high quality protein from excessive ruminal degradation? - e.g., a) Heat treatment, b) treatment with formaldehyde or tannins, c) encapsulation of amino acids, d) use of amino acid analogs, and e) control microbial metabolism in the rumen.

F. Metabolizable protein or amino acids (also called "absorbable protein"):

1) Can be defined as the quantity of protein digested or amino acid(s) absorbed in the postruminal portion of the digestive tract of cattle and other ruminants.
2) In nonruminants, it has the same meaning as apparent digestible protein or absorbable amino acids.
3) But, in ruminants, metabolizable protein differs from digestible protein in that it reflects:

a) The quantity of feed protein consumed that escapes degradation in the rumen.
b) The quantity of degraded protein reformed into rumen microbial protein.

4) Major advantages of using the metabolizable protein system?

a) Its greater accuracy in predicting protein needs of cattle.
b) It gives a better insight into the individual amino acid needs of cattle and how these needs can best be supplied by a combination of performed protein and NPN.

PROTEIN AND(OR) AMINO ACID REQUIREMENTS

1. Introduction

A. Protein requirements:

1) Pigs & poultry do not have "protein" requirements!
2) Instead, they require amino acids!
3) e.g., In general, pigs depend on diets for 10 indispensable AA & sufficient amounts of nonspecific N to synthesize dispensable AA.

B. The use of "crude protein" values:

1) Often used for characterizing feedstuffs & expressing the dietary requirement for a "nitrogen fraction."
2) Reasons? Perhaps, tradition, convenience & ease of analysis (vs AA).
3) May be appropriate to use when:

a) Using a certain combination of feed ingredients (e.g., corn & soy) or
b) Using the "ideal protein" or balanced protein.

C. Ways to express the requirement:

1) % of diet - Works well if variations in the energy density are minimal.
2) g/day - Works well when intake is restricted, and if a certain intake level can be assured.
3) g/kg/day or g/kg$^{.75}$/day - Accounts the body size or metabolic body size, ∴ theoretically the best.
4) g/Mcal DE or ME - Important, or even necessary, when large differences in the energy density exist.
5) % crude protein for AA - Have to know the exact protein requirement.

☛ 1° objective? - "*To make sure that the animal can consume adequate daily nutrient allowances for optimum performance!*"

2. **Estimating the Requirement**

◦ Can be estimated in one of the two ways, a factorial or empirical method (or a combination of two in some instances).

A. Factorial method:

1) Estimation by the sum of requirements for maintenance and growth.
2) A simple example for a 50-kg pig - Assuming a pig is growing at a rate of 450 g of lean tissues/day:

a) Maintenance:

▹ 50 kg x 16% protein x 12% recycled/d x 6% loss of recycled protein = **58 g protein** (maintenance requirement)

b) Growth:

- 450 g lean x 23% protein = **104 g protein/d** (needed for growth)

c) Thus, the requirement is **162 g protein/d** (58 g + 104 g).

d) Then, must consider:

(1) Efficiency of utilization of absorbed nitrogen or protein (e.g., BV = N retained/N absorbed) - assume corn-soy = 0.60 or 60% in this example.
(2) Digestibility - Assume corn-soy = 0.75 or 75% in this example.

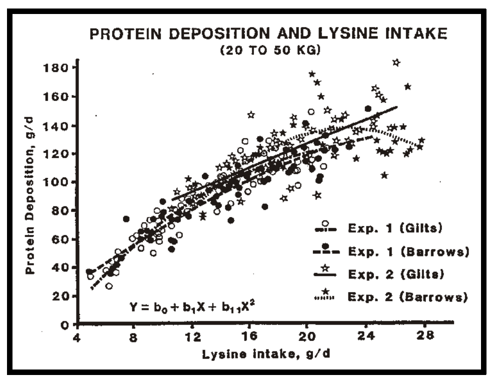
e) Thus,

- 162 ÷ 0.60 = 270 g digested protein/d.
- 270 ÷ 0.75 = 360 g dietary protein/d.

f) Conversion to a percentage of diet:

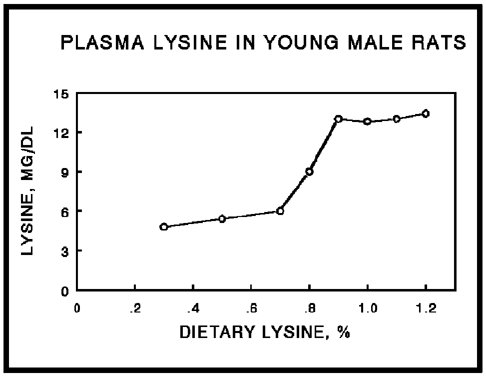
- Energy intake = 8 Mcal DE/d.
- 8 ÷ 3.4 (Mcal DE/kg) = 2.35 kg feed/d.
- ∴ 360 ÷ 2.35 = 153.2 g/kg diet or **15.32%** ⇐ Protein requirement!

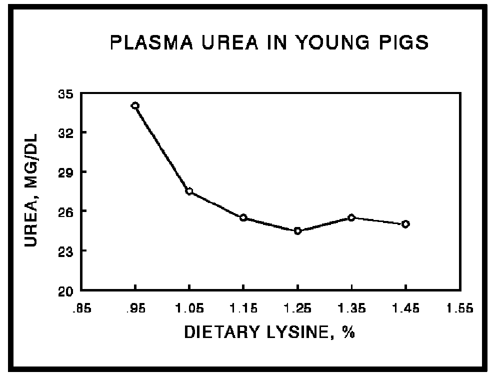
- Factorial method - Not absolute, i.e., many assumptions/estimations are involved in the process, ∴ influencing the requirement estimate!



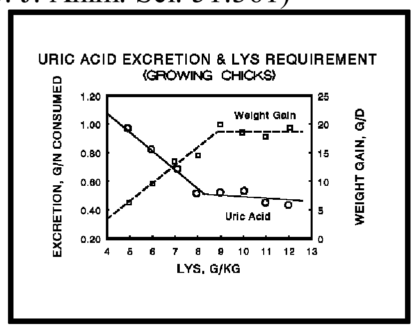
B. Empirical method:

1) Examine response patterns of animals to various levels (graded levels or intakes) of protein or amino acids.
2) Various response criteria have been used in the past - e.g., Weight gain, feed efficiency, nitrogen retention, protein deposition, plasma amino acid & urea, etc.
3) Some examples:





a) Protein deposition rate: (Chiba et al., 1991. J. Anim. Sci. 69:708)
b) Plasma amino acid (lysine): (Redrawn from Morrison et al., 1961. Can. J. Biochem. Physiol. 39:1675)
c) Plasma urea: (Redrawn from Lewis et al., 1980. J. Anim. Sci. 51:361)
d) Uric acid excretion or plasma uric acid for the bird - e.g., Miles and Featherston, 1974. Proc. Soc. Exp. Biol. Med. 145:686-689.



4) Difficulties associated with the empirical method?

a) Defining a point of maximum response? - Can be done easily mathematically or statistically, but "biologically?"
b) The response can be dependent on a number of factors such as availability of amino acids, sex and(or) genetics, other nutrients, etc.

C. Alternative - Modeling? See NRC (1998), Chiba (2000), and others on the topic.

3. Requirements

A. Amino acid requirements for nonruminant species (see appropriate "Nutrition & Feeding" sections for details) - Lysine and(or) sulfur-amino acids are likely to be the first or second limiting amino acid in many practical diets for nonruminant animals.

Species	CP, %	Lys, %	S-AA, %
Swine (NRC, 1998):			
Growing	13-26	0.60-1.50	0.35-0.86
Gestating sows/boars	11-14	0.52-0.60	0.36-0.42
Lactating sows	16-19	0.82-1.03	0.40-0.49
Poultry (NRC, 1984):			
Chickens, growing	15-18	0.45-0.85	0.42-0.62
Chickens, laying	12.5-18.8	0.58-0.86	0.48-0.73
Broilers	18-23	0.85-1.10	0.60-.90
Turkeys, growing	14-28	0.65-1.60	0.45-1.05
Horses (NRC, 1989): (In total diet, DM)			

Growing (up to 2 yr-old)	10.4-14.5	0.42-0.68	-
Working	9.8-11.4	0.35-0.40	-
Pregnant	10.0-10.6	0.35-0.37	-
Lactating	11.0-13.2	0.37-0.46	-
[Pagan (1998) - Growing, g/Mcal DE	42.5-50.0	1.7-2.1	-]
Fish (NRC, 1993):			
Channel catfish	32	1.43	0.64
Rainbow trout	38	1.80	1.00
Pacific salmon	38	1.70	1.36
Common carp	35	1.74	0.94
Tilapia	32	1.43	0.90

B. Variations in estimates - e.g., NRC (1988) vs ARC (1981; UK) & SCA (1987; Australia):

1) ARC & SCA - Tend to be higher than the NRC.
2) e.g., Lysine requirements (%):

	ARC	SCA(♂)	SCA(♀)	NRC
15 (or 20)-50 kg	1.19	1.07	0.95	0.75
50-90 (or 110) kg	0.85	0.85	0.85	0.60
Gestating sows[a]	0.43		0.43	0.43
Lactating sows	0.63		0.63	0.60

[a]Based on 2 kg/d (ARC & SCA) or 1.9 kg/d (NRC).

☛ Perhaps, a reflection of numerous factors that can affect the requirement!?

[*See Lewis (1991) in Miller et al. (1991) and Chiba (2000) in Theodorou & France (2000) for the comparison of NRC & ARC.*]

C. Factors that affect the requirement:

1) Stage & levels of production - Growth, gestation, lactation, etc.
2) Genetic capacity - Breeds, strains, sex, etc.
3) Response criteria used - e.g., Protein or AA requirement for a maximum leanness is higher than that required for a maximum rate of weight gain.
4) Health/disease.
5) Any factors that affect feed intake such as energy density & environmental temperatures, . . . , etc.

D. Satisfying the requirement (e.g., pigs):

1) Amino acids (%) in corn and corn+soybean meal (44% CP) vs amino acid requirements of a 25-kg pig (. . . based on 1988 NRC):

Amino acid	Corn	Corn+SBM[a]	Requirement

Arg	0.43	0.95	0.25
His	0.27	0.43	0.22
Ile	0.35	0.66	0.46
Leu	1.19	1.58	0.60
Lys	0.25	0.75	0.75
Met + Cys	0.40	0.54	0.41
Phe + Tyr	0.84	1.35	0.66
Thr	0.36	0.61	0.48
Trp	0.09	0.19	0.12
Val	0.48	0.76	0.48

[a]Formulated to meet the lysine requirement.

2) Cereal grains (70-80% of the diet) provide over half of the total AA:

   a) The Lys content in grain is low, thus nearly always the first limiting AA in swine diets.
   b) Analysis is important because of considerable variations in nutrient contents of grains - e.g., Corn, 0.20 -0.30% Lys vs the NRC value of 0.25% Lys.

3) Soybean meal:

   a) High in Lys (& other AA) content.
   b) Thus, complement corn very well in meeting the AA requirements.

4. **Protein/Amino Acid Sources**

A. The nutritional value of ingredients depends on "digestibility of protein" and "biological value (efficiency of utilization)" of digested protein. [See Chiba (2001) in Lewis & Southern (2001) for "Relative feeding values and maximum incorporation rates of some protein sources."]

B. Proportion of Lys in protein: [Compiled by Cromwell, Univ. of Kentucky; Also, see Chiba (2001) in Lewis & Southern (2001)]

Feedstuff	CP, %	Lys, %	Lys, % CP
Blood meal	86	7.4	8.7
Dried skim milk	33	2.6	8.2
Dried whey	13	1.05	8.1
Fish meal, menhaden	61	4.80	7.9
Brewers dried yeast	45	3.20	7.1
SBM, dehulled	48	3.10	6.5
SBM	44	2.80	6.4
Canola meal	38	2.30	6.1
Meat & bone meal	50	2.90	5.8
Meat meal	56	3.10	5.5
Alfalfa meal	17	0.80	4.7
Wheat middlings	16	0.70	4.4

Cottonseed meal	41	1.70	4.1
Sunflower meal	47	1.70	3.6
Brewers dried grains	26	0.90	3.5
Wheat, hard	12	0.42	3.5
Wheat, soft	11	0.35	3.2
Triticale	16	0.50	3.2
Barley	11	0.35	3.2
Coconut meal	20	0.64	3.2
Peanut meal	49	1.45	3.0
Oats	12	0.36	3.0
Sesame meal	45	1.30	2.9
Distillers grains	27	0.70	2.6
Corn gluten feed	23	0.60	2.6
Sorghum	9	0.24	2.6
Corn	9	0.24	2.6
Feather meal	84	1.65	1.9

1) The proportion of Lys in protein gives a crude assessment of the biological value because it is the first limiting AA in many swine diets (& others?).
2) Possible problems in using these values:

   a) The differences in digestibility.
   b) The differences in availability (e.g., heat damaged feedstuffs).
   c) May be limiting in other AA (e.g., Trp in meat meal).

C. Other factors affecting the nutritional value of protein sources? - e.g., Stability, presence of anti-nutritional factors, interactions among nutrients and with non-nutrient factors, palatability, etc.

5. Amino Acid Digestibility or Availability

A. Apparent ileal digestibilities (%) of AA in swine feedstuffs: (NRC, 1998)

Feedstuff	Lys	Trp	Thr	Met
Barley	68	70	66	80
Blood, meal, spray/ring dried	91	88	86	85
Blood, plasma	87	92	82	64
Canola meal	74	73	69	82
Corn	66	64	69	86
Cottonseed meal, sol. ext.	61	67	63	73
Fish meal, menhaden	89	79	85	88
Meat & bone meal	74	60	70	79
Oat groats	79	80	76	85
Oats	70	72	59	79
Peanut meal, sol. ext.	78	73	74	85
Rye, grain	64	67	59	76
Sorghum	62	75	68	81

SBM, dehulled	85	81	78	86
SBM	85	80	78	86
Triticale	76	74	69	76
Sunflower meal, without hulls	74	76	71	87
Wheat, soft red winter	73	81	72	85

B. The swine industry is moving toward expressing the requirement & formulating diets based on the AA availability (or often in terms of "ileal digestibility"). (Poultry industry has been using the available values for a while.)

IDEAL PROTEIN

1. **Introduction**

A. To deposit "1 g" of protein or lean, relative amounts or proportions of different (indispensable) AA needed to deposit that amount should be the same. (Must make an assumption that age, sex & others have no effect on proportions of AA in tissue proteins or lean tissues!)
B. It is possible that some protein or a mixture of proteins may supply AA in exactly those proportions required by the animal.
C. For different classes (i.e., differences in the body wt, sex, breed, etc.):

1) Different amounts of the "balanced AA" may be required.
2) But, the quality (or AA balance/proportion) of protein would be the same!

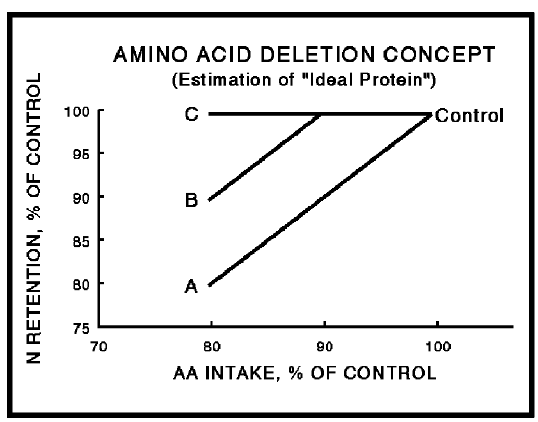
D. Definition of ideal protein?

"*A protein which supplies AA in exactly the proportions required by the pig or poultry and which may, therefore, be utilized fully under appropriate circumstances!*"

E. Should be the most efficient protein or diet because there would be no deficiency or excess of AA.

2. **Estimation of "Ideal Protein"**

A. Estimation of AA requirements by a "dose-response" type experiment - e.g., Lys: found to be 6-8 g/100 g protein, ∴ Lys should be ≈ 7 g/100 g of protein.
B. Estimation via experiment designed for that purpose - e.g., "Amino acid deletion concept" (Wang & Fuller, 1989. Br. J. Nutr. 62:77.).

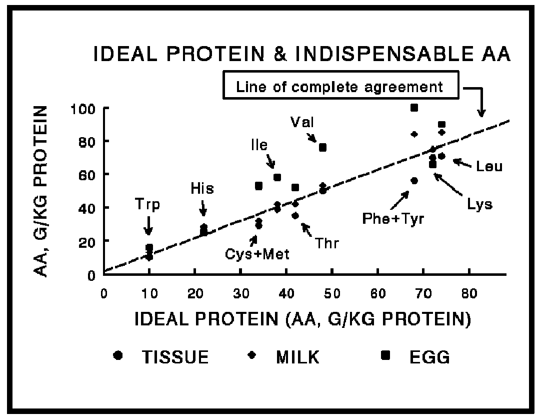


◦ This method is based on the assumption that the removal of a non-limiting AA has no effect on N-retention (NR):

a) The removal of the first limiting AA reduces NR (as **A** in a figure).
b) If the removal of AA does not reduce NR (as in **C**), the quantity removed was excess relative to the first limiting AA.
c) If the removal of AA results in reduced NR (as in **B**), then the proportion that could have been removed without reducing NR can be interpolated proportionately.

C. Consider both A (dose-response) & B (via experiments), and also the AA composition of body tissues:

1) Why body tissues?



a) Assuming a complete utilization of protein, a major end product should be body protein, thus, body AA pattern may dictates AA pattern required.
b) Proteins with high BV tend to resemble in their AA composition in tissues - “Ideal Protein & Indispensable AA” [Fuller and Chamberlain, 1985. In: Cole & Haresign (Ed.)].

▹ Efficiency of utilization (BV)? Sow's milk - 0.90 or 90%, and egg protein - 1.00 or 100%.

2) AA requirements for maintenance & protein accretion:

a) Proportions needed differ, but the N requirement for maintenance is a small proportion of overall needs (about 30% in normally growing pigs).
b) Thus, likely to have no or small influence for overall pattern needed.

3. Ideal Protein

A. Ideal protein or balanced protein (relative to Lys in %) in pigs:

Item	ARC (1981)/ SCA (1987))	NRC (1998)[a]
IDAA:		
Arg	-	48
Lys	100	100

Met+Cys	50	55
Trp	14	18
Thr	60	60
Ile	54	54
Leu	100	102
His	33	32
Phe+Tyr	96	93
Val	70	68
Total IDAA, g/kg CP	404	
DAA (total), g/kg CP	596	

[a]For protein accretion.

B. Ideal protein in poultry (relative to Lys)*:

	ARC, 1975	NRC, 1977	NRC, 1994	AEC, 1978[a]	Scott, 1982[b]	SCA, 1983	Authors
Lys	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Arg	0.94	1.20	1.10	1.05	1.00	0.90	1.05
Gly & Ser	1.27	1.25	1.14	1.41	-	-	1.31
His	0.44	0.29	0.32	0.39	0.40	0.35	0.40
Ile	0.78	0.67	0.73	0.72	0.80	0.50-0.76	0.72
Leu	1.33	1.13	1.09	1.33	1.20	1.03-1.72	1.25
S-AA	0.83	0.78	0.72	0.76	0.72	0.75	0.75
Phe & Tyr	1.44	1.12	1.22	1.23	1.28	1.20	1.21
Thr	0.67	0.63	0.74	0.62	0.64	0.60	0.63
Trp	0.19	0.19	0.18	0.17	0.18	0.19	0.18
Val	0.89	0.68	0.82	0.79	0.64	0.68-0.94	0.79

* Based on: Boorman, K. N., and A. D. Burgess. 1986. Responses to amino acids. In: C. Fisher and K. N. Boorman (Ed.). Nutrient Requirements of Poultry and Nutritional Research. pp 99-123. Butterworths, London. Added the data (based on 3- to 6-wk old broilers) from NRC (1994).]
[a]AEC = Document No. 4, Animal Feeding. Commentary, France, AEC; [b]Scott et al., 1982. Nutrition of the Chicken.

B. Once established the "ideal balance," the next step is to determine the "ideal protein requirement" for each class of swine.

4. Deviations from the Ideal Protein/Pattern

A. Theoretically:

1) Amino acids are likely to be utilized less efficiently.
2) Can create amino acid disproportions such as deficiency, imbalance, antagonism, and possibly toxicity.

B. Effect of moderate oversupply (. . . assuming that all AA are supplied to meet or exceed the requirements)?

1) Effects of excess Arg on performance of G-F pigs: (Anderson et al., 1984. J. Anim. Sci. 58:362)

% NRC for Arg:	500	400	300	200
Arg:Lys (27-44 kg):	1.43	1.14	.86	.57
Arg:Lys (44-97 kg):	1.48	1.18	.89	.59
27-44 kg:				
Feed, kg/d[a]	1.77	1.92	1.87	1.84
Gain, kg/d	0.59	0.64	0.63	0.63
Gain:feed	0.338	0.335	0.335	0.344
44-97 kg:				
Feed, kg/d	3.09	3.16	3.19	3.03
Gain, kg/d[a]	0.77	0.81	0.82	0.74
Gain:feed[b]	0.251	0.257	0.257	0.244

[a]Quadratic effect, $P < .05$; [b]Quadratic effect, $P = 0.10$.

- Reduction of the Arg content of typical diets resulted in little or no improvement in performance of pigs.

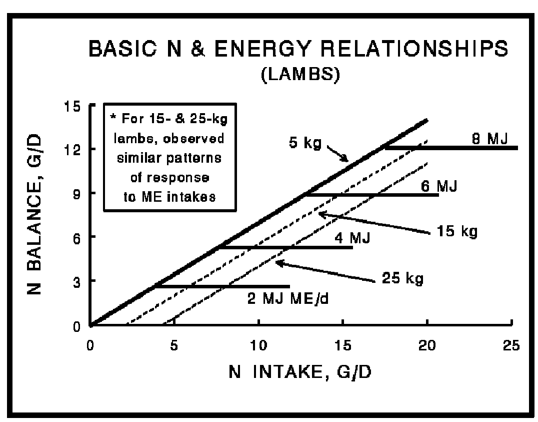
2) Similar results with Arg & Leu have been observed by others - e.g., Southern & Baker, 1982. J. Anim. Sci. 55:857, and Cromwell et al., 1982. J. Anim. Sci. 55(Suppl. 1):41 (Abstr.).
3) The bottom line?

   a) Moderate excesses are unlikely to produce adverse effects on performance under practical conditions (e.g., when using corn-soy type diets).
   b) Using many protein sources (especially, byproducts) or crystalline AA, then may need to pay an attention!

AMINO ACIDS AND ENERGY

1. The Basic N & Energy Relationships

- Nitrogen retention and nitrogen intake in lambs: (Redrawn from Black and Griffiths, 1975. Br. J. Nutr. 33:399)

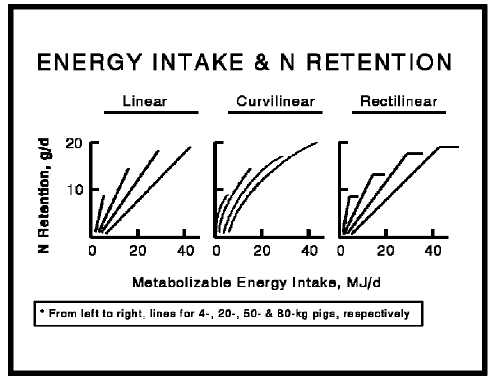


1) In the initial phase:

   a) N retention is dependent on N intake & independent of energy intake.
   b) A slope of line is a measure of the BV of protein.
   c) A line shifts to the right as the weight increases because of the increase in endogenous N losses.

2) In the second phase:

   a) N retention is dependent on energy intake and live weight.
   b) i.e., at a given wt, an additional N intake has no effect unless additional energy is supplied.

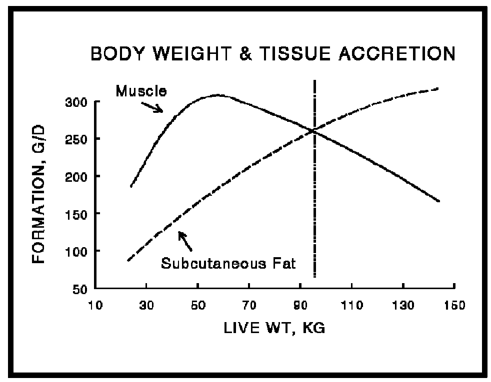


2. **Three Possible N & Energy Relationships**

A. Linear, curvilinear or rectilinear:

◦ Energy intake and nitrogen retention: (Redrawn from Williams, 1980. Proc. Aust. Soc. Anim. Prod. 13:126 & ARC, 1981)

B. Body weight and tissue accretion in pigs: (Redrawn from Just, 1984. J. Anim. Sci. 58:740)

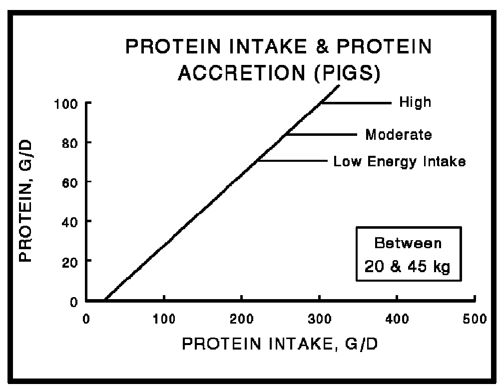


1) Up to ≈ 50 kg, the rate of muscle deposition is almost linear.
2) Ths, protein (AA) and energy requirements probably increase linearly during this phase.

B. Young animals (e.g., pigs up to 50 kg or so):

1) Protein/energy intake & protein deposition in pigs weighing 20 to 45 kg: (Campbell et al., 1985. Anim. Prod. 40:489)

   a) As the energy intake increases, protein deposition (PD), and also the protein requirement increase.
   b) Increases in PD & protein requirement/unit ↑ in energy intake are constant.

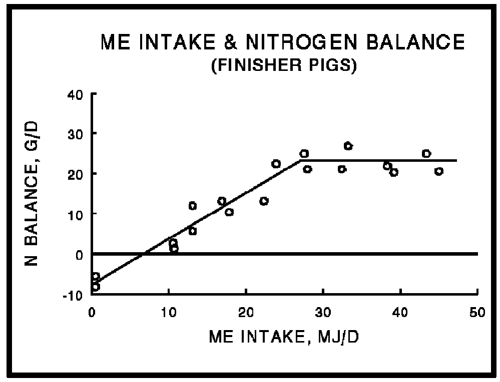


2) The bottom line? - The relationship between energy intake & PD (& protein intake) in young animals (e.g., pigs ≤ 50 kg) is a linear!

D. Implication(s) of a linear relationship in young animals (e.g., pigs ≤ 50 kg):

☛ *"The pig's potential for protein growth from birth to 50 kg seems to lie beyond the upper limit of appetite (SCA, 1987)."*

1) Diets of high energy density can be fed ad libitum without excessive fat deposition or reducing the efficiency of feed utilization.
2) A single diet can be fed to meet both energy and amino acid requirements.
3) Expressing amino acid requirements in terms of energy is appropriate.



E. Older animals (e.g., finishing pigs):

1) "ME intake and N Balance (Finisher Pigs): (Dunkin et al., 1984. Proc. Aust. Soc. Anim. Prod. 15:672)

   a) Protein/AA intake was not a limiting factor, and avg wt was 73.8 kg.
   b) N balance ↑ up to 27.6 MJ ME/d (6.6 Mcal ME/d) & no response with further increases.

2) Energy intake and protein & fat accretions in ♀ (g/d): (Campbell et al., 1985. Anim. Prod. 40:497.)

MJ/d	Protein	Fat
23	63.4	125
27.5	84.5	208
33	103.0	279
37.5	102.0	332
39.2	99.0	371

☛ The bottom line?

   a) The relationship between energy intake and protein deposition in larger/older animals may not be a linear!
   b) Larger animals consume more energy than they need for maximum/optimum protein accretion, and excess energy can be deposited as fat!
   c) Can reduce energy intake of larger pigs without adverse effect on protein accretion . . i.e., can/should use a "restricted energy or feeding" practice!?

AMINO ACIDS AND ENVIRONMENT

1. **Amino Acids & Thermal Environment**

A. Dietary lysine & temperatures: [Stahly & Cromwell, 1987. J. Anim. Sci. 65 (Suppl. 1):299)]

	10 °C	22.5 °C

Lys, %:	0.50	0.65	0.80	0.95	0.50	0.65	0.80	0.95
Lys intake, g/d[a]	13.6	17.6	21.8	25.0	11.7	15.3	17.8	22.6
Growth (26-92 kg), g/d:								
Live wt[b]	762	788	792	806	691	751	748	802
Water[c]	316	337	334	352	269	325	325	358
Protein[d]	112	116	120	122	101	112	113	121
Fat	307	306	309	302	299	286	281	291
Fat, %[e]	32.8	31.9	31.4	30.4	34.7	31.1	30.8	30.1

[a]Temperature & Lys effects, $P < 0.01$; [b]Temperature x Lys, $P = 0.15$; [c]Temperature x Lys, $P < 0.05$; [d]Temperature x Lys, $P = 0.10$; [e]Temperature x Lys, $P = 0.13$.

1) At low environmental temperatures:

   a) Pigs increase feed intake to meet energy requirement, ∴ increasing amino acid intakes.
   b) Thus, can reduce amino acid content of the diet.

2) At high environmental temperatures:

   a) Pigs reduce feed intake, ∴ reducing amino acid intakes.
   b) Thus, need to increase amino acid content of the diet.

B. The bottom line?

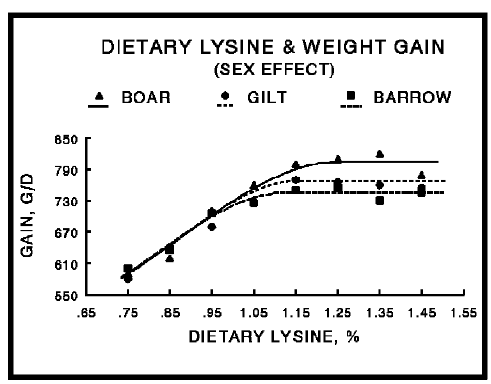
1) Adequate daily amino acid intakes is the "key" to achieve optimum performance of animals.
2) Thus, AA levels must be adjusted for any factors that influence feed intake.

☞ Adjusting amino acids is necessary for changes in dietary energy densities too, not just for changes in temperatures!

GENDER/TYPE OF ANIMALS AND AMINO ACID REQUIREMENTS (e.g., PIGS)

1. **Effect of Sex**

A. Dietary lysine and weight gain for boars, gilts and castrates: "Fuller & Chamberlain, 1985. In: Cole & Haresign (Ed.)."
B. Potential for lean deposition - Boars > gilts > castrated males (barrows).

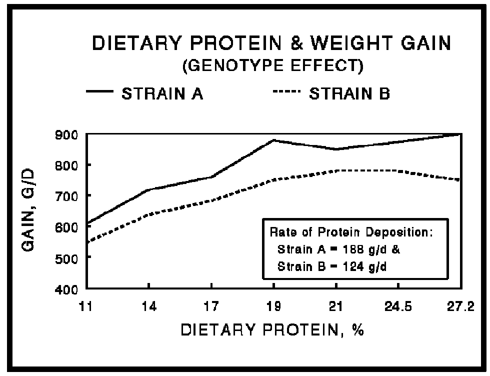


☛ Because of this (& others - e.g., animal welfare issue), raising boars for meat production is popular in Europe and Australia . . . Not in the US for various reasons though!

C. Protein or AA requirements are reflection of the potential for protein or lean accretion.

2. **Type of Pigs**

A. Dietary lysine and weight gain: "Campbell, 1988. Hog Farm Management 25(5):34."



☛ Strain A, which has a higher potential for protein deposition, responded to higher dietary protein concentrations, thus, they have a higher protein requirement!

B. The bottom line?

1) A wide variation in the genetic potential for growth (lean growth) exist in today's swine industry.
2) Amino acid requirements are dependent on the genetic potential for protein (or lean) deposition.
3) Thus, for the efficient utilization of amino acid(s) (& also for optimum lean accretion), may have to formulate diets accordingly for sex, type of pigs, etc.

REPARTITIONING AGENTS AND AMINO ACIDS

1. **Repartitioning Agents**

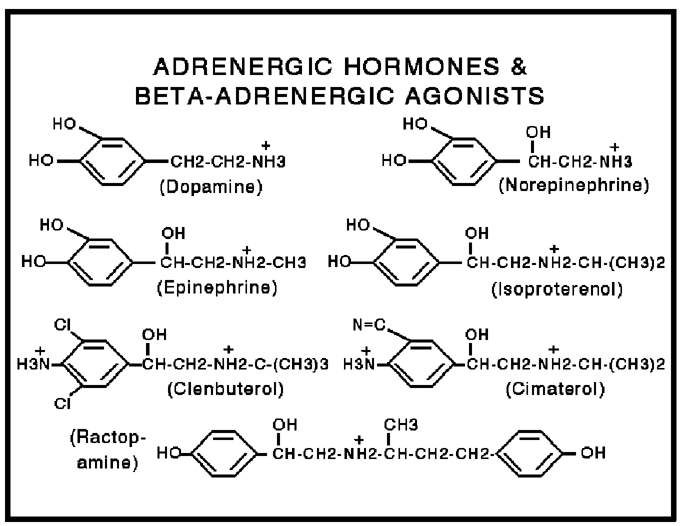
A. Partition nutrients away from fat deposition & toward lean muscle (or protein) accretion!

B. Examples:

1) pST (porcine somatotropin):

a) Can increase muscle deposition & reduce fat deposition.
b) Must be injected daily or use implants [weekly or monthly (?)].

2) β-adrenergic agonists (dietary supplement):



a) Similar to catecholamines, which may function as hormones or neurotransmitters.
b) May or may not increase muscle deposition, but ↓ fat deposition.

2. **Effects of Repartitioning Agents - e.g., Effect on Pigs**

	β-agonists	pST
Weight gain	+ 8	+ 22
Feed to gain	- 10	- 28
Loin muscle area	+ 12	+ 14
Backfat	- 12	- 26
Carcass lean	+ 8	+ 21
Protein accretion		+ 31
Heat production		+ 8
MEm		+ 17

2. **Effects of Dietary Lysine**

A. pST and dietary lysine: [Goodband et al., 1989. J. Anim. Sci. 67(Suppl. 2):122 & 123]

		4 mg pST				8 mg pST			
Lys, %:	0 .80	0.80	1.00	1.20	1.40	0.80	1.00	1.20	1.40
Lys, g/d[abcd]	25.1	23.3	27.0	32.6	38.7	22.5	26.4	30.1	36.5
Feed, kg/d[abc]	3.14	2.92	2.70	2.72	2.77	2.82	2.64	2.51	2.61
Gain, kg/d[ab]	1.14	1.27	1.30	1.23	1.31	1.24	1.27	1.30	1.43
Feed:gain[e]	2.76	2.29	2.09	2.22	2.11	2.28	2.08	1.93	1.83
PU, mg/dL[acd]	35.6	21.0	17.8	19.7	22.1	17.0	12.0	12.9	12.0
LMA[a]	35.4	39.8	37.7	37.7	39.8	40.2	41.7	45.1	43.8
BF[a]	2.62	2.32	2.38	2.31	2.27	2.24	2.05	2.11	1.85

[a]Linear effect of pST, $P < 0.05$; [b]Linear effect of Lys, $P < 0.05$; [c]Quadratic effect of Lys, $P < 0.05$; [d]Quadratic effect of pST, $P < 0.05$; [e]pST x Lys, $P < 0.05$.

B. The bottom line:

1) Repartitioning agents increase the rate of protein accretion.
2) Dietary amino acid contents may need to be adjusted concomitantly.

CRYSTALLINE AMINO ACIDS

1. **Reasons for Interest**

A. Soybean meal - A major protein supplement for nonruminant species:

1) The cost fluctuates considerably.
2) May not be available in the future since it is a byproduct of soybean oil production.

☛ Thus, important to make efforts to find alternative protein supplements for animal production!

B. "Feed-grade" amino acids are currently available commercially (Lys, Trp & Thr; Met has been available for a long time!), and they might be economically viable alternatives.

2. **Replacing SBM with Crystalline AA**

A. Effect of a mixture of AA: (Kephart & Sherritt, 1990. J. Anim. Sci. 68:1999)

(CP:)	Contr. (16.9%)	corn + AA (10.9%)	Corn + AA + Glu (3.5%) (13.0%)
Gain, g/d	797	693	660
Feed Intake, g/d	1,805	1,765	1,696
Feed:gain	2.27	2.55	2.57

B. Addition of crystalline AA to corn: Lewis, 1989. NE Swine Rep."

	Corn-soy positive control	Corn negative control	Corn + Lys & Trp	Corn + Lys, Trp & Thr
Initial wt, kg	60.2	60.0	60.1	59.8
Final wt, kg	112.2	96.9	108.5	107.8
Feed, kg/d	3.00	2.15	2.69	2.52
Gain, kg/d	0.80	0.32	0.54	0.59
Feed:gain	3.77	6.79	4.98	4.28
Backfat, mm	31.0	35.1	34.0	32.8
% lean	54.9	53.0	53.4	54.1

C. The bottom line?

1) Pigs fed low-protein diets supplemented with crystalline AA do not perform well compared to those fed corn or milo-soy diets.
2) But, the performance of pigs improves progressively as "limiting" AA are added to low-protein diets sequentially.
3) Thus, may have the potential in the future depending on other pertinent information:

a) The order of limiting amino acids in grains.
b) The amount of dietary nonspecific N needed for the synthesis of dispensable amino acids.

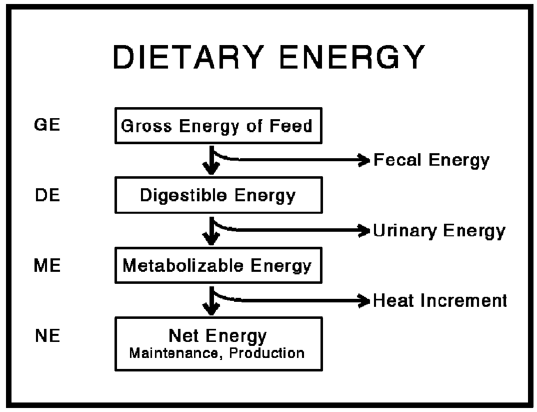
ENERGY METABOLISM AND VITAMINS/MINERAL

ENERGY SYSTEMS

1. **Various Systems**

A. Based on the quantity needed, energy is required in the highest amounts in an animal's diet.

1) Feeding standards used for formulating diets for all species are based on some form/measure of energy.
2) And, additional needs for protein or amino acids, essential fatty acids, vitamins, and minerals.



B.. Partition of dietary energy: [Redrawn from Wiseman & Cole, 1985. In: Cole & Haresign (Ed.)]

1) Energy:

a) Defined as the capacity to do work, and it is the amount of heat produced when completely oxidized in the body, or loss of energy from the body.
b) European countries use the joule, but calorie (cal), kilocalorie (kcal), and megacalorie (Mcal) are commonly used in animal nutrition in the US.
c) One calorie is the heat required to raise the temperature of 1 gram (g) of water 1°C (= 4.1855 joules). A kilocalorie equals 1,000 cal, and a megacalorie (or therm) equals 1,000 kcal or 1,000,000 cal.

2) Gross Energy (GE):

a) Refers to the heat generated when a feed is completely oxidized/burnt.
b) To measure, a known amount of sample is placed a bomb calorimeter, and then oxygen is used to fill the chamber so that the sample will be completely oxidized.
c) The GE content of a feed has little correlation with the portion of the energy that is available to an animal.

3) Digestible Energy (DE):

a) The amount of energy apparently absorbed from a feed.
b) Obtained by subtracting fecal energy from GE - Not strictly a measure of absorbed energy because some fecal energy is derived from sloughed off tissues lining the digestive tract rather than from undigested food.

c) Can be determined relatively easily by a digestion trial, and DE values have been developed for quite a number of species & feedstuffs and are widely used.

4) Metabolizable Energy (ME):

a) Determined by subtracting energy losses in urine and combustible gases from DE consumed - Must collect feces, urine, and gaseous losses.
b) Slightly more accurate than DE in terms of estimating the available energy, but more expensive to determine.

5) Net Energy (NE):

a) Determined by subtracting energy losses due to rumen fermentation and tissue metabolism from ME.
b) Most accurately predicts the available energy for the animal - Also, specifically for maintenance (NEm), gain (NEg) and milk production (NEl).
c) Have been determined on only a few feedstuffs, and many available values have been calculated using equations, but widely being used in formulating diets for various ruminant species.

C. Total Digestible Nutrients (TDN):

1) A method used for many years for estimating the energy content of a feed - Sums all the fractions that are digestible.
2) TDN = digestible crude protein + digestible crude fiber + digestible nitrogen-free extract (starch and sugars) + 2.25 digestible ether extract (fat).

[The ether extract is multiplied by 2.25 in an attempt to adjust its energy value to reflect its higher caloric density (fat = 9.1 cal/g and carbohydrates = 4.1 cal/g).]

3) Usefulness?

a) Based on many assumptions & approximations, and perhaps, many errors associated with each one of those assumptions or approximations?
b) Using the same weight for protein and carbohydrates.
c) To use the "calorie" system, must be converted to ME or DE.

4) The TDN is very similar to DE, but DE and NE are more commonly used.

E. DE, ME & TDN systems - The heat loss is ignored.
F. NE system - Considers a heat loss, but it may vary with a source of energy & also with purposes:

1) ME utilization for energy gain & maintenance - e.g., 27% for wheat middlings, 69% for corn & 75% for soybean oil.

2) Efficiency of utilization of major nutrients for different purposes (ARC, 1981):

Item	Maintenance	Fat production
Carbohydrate	100	100
Fat	95	112
Protein	78	81

☛ The bottom line?

1) The NE system - Theoretically the best measure of available energy for maintenance & production . . . But, may not be practical to use!?
2) Also, from "GE to NE," progressively the function of animals rather than the feed ingredient or diet, so . . . !?

2. Choosing the System

A. The system should be: 1) Precise, 2) simple to apply, and 3) easily estimated!

B. TDN - As indicated before:

1) Various assumptions/estimates are involved in its calculation, thus not "exact," vs DE & ME, which can be measured directly.
2) Must be converted to DE or ME when switching to the "calorie" system.

☛ Thus, the DE, ME or NE system is preferred by many!

C. DE or ME vs NE:

1) In evaluating feedstuffs:

a) Again, from "**GE** → DE → ME → **NE**" estimations, values are influenced more by animals, i.e., not the value of a feedstuff or diet *per se*.
b) "NE values" may be too sensitive for a practical use, i.e., may have to use different values according to age, sex, etc.

2) Estimation of NE:

a) Direct determination - Very complex since it requires a measurement of total energy exchange by the calorimetry.
b) Based on the prediction equations using N, EE, CF & NFE in both feed & feces - May not be precise!

3) Practical diets for nonruminant species (e.g., grain-protein supplement-based diets) - Usually less variations in relative contributions of energy from protein, CH_2O and

fat to the total digested energy, thus the relationships among various systems would be relatively similar?

☛ Thus, DE or ME values are commonly used for nonruminant species!

D. Relationships between DE and ME:

1) Some estimated relationships between ME & DE:

a) ME/DE = 0.957, 0.949, 0.947, 0.977, 0.963, 0.982, 0.970, 0.967, 0.972, etc. with an average of "**0.965**."
b) The most commonly used/quoted assumption - "ME consists of 96% of DE!"

2) But, the quantity & quality of dietary protein can affect this relationship, ∴ adjustment factor(s) must be used:

a) There are many equations to estimate ME values from DE!
b) Most commonly used?

ME = DE x [96 - (0.202 x % CP)] (Asplund and Harris, 1969; NRC, 1988).

3) DE or ME to use?

a) The loss of energy as combustible gases in pigs - Generally ignored because losses are negligible & difficult to measure (NRC, 1988).
b)) The variation in the relationship between DE & ME - More of a function of the animal rather than feed or ingredient itself?
c) "Determined" DE values for most ingredients are available?

☛ Thus, preferable to use DE values? (See Chiba , 2000. In: Theodorou & France.)

ENERGY REQUIREMENT

1. Energy Requirement of Growing Animals (e.g. with Pigs)

◦ The sum of requirements for maintenance, protein retention, fat retention and cold thermogenesis:

$DE = \sum(DE_m + DE_{pr} + DE_f + DEH_c)$ (NRC, 1988).

A. Energy requirement for maintenance:

1) Influenced by environmental temperatures, activity, group size, stress, body composition, etc.

2) Can be estimated from: [Close & Fowler (1985) in Cole & Heresign]

   a) Measurements from fasting metabolism.
   b) Linear regressions relating energy retention (ER) to ME intake & calculating ME_m where ER = 0.
   c) The relationships between ME intake and protein & fat accretion rates, and determining ME_m as the intercept of the multiple regression analysis.

3) Live weights and maintenance requirements:

   a) e.g., Estimates based on two separate equations: [ARC, 1981; Close & Fowler (1985) in Cole & Haresign]

	ME, MJ/day	
Weight, kg	ME_m=0.719$W^{0.63}$	ME_m=0.458$W^{0.75}$
5	1.98	1.53
10	3.07	2.58
20	4.75	4.33
30	6.13	5.87
40	7.35	7.28
50	8.45	8.61
60	9.48	9.87
70	10.45	11.08
80	11.37	12.25
90	12.24	13.38

   b) The most commonly used estimate is ≈ **110 kcal/kg $BW^{.75}$**.

B. Energy requirements for protein and fat retention:

1) Chemical composition of growing pigs (% of body weight): [Kotarbinska, 1969. (Cited by ARC, 1981)]

Weight, kg	Protein	Fat	Water
2.5	15.6	5.0	77.3
8.5	16.7	6.1	75.3
20.7	16.2	9.6	71.0
30.2	16.4	12.4	67.8
60.6	16.6	20.5	59.9
90.4	15.9	26.3	55.1

2) Considerable variations among reported estimates on the cost of protein or fat retention - One example (Tess et al., 1984. J. Anim. Sci. 58:111):

a) Protein - 7.1 to 14.6 Mcal DE/kg with an average of 12.6 Mcal DE/kg protein.
b) Fat - 9.5 to 16.3 Mcal DE/kg with an average of 12.5 Mcal DE/kg fat.

C. "Below" critical temperatures & energy requirement:

1) Equation to estimate the cold thermogenesis:

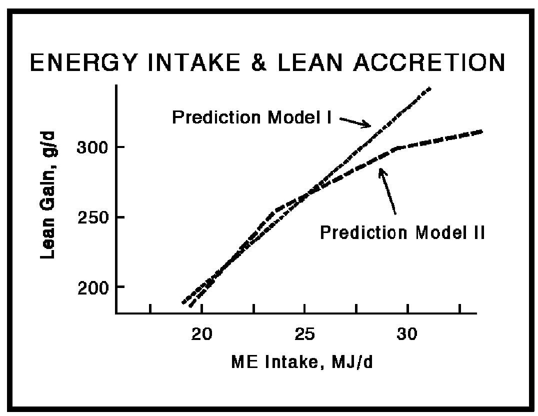
DEH_c (kcal DE/day) = 0.326W + 23.65 (T_c - T) [where W = weight in kg and T (ambient temperature) & T_c (critical temperature) in °C.]

2) According to one estimate, need additional 25 g (80 kcal ME) of feed/day to compensate for each 1°C below T_c in 25- to 60-kg pigs.

D. Energy requirements: (e.g, NRC, 1988)

Body wt., kg	DE, kcal/d	ME, kcal/d
1-5	850	805
5-10	1,560	1,490
10-20	3,220	3,090
20-50	6,460	6,200
50-110	10,570	10,185

E. Energy intake & growth rate of lean tissues: [ARC, 1981; Close & Fowler, 1985. In: Cole & Haresign (Ed.)]



1) Presented only two regression lines covering a range of most ME intakes.
2) Assuming that N intake is not limiting!
3) Considerable variations in responses.
4) Young pigs tend to show a linear response, whereas a response tends to be curvilinear with older/larger pigs & higher energy intakes.

2. **Energy Requirement of Breeding Animals (e.g. With Swine)**

A. During pregnancy:

1) Should be gaining ≈ 25 kg (. . . more like 10 to 15 kg in net weight?) during gestation for the first 4-5 parities, plus ≈ 20 kg for placenta & products of conception, thus a total of ≈ 45 kg?!
2) Estimation of energy requirements (similar to growing swine):

a) Estimate the maintenance requirement.

b) Consider the rate and efficiency of both uterine (all ♀) & net maternal tissue accretions (gilts & young sows).

3) Maintenance, maternal & conceptus gains:

a) DE_m - 96 to 167 Mcal DE with an average of 110 kcal DE/kg $BW^{.75}$/day.
b) Maternal protein and fat gains (assuming maternal gains = 25% fat & 15% protein) - ≈ 12.5 Mcal DE/kg of gain with 40% efficiency, thus, 5 Mcal DE/kg of maternal gains.
c) Conceptus gain - Assuming 1% fat & 9% protein with 10% efficiency, thus, 1.3 Mcal DE/kg!
d) Intrauterine deposition[a]: (Noblet et al., 1990. J. Anim. Sci. 68:562)

	Weight, kg	DM, g	Protein, g	Energy, Mcal
Fetus	13.8 (61)	2444 (73)	1368 (68)	11.1 (72)
Placenta	4.3 (19)	387 (12)	272 (13)	1.9 (12)
Fluids	2.1 (9)	173 (5)	108 (5)	0.7 (5)
Uterus	2.3 (10)	350 (10)	276 (14)	1.7 (11)
Total	22.1 (100)	3365 (100)	2153 (100)	15.6 (100)

[a]Determined at d 110 of pregnancy & determinations are based on 12 fetuses; ( ) = %; Uterus = empty uterus.

B. During lactation - Need energy for maintenance & milk production.

1) DE_m = 110 kcal/$BW^{0.75}$/day.
2) Milk production - 2 Mcal DE/kg milk (assuming GE content of milk = 1.3 Mcal/kg & efficiency of utilization = 65%.)

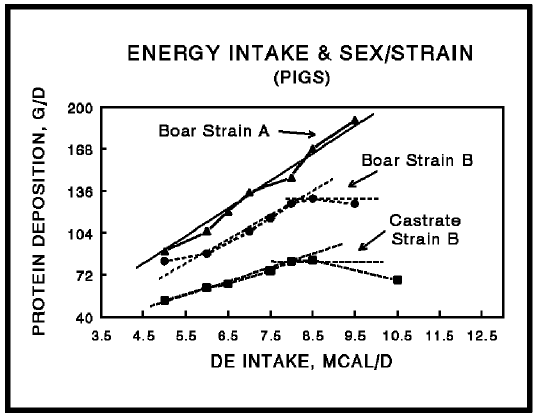
C. Requirements for sows:

Weight, kg:	
Weight at breeding time	140
Pre-farrowing	185
Post-farrowing	165
Gestation:	
Mean gestation wt, kg	162.5
Energy requirement, Mcal DE/d:	
Maintenance (110 x $Wt^{.75}$)	5.00
Maternal gain (25 kg x 5 Mcal/kg ÷ 114)	1.10
Conceptus gain (20 kg x 1.3 Mcal/kg ÷ 114)	.23
Total	**6.33**
Lactation:	
Milk yield, kg/d	6.25
Energy requirement, Mcal DE/d:	
Maintenance (110 x post-farrowing $wt^{.75}$)	5.1
Milk production [(1.3 Mcal/kg ÷ .65) x 6.25]	12.5
Total	**17.6**

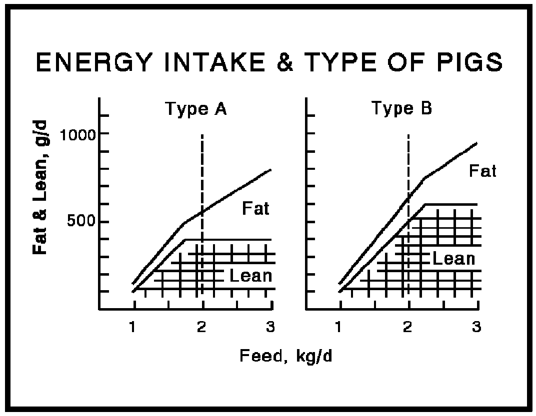
GROWING ANIMALS AND ENERGY (EXAMPLES WITH PIGS)

1. Energy Intake & Body Component Deposition

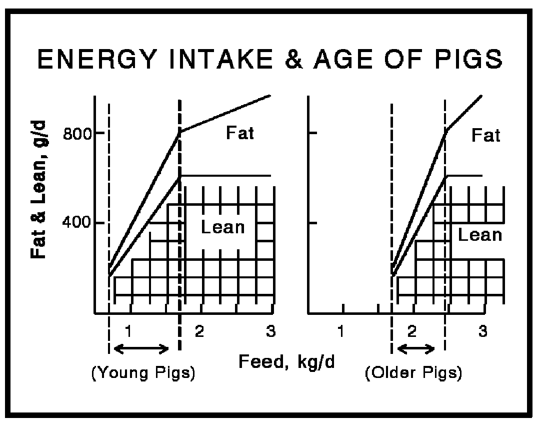
A. Effects of energy intake & sex/strain of pigs on protein deposition - Adapted & redrawn from Campbell and Taverner, 1988. J. Anim. Sci. 66:676.



B. Effects of energy intake and type of pigs on lean/fatty tissue growth - Whittemore, 1985. In: Haresign & Cole.



C. Effects of energy intake and age on lean/fatty tissue growth - Whittemore, 1985. In: Haresign & Cole.



☛ The bottom line?

1) No response in lean growth to additional energy once pigs consumed adequate energy for a maximum protein accretion! The potential for lean growth is determined by age, sex, breeds, strains, use of repartitioning agents, etc.
2) Excess energy consumed can be partitioned into fat deposition, thus increasing fat to lean ratio.

2. **Restricting Energy Intake or Limit-Feeding**

A. Finisher pigs tend to consume energy in excess of that needed for maximum protein or lean deposition.
B. Thus, energy intake can be restricted (usually ↓ by 10-15%) without adversely affecting performance.
C. A limit feeding is very popular in many countries possibly because:

1) Pigs are sold on carcass basis (discounts for fat carcasses).
2) Availability & cost of feed ingredients.
3) Possibly, lower labor costs.

D. Energy intake and pig performance[a]: (Haydon et al., 1989. J. Anim. Sci. 67:1916)

Item	Ad libitum	85%	70%
20-50 kg:			
ADG, kg	.798	.686	.573
Gain:feed	.402	.402	.373
Avg. backfat, cm	2.14	1.78	1.51
Loin muscle, cm^2	23.97	25.61	24.09
Lean cut, %	65.12	66.11	68.32
50-80 kg:			
ADG, kg	1.015	.856	.668
Gain:feed	.297	.308	.286
Avg. backfat, cm	3.23	3.21	2.97
Loin muscle, cm^2	29.40	28.02	31.36
Lean cut, %	60.45	61.58	63.24
80-110 kg:			
ADG, kg	.773	.693	.546
Gain:feed	.205	.219	.208
Avg. backfat, cm	4.00	3.22	2.78
Loin muscle, cm^2	34.31	34.73	40.28
Lean cut, %	58.31	60.71	61.53
Overall:			
ADG, kg	.848	.745	.586
ADFI, kg	2.99	2.50	2.11
Gain:feed	.281	.295	.273

[a]Nutrient levels were adjusted to achieve similar daily intakes.

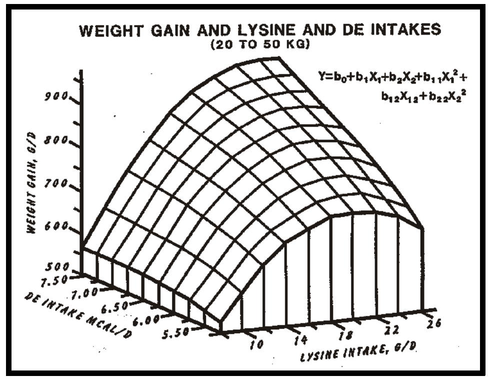
1) Carcass quality can be improved, but a limit-feeding ↑ days to market because of ↓ weight gain, thus need some incentive programs (premiums) to produce leaner pigs!
2) Presently, no practical means or feeding methods to ensure an adequate individual daily feed intake (i.e., in the group housing/feeding situation).
3) Probably, will not be accepted in the US (at least not in the near future) because:

a) Most pigs are sold on a live weight basis.
b) Feed ingredients are abundant and cheap.

c) Pigs have been selected based on ad libitum feeding.

3. **Interaction of Energy and Amino Acids**

A. Effects of amino acid & energy intakes on weight gain - Chiba et al., 1991. J. Anim. Sci. 69:708)



B. When AA intake is inadequate:

1) ↑ AA intake results in a concomitant ↑ in protein deposition to a point.
2) ↑ energy intake has little beneficial effects on protein metabolism, and excess energy may be used for fat deposition!

C. When energy intake is limited:

1) ↑ energy supply ↑ protein deposition to a point, and excess energy may be used for fat deposition!
2) ↑ AA intake has little beneficial effects on protein metabolism, and some AA may be utilized for energetic purposes.

☛ For optimum growth/nutrient utilization - Must supply energy & AA in the correct proportion!

BREEDING ANIMALS AND ENERGY (EXAMPLES WITH SWINE)

1. **Energy Intake During Gestation**

A. Effect of additional feed during the late gestation on reproductive performance[a]: [Cromwell et al., 1989. J. Anim. Sci. 67(1):3]

Item	Contr.	+ 1.36 kg/d
Gestation wt gain, kg	39.0	48.7
Weight change during lactation (from d 110 to d 21), kg	- 16.4	- 21.3
Total pigs born	10.42	10.77
Pigs born alive	9.71	10.05
No. of pigs at 21 d	8.06	8.35
Birth wt, kg	1.44	1.48
Weight at 21 d, kg	5.20	5.37
Return to estrus, d	5.81	5.70

[a]Involving 1,080 litters at 8 Exp. Stations (S-145); Additional feed offered during the last 23 d of gestation.

B. The bottom line?

1) Additional feed in the late gestation can improve reproductive performance of sows.

2) Benefits (0.3 more pig/litter at weaning & 2.6 kg more total litter weaning wt) can offset additional feed costs.

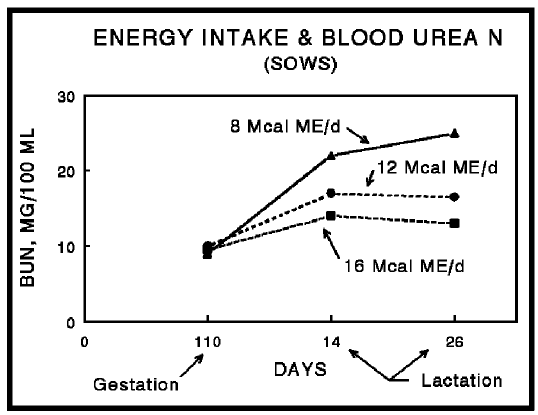
2. Energy Intake During Lactation

A. Effect of energy intake during lactation on reproductive performance: (Reese et al., 1982. J. Anim. Sci. 55:590) [Provided 8, 12 or 16 Mcal ME/d during lactation.]

1) Sow & pig performance:

Item	8 Mcal/d	12 Mcal/d	16 Mcal/d
Sow wt change (lact.), kg	- 25.7	- 13.3	- 3.3
Sow BF change (lact.), mm	- 8.4	- 4.6	- 1.8
Return to estrus (≤ 7 d), %	65.2	91.3	95.7
Avg. pig weaning wt, kg	6.6	6.7	7.0

2) Energy intake & changes in blood urea N - Figure on the right.
3)) An inadequate energy intake may increase the rate of protein catabolism (tissues and dietary sources) to support lactation.
4) An adequate energy intake is important in minimizing weight and backfat losses of lactating sows.
5) An excessive wt loss is likely to have adverse effects on early return to estrus & others.



B. Effects of a source of energy during lactation:

1) Effect of tallow or cornstarch on reproductive performance (restricted to 8 Mcal ME/d): (Nelssen et al., 1985. J. Anim. Sci. 60:171)

Item	Tallow	Cornstarch
Lactation wt change, kg	- 27.5	- 24.3
Lact. backfat change, mm	- 10.0	- 9.6
Return to estrus (%):		
≤ 7 d	68.2	56.5
≤ 14 d	79.5	73.9
Pig wt at d 28, kg	6.7	6.5
No. of pigs at d 28	8.5	8.9

2) Other research:

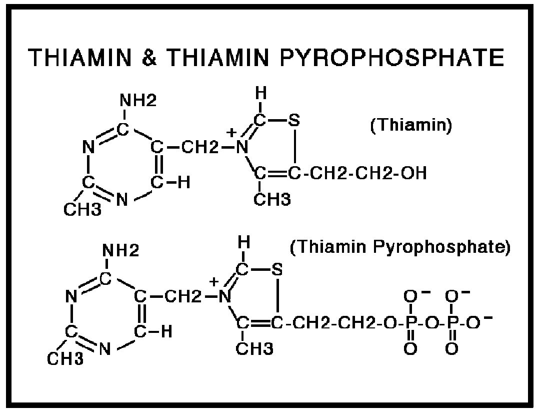
a) Addition of 2.5% sucrose - No effect. (NCR-89, 1990. J. Anim. Sci. 68:3498.)
b) Addition of fructose - No effect. (Campbell et al., 1990. J. Anim. Sci. 68:1378.)

☛ The bottom line? - "*For optimum reproductive performance, ensuring an adequate energy intake during lactation is more important than the source of energy!*"

3. **Some Important Vitamins in Energy Metabolism?** - Thiamin (B_1), Riboflavin (B_2), Niacin, Pantothenic acid, and Biotin!

THIAMIN (VITAMIN B_1)

1. **General**



A. Considered to be the oldest vitamin:

1) The first "water-soluble" vitamin to be discovered from so called a "growth factor."
2) The deficiency disease, beriberi, is probably the earliest documented disorder. (Recorded in China as early as 2,600 B.C.).

B. Beriberi in general: [Please see Maynard et al. (1979), McDowell (1989) & others]

1). The major health problem observed in the Far East for a long time, and the problem persisted until fairly recently - e.g., Even as recently as 1940's, the mortality rate from beriberi in Philippine was 132/100,000 (1947).
2) Usually both cardiac and nervous functions are disturbed:

a) Signs include edema (ankles), puffiness of face, anorexia, digestive disturbances, heart enlargement, tachycardia, lassitude & muscle weakness, loss of knee & ankle reflex, etc.
b) Beriberi patients are unable to rise from a squatting position, indicating the neurological damages.

3) In the early 1880s - A physician in the Japanese Navy substituted some of polished rice with other foods, and was able to ↓ the incidence of beriberi, and incorrectly thought that added protein was responsible for preventing beriberi.
4) In the 1890s:

a) Eijkman discovered polyneuritis in chickens & symptoms were similar to beriberi.

b) Rice bran was effective in curing & preventing beriberi, and also it had similar effects on polyneuritis.
c) Incorrectly assumed that polished rice produced a toxin.

5) Casmir Funk (1910s) otained a potent anti-beriberi substance from rice bran (discovery of thiamin), and a substance had characteristics of amine, thus coined the term "vitamin(e)" (vital amine). (Found later that many vitamins are not amines!)

2. **Structure** - See the figure on thiamin and thiamin pyrophosphate (TPP; Martin et al., 1983).

3. **Functions**

A. Along with riboflavin and niacin, plays important roles in the citric acid cycle.
B. TPP is responsible for decarboxylation:

1) Pyruvate → acetyl-CoA + CO_2
2) α-Ketoglutaric acid → succinyl-CoA + CO_2

C. TPP is also involved in transketolase reaction (pentose pathway/synthesis of ribose).
D. In nervous tissues - Little is known, but involved in:

1) The synthesis of acetylcholine - Transmission of neural impulses.
2) A passive transport of Na (excitable membranes) - Transmission of impulses.

4. **Deficiency**

A. Signs in poultry - Loss of appetite & weight, weakness in leg/muscular, bradycardia (from 300 to 90-100/min), edema, diarrhea, vomiting, . . . & death.
B. Signs in pigs - Loss of appetite & weight, weakness, premature birth, high mortality, slow pulse, heart failure, edema, hemorrhages, diarrhea, vomiting & sudden death.
C. Fish:

1) Signs include poor appetite, muscle atrophy, convulsions, instability & loss of equilibrium, edema & poor growth.
2) Thiaminase - Found in tissues of most fish, and can destroy thiamin:

a) Can split the vitamin into two component ring structures in non-living tissues.
b) Thiaminase in unheated fish or fish viscera can destroy the vitamin prior to ingestion - e.g., Channel catfish can develop a deficiency by feeding diets containing 40% unheated fish viscera for 10 wk.

5. **Requirements and Sources**

A. Thiamin (B_1) requirements: (Also see appropriate "Nutrition & Feeding" sections)

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	0.8-1.0
Laying	0.60-0.88
Broilers	1.80
Turkeys, all classes	2.0
Swine (NRC, 1998):	
3-120 kg	1.0-1.5
Adults	1.0
Horses (NRC, 1989):	
Horses &ponies (DM)	3.0-5.0
Also via	Microbial synthesis?
Fish (NRC, 1993):	
Channel catfish & rainbow trout	1.0
Pacific salmon	No dietary requirement?
Common carp	.5
Tilapia	Not tested

☛ Usually, can be met by natural ingredients!

B. Sources:

1) Cereal grains (seed coats & germs) & their by-products, oil extraction residues - relatively rich sources (≈ 3-12 mg/kg).
2) Brewer's yeast is the richest known natural source (95.2 mg/kg).

C. Thiamin in pork:

1) For some unknown reason, pigs' tissue contains high levels of thiamin vs other species (several times higher).
2) Thus, pork is an excellent source of thiamin (0.87 mg/3 oz of broiled chop vs RDA of 1-2 mg/day).

D. Factors affecting the requirement:

1) Heat processing - Cooking, pelleting, etc. (Thiamin is relatively heat-stable, but it's not stable in a moist-heat!)
2) Presence of thiaminases - e.g., Moldy grains/feeds (microbes can produce thiaminases).

RIBOFLAVIN (VITAMIN B_2)

1. **General** [Please see Maynard et al. (1979), McDowell (1989) & others]

A. "Water-soluble" factor or factors promoted growth & prevented beriberi.
B. Heating destroyed anti-beriberi effect more rapidly than growth-promoting effect.
C. Water-soluble fractions consisted of two essential factors:

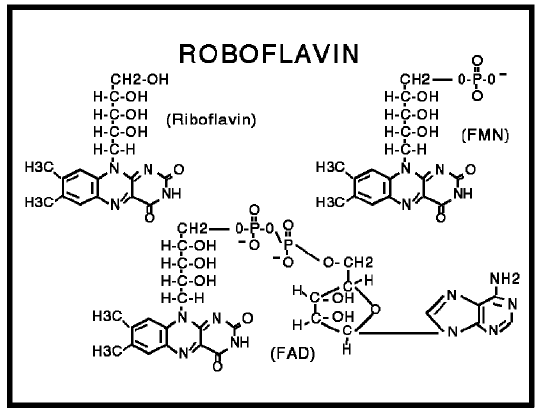
1) Less heat stable factor - Thiamin.
2) Heat stable factor - Riboflavin.

D. Warburg & Christian (1932) - Isolated an oxidative enzyme from yeast, which showed "yellow" color with green fluorescence (∴ "Old Yellow Enzyme!"), and able to split it into a protein- & nonprotein (pigment)-fraction.

☛ Perhaps, this was the first identification of a "prosthetic" group of the enzyme!?

E. Kuhn (1933) - Isolated a yellow pigment from egg white with oxidative properties & suggested the name "flavin."

1) e.g., Ovoflavin - isolated from eggs, lactoflavin - isolated from milk, hepatoflavin - isolated from liver, & uroflavin - isolated from urine.
2) Crystalline compounds contained a ribose, thus the name, "riboflavin!"

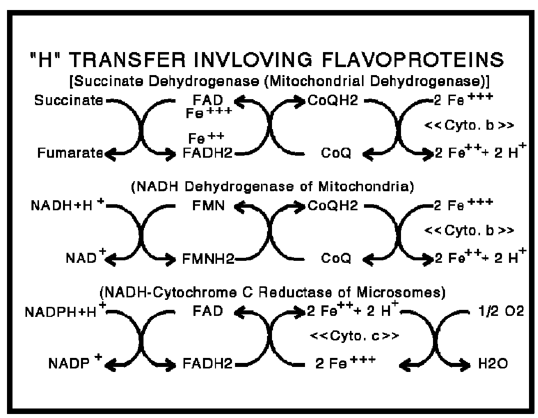


2. **Structure** - Redrawn from Martin et al. (1983).

3. **Functions**

A. A component of FMN and FAD - A prosthetic group for active enzymes, flavoproteins. (Most flavoproteins contain FAD.)
B Involved in a transfer of electrons in biological oxidation-reduction reactions.
C. About 40 flavoprotein enzymes participate in the electron transfer:

a) Some examples - "Hydrogen transfer involving flavoproteins:" (Adapted & redrawn from McDowell, 1989)
b) Aerobic dehydrogenases (no metal) - D- & L-AA oxidase, glucose oxidase, etc.
c) Oxidases (Cu, Fe or Mo) - Cuproflavoprotein in butyryl-CoA-dehydrogenase, xanthin oxidase, etc.
d) Anaerobic dehydrogenases - acyl-CoA dehydrogenases & electron-transferring flavoprotein, succinic dehydrogenase, fumaric reductase, etc.
e) Others - Choline dehydrogenase, α-glycerophosphate dehydrogenase, L-lactate dehydrogenase, D-lactate cytochrome reductase, etc.



4. **Deficiency**

A. Poultry - A characteristic sign, curled-toe paralysis, is a reflection of degenerative changes in myelin sheaths in sciatic & brachial nerves; other signs include retarded growth, diarrhea, high mortality, reduced hatchability, reduced egg production, etc.
B. Swine - Signs include anorexia, slow growth, rough hair coat, dermatitis, unsteady gait, scours, reproductive & digestive tracts disorders, vomiting, cataracts, light sensitivity, etc.
C. Fish - Signs include cloudy lens, hemorrhagic eyes & other organs, photophobia, dim vision, incoordination, abnormal pigmentation of iris, striated constriction of abdominal wall, dark coloration, poor appetite, anemia, poor growth, etc.

5. **Requirements and Sources**

A. Riboflavin requirements: (Also, see appropriate "Nutrition & Feeding" sections)

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	1.7-3.6
Laying hens	2.1-3.1
Broilers	3.0-3.6
Turkeys	2.5-4.0
Swine (NRC, 1998):	
3-120 kg	2.0-4.0
Adults	3.75
Horses (NRC, 1978):	2.0
Fish (NRC, 1993):	
Channel catfish	9.0
Rainbow trout	4
Pacific salmon & common carp	7
Tilapia	6

☛ One of the vitamins most likely to be deficient in nonruminant species, and also in humans!

B. Sources:

1) Cereal grains, their by-products & soybean meal are rather low (e.g., corn, 1.4 mg & SBM, 3.2 mg/kg DM) - Corn-soy diets are borderline to deficient, thus must be supplemented!
2) Green, leafy vegetables, yeast & forages are good sources - e.g., Sun cured alfalfa leaves contain 23.1 mg/kg.

☛ For humans, milk, eggs, liver, heart & muscle are rich sources!

C. Factors affecting the requirement:

1) Heating will destroy some vitamin (little more stable than thiamin though).
2) A free-form (produced by microbes or by chemical synthesis) is sensitive to light.
3) Divalent heavy metals (Cu, Fe, Mn, Zn, Cd) bind the vitamin & make it unavailable.

NIACIN

1. **General** [Please see Maynard et al. (1979), McDowell (1989) & others]

   A. Niacin has been known to organic chemists since 1867, a long before its importance as an essential nutrient was discovered.
   B. Funk (1911-1913) isolated niacin from yeast & rice polishing.
   C. The interest in niacin was lost because of its ineffectiveness in curing beriberi.
   D. Warburg et al. (1935) reported that niacin functioned as part of a hydrogen transport system.
   E. Third vitamin to be discovered from the "vitamin B complex," i.e., thiamin first, riboflavin second & then niacin.

2. **Pellagra in General**

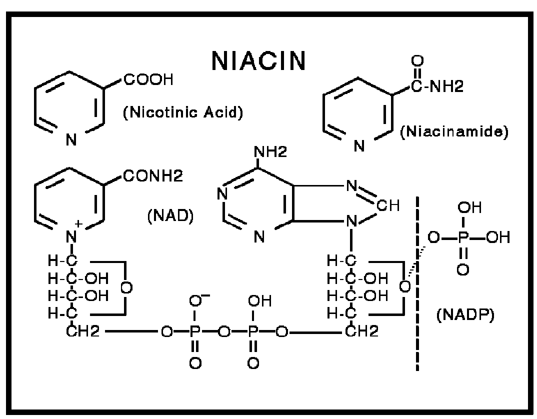
   A. A niacin deficiency in humans - Means a rough skin (dermatitis).
   B. May also involve Trp, thiamin, riboflavin and pyridoxine.
   C. A condition common in the corn-eating population - Appeared in Europe in the 1730s when corn from the New World became the major staple foodstuff.
   D. Most cases occurred in a low-income group - Diets associated with the disease were referred to as three **M's**:

      ◦ **M**eal (corn), **M**eat (back fat) and **M**olasses. (+ **poverty**!)

   E. In the US (especially in the south), it's common for 20,000 deaths/year from pellagra around the turn of the century.
   F. Clinical signs & mortality are referred to as the **four D's**:

      ◦ **D**ermatitis of the area exposed to sun, **D**iarrhea, **D**ementia [a mental disorder - depression & schizophrenia (indifference, withdrawal, hallucination, illusion of persecution and omnipotence)], and **D**eath.

3. **Structure** (Redrawn from McDowell, 1989)



4. **Functions**

   A. Component of 2 important coenzymes, NAD (formally called DPN) & NADP (formally called TPN), which are involved in biological oxidation-reduction systems.
   B. Important reactions catalyzed by NAD & NADP:

      1) CH_2O metabolism - Glycolysis (anaerobic & aerobic oxidation of glucose) & citric acid cycle.

2) Lipid metabolism - Glycerol synthesis and breakdown, fatty acid oxidation and synthesis & steroid synthesis.
3) Protein metabolism - Degradation and synthesis of amino acids & oxidation of carbon chains via citric acid cycle.
4) Others - Photosynthesis & rhodopsin synthesis.

5. **Deficiency**

A. Poultry - Black tongue (inflammation of the tongue, mouth cavity, & esophagus), ↓ appetite & growth or weight loss, reduced egg production and hatchability, etc.
B. Swine - Poor appetite & weight gain, dermatitis, hair loss, diarrhea, inflammation & necrosis of the GI tracts, etc.
C. Fish - Loss of appetite, lesions in colon, jerky or difficult motion, weakness, edema of stomach & colon, muscle spasms, poor growth, anemia, fin lesions, etc.

6. **Requirements and Sources**

A. Niacin requirements: (Also, see appropriate "Nutrition & Feeding" sections.)

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	10.3-27.0
Laying hens	8.3-12.5
Broilers	25-35
Turkeys	40-60
Swine (NRC, 1998): (Available)	
3-120 kg	7-20
Adult	10
Horses (1978):	Microbial synthesis
Fish (NRC, 1993):	
Channel catfish	14
Rainbow trout	10
Pacific salmon	Required, but not determined
Common carp	28
Tilapia	Not tested

◦ Usually, diets are supplemented!

B. Sources:

1) Grains (corn, sorghum, wheat & oats) are low in niacin, and it exits 1° as a bound form (85 to 90%) & not available to animals.
2) Soybean meal (31 mg/kg DM) - 100% available based on a chick assay.
3) Wheat bran (268 mg) & brewer's yeast (482 mg/kg DM) are good sources.

7. **Trp & Niacin Requirement**

A. Animals can synthesize niacin from Trp, but there are wide variations in their ability to synthesize this vitamin.

B. Trp levels in the diet may affect niacin requirements: (e.g. in pigs)

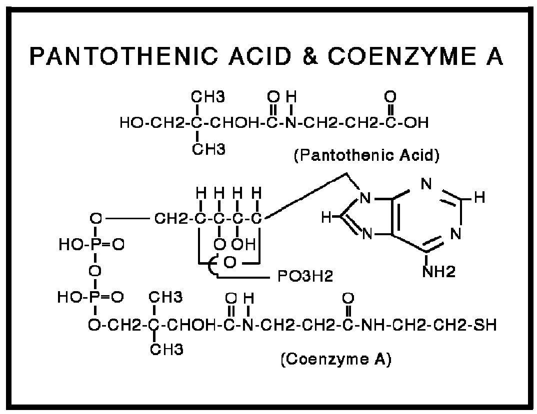
1) ≈ 50 mg Trp → ≈ 1 mg niacin - i.e., Every 0.01% Trp above the requirement (or 100 mg/kg), pigs can synthesize 2 mg niacin/kg of diet.
2) Thus, for high-protein diets, probably no need for niacin supplementation.

PANTOTHENIC ACID

1. **Introduction** [Please see Maynard et al. (1979), McDowell (1989) & others]

A. Isolated during the 1930s from the vitamin B_2 complex along with pyridoxine.
B. Previously called a chick anti-dermatitis factor.
C. The name pantothenic acid was derived from the Greek word "*Pantos*," meaning found everywhere.
D. Found in two enzymes, coenzyme A and acyl carrier protein, which are involved in many reactions in CH_2O, fat & protein metabolism.

2. **Structure** (Adapted & redrawn from McDowell, 1989)



A. Found in feeds in both bound (as coenzyme A) & free forms.
B. A free form is unstable & easily degraded by heat, acids & bases.

3. **Functions**

A A constituent of coenzyme A and acyl carrier protein.
B The most important function of coenzyme A is probably its role as a carrier of carboxylic acids.
C. Some biochemical reactions involving pantothenic acid: (McDowell, 1989)

Enzyme	Derivative	Reactant	Product	Site
Pyruvate dehydrogenase	CoA	Pyruvate	Acetyl CoA	Mitochondria
α-ketoglutarate dehydrogenase		CoA	α-ketoglutarate	Succinyl CoA
Mitochondria				
Fatty acid oxidase	CoA	Palmitate	Acetyl CoA	Mitochondria
Fatty acid synthetase	Acyl carrier protein	Acetyl CoA, malonyl CoA	Palmitate	Microsomes
Propionyl CoA carboxylase	CoA	Propionyl CoA, CO_2	Methylmalonyl CoA	Microsomes
Acyl CoA synthetase	Phospho-pantetheine	Succinyl CoA, GDP + Pi	Succinate, GTP + CoA	Mitochondria

4. **Deficiency**

A. Poultry - Signs include severe dermatitis, broken feathers (become brittle & fall-off), perosis, poor growth, reduced egg production & hatchability, mortality, etc.
B. Swine - Signs include anorexia, poor growth, diarrhea, rough hair coat, brown exudates around eyes, anemia, "goose stepping" (resulting from sciatic nerve damages), etc.
C. Fish - Signs include clubbed gills, prostration, loss of appetite, necrosis & scarring, cellular atrophy, gill exudate, sluggishness, poor growth, anemia, etc.

5. **Requirements and Sources**

A. Pantothenic acid requirements: (Also, see appropriate "Nutrition & Feeding" section.)

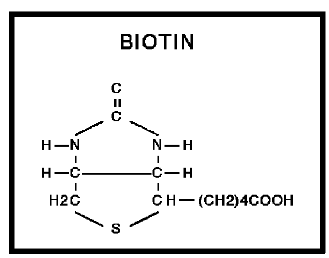
Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	9.4-10.0
Laying hens	1.7-2.5
Broilers	10.0
Swine (NRC, 1998):	
3-120kg	7-12
Adults	12
Horses (NRC, 1978):	Microbial synthesis
Fish (NRC, 1993):	
Channel catfish	15
Rainbow trout	20
Pacific salmon	20
Common carp	30
Tilapia	Not tested

B. Sources:

1) Corn (6.6 mg) & SBM (18.2 mg/kg DM) based diets tend to be deficient in pantothenic acid, ∴ diets are usually supplemented.
2) Milling by-products such as rice bran (25.2 mg) & wheat bran (33.5 mg/kg DM) are good sources.

BIOTIN

1. **General** [Please see, e.g., Maynard et al. (1979), McDowell (1989)]



A. Different lines of investigations led to the discovery of biotin:

1) Coenzyme R - Required for legume nodule bacteria.
2) Biotin - Isolated from egg yolk, which was necessary for yeast growth.
3) Factor H or vitamin H - A factor present in certain foods (especially in the liver & kidney) that protected egg-white injury (dermatitis).

B. Szent-György et al. (1940) found that all three were the same substance.

C. Generally believed for many years that supplemental biotin is not necessary for swine & poultry because biotin is widely distributed in nature/feedstuffs & it is synthesized by many different microorganisms in the GI tract.
D. But in the mid 1970s, several field cases of deficiency signs were observed, and animals responded to a supplemental biotin, which led to re-evaluation of the role of biotin in animal diets.

2. **Structure** (Adapted and Redrawn from Martin et al., 1983 - See the box)

3. **Functions**

   ◦ Serves as a prosthetic group for a number of enzymes (carboxylases, transcarboxylases & decarboxylases), and biotin moiety functions as a mobile carboxyl carrier.

A. Carbohydrate metabolism:

   1) Carboxylation of pyruvic acid to oxaloacetic acid.
   2) Conversion of malic acid to pyruvic acid.
   3) Interconversion of succinic acid and propionic acid.
   4) Conversion of oxalosuccinic acid to α-ketoglutaric acid, etc.

B. Protein metabolism:

   1) Protein synthesis.
   2) Amino acid deamination.
   3) Purine synthesis & nucleic acid metabolism, etc.

C. Lipid metabolism:

   1) Conversion of acetyl-CoA to malonyl-CoA (the first reaction in FA synthesis).
   2) Essential FA metabolism, etc.

4. **Deficiency**

A. Poultry - Signs include reduced performance, broken feathers, dermatitis, leg & beak deformities, increased embryonic mortality & reduced viability after hatching, etc.
B. Swine - Signs include reduced performance, loss of hair, dermatitis (dry & rough), brownish exudate, ulceration of skin, inflammation of the mouth mucosa, cracking of soles & top of hooves, etc.
C. Fish - Signs include loss of appetite, lesions in colon, coloration, muscle atrophy, spastic convulsion, fragmentation of erythrocytes, skin lesions, poor growth, etc.

5. **Requirements and Sources**

A. Requirements: (Also, see appropriate "Nutrition and Feeding" sections.)

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	0.09-0.15
Laying hens	0.08-0.13
Broilers	0.12-0.15
Turkeys	0.10-0.25
Swine (NRC, 1998):	
3-120 kg	0.05-0.08
Adults	0.20
Horses (NRC, 1978)	Microbial synthesis?
Fish (NRC, 1993):	
Channel catfish	Required, but not determined
Rainbow trout	.15
Pacific salmon	Required, but not determined
Common carp	1.0
Tilapia	Not tested

B. Sources:

1) Exists in both bound (unavailable) & free forms - e.g., > ½ of biotin in various feedstuffs is in the bound form & biologically unavailable.
2) Contents in cereal grains are influenced by variety, season, yield, storage conditions, etc.
3) Corn (.07 mg/kg) and SBM (.32 mg/kg DM) are highly available sources, but the availability in wheat, barley & milo is very low.

C. Avidin (antivitamin):

1) Present in raw eggs, which is denatured by moist heat.
2) Secreted by mucosa of oviduct of the hen into egg white, and combines with biotin in "1:1 ratio" (the bound biotin is not available).
3) Dietary avidin < biotin - Cures/prevent deficiency symptoms.

6. **Biotin Supplementation (e.g. with Swine)**

A. In general, no improvement in performance of growing pigs with biotin supplementation.
B. In sows, inconsistent responses:

1) Observed improved hoof hardness/strength, improved skin & hair coat condition, reduced hoof cracks & footpad lesions in some investigations.
2) Also observed improved reproductive performance (litter size, weaning wt, days to return to estrus, etc.) in some studies.

C. Recent data:

A. Biotin and reproductive performance of sows: (Watkins et al., 1991. J. Anim. Sci. 69:201)

Item	Basal	+ Biotin
Foot score	7.16	6.48
Hair score	1.68	1.58
Soundness score	2.38	2.23
Rebreeding interval, d	4.98	5.25
No. of pigs born	11.41	10.66
% born alive	78.8	81.9
Pig birth wt, kg	1.58	1.45
No. of pigs at 21 d	7.42	7.56
% alive at 21 d	89.0	85.8
Pig 21-d wt, kg[a]	5.15	4.73

[a]Biotin effect, $P < 0.03$.

B. Biotin and foot lesions: (Lewis et al., 1991. J. Anim. Sci. 69:207)

Item	0	330 µg/kg	*P*
Kentucky:			
No. of lesions[a]	2.59	2.40	0.59
Overall lesion score[b]	1.20	1.07	0.24
Minnesota & Nebraska:			
No. of horn crack[a]	3.04	3.19	0.68
Severity of horn cracks[c]	0.91	0.98	0.51
No. of heal cracks[a]	2.86	3.03	0.58
Severity of heal cracks[c]	1.19	1.14	0.72
No. sidewall cracks[a]	3.57	4.57	0.08[d]
Severity of sidewall cracks[c]	1.27	1.44	0.19
No. of bruises[a]	0.87	1.40	0.01
Severity of bruises[c]	0.52	0.93	0.01

[a]Total No. of lesions for all four feet; [b]Based on overall condition of the feet where 0 represents no lesions & 5 represents many lesions; [c]Based on the system where each lesion was give severity score ranging from 1 (a very small lesion) to 5 (a very large severe lesion); [d]Station x treatment, $P < .05$.

- Biotin has no effect on cracks & bruises on the feet of sows.

CHROMIUM

1. **Essentiality**

A. Glucose Tolerance Factor (GTF): (Bosco, 1989)

1) In 1955, researchers found that rats maintained on a diet of torula yeast (not brewer's yeast) had impaired glucose tolerance (unable to handle large doses of sugar).
2) No other nutrients could overcome this, ∴ they concluded that something was missing from torula yeast, and named this mystery substance "*Glucose Tolerance Factor* (GTF)."

3) Subsequently, GTF was found to exist in brewer's yeast, and the active component was identified to be a trivalent chromium. The GTF also contains nicotinic acid, Gly, Glu & Cys, but exact structure is not yet known.
4) Further studies revealed that a severe Cr deficiency can impair glucose tolerance as serious as mild diabetes.

- Most animal products contain much of their total Cr in the form of GTF, and GTF organic complex is 50 times more active than inorganic Cr.
- The GTF may qualify as a vitamin!? (An organic compound containing Cr, and has a greater biological activity than inorganic Cr . . . similar to vitamin B_{12}!)

B. Other research:

1) In rats & mice, 5 ppm Cr supplementation in drinking water ↑ growth rate over controls for both sexes, and ↓ mortality rate in ♂ (Schroeder et al., 1963a,b. J. Nutr. 80:39 & 48).
2) In humans, Cr had beneficial effects on malnourished children, i.e., restored glucose tolerance (Mertz, 1974. In: Proc. 2nd Int. Symp. Trace Elem. Metab. p 185).
3) In birds, 10 ppm Cr as $CrCl_3$ improved interior egg quality as measured by Haugh units (Jensen et al., 1978. Fed. Proc. 37:404).
4) In ruminants, supplementation of Cr as GTF to stressed calves improved weight gain and efficiency [Chang et al., 1991. JAS 69(Suppl. 1):212.].

C. The deficiency is characterized by impaired growth, impaired glucose tolerance, ↑ serum cholesterol & triglycerides, ↑ incidence of aortic plaques, ↓ fertility and sperm count and shortened life-expectancy.

D. The function seems to be to potentiate the action of insulin:

1) According to Mertz et al. (1974. Fed. Proc. 33:2275), Cr may form a complex between insulin & insulin receptor, ∴ facilitating the insulin-tissue interaction.
2) Effects of Cr on the metabolism?

   a) "Glucose" - a Cr deficiency can cause a syndrome resembling diabetes mellitus with hyperglycemia. (Cr & action of insulin?)
   b) "Lipids" - Cr has effects on serum cholesterol homeostasis. (↓ serum levels?)
   c) "Protein" - Cr ↑ incorporation of AA (Gly, Ser, Met) into heart muscle. (via the action of insulin?)

2. **Toxicity**

A. General:

1) Chromic oxide (Cr_2O_3) has been used as a fecal marker for several wk at levels as high as 3,000 ppm without adverse effects.
2) The rat can tolerate 100 mg/kg, whereas cats can tolerate 1,000 mg/kg.

3) Chicks were not adversely affected by feeding 1,000 ppm Cr, but ↓ growth rate with 2,000 ppm.
4) A single oral dose of 700 mg or 30-40 mg Cr/kg BW resulted in acute toxicity in mature cattle & young calves, respectively.

B. Toxicity signs:

1) "Industrial exposure (humans)" - allergic dermatitis, skin ulcers & ↑ incidence of bronchogenic carcinoma.
2) "Animals" - skin-contact dermatitis, irritation of respiratory passages, ulceration & perforation of the nasal septum & lung cancer.
3) "Acute toxicosis in ruminants" - inflammation & congestion of the stomach & ulceration of the rumen & abomasum.

C. Maximum tolerable dietary level - 3,000 ppm Cr as oxide & 1,000 ppm as Cl for domestic animals (NRC, 1980).

D. "Adequate" & "safe" intake levels in humans: (RDA, 1989)

1) 10-60 for infants, 30-120 for children (> 6 yr) & 50-200 μg/d for others.
2) The upper levels should not be habitually exceeded.

3. **Cr & Heart Disease**

A. Leading cause of death among diabetics is cardiovascular disease:

1) Diabetics suffer the lesions of atherosclerosis, and people with atherosclerosis also have impaired glucose tolerance.
2) People dying from atherosclerosis have lower (or absent) Cr levels than people dying from other causes such as accidents.
3) People with heart disease had consistently lower Cr, while none of people with blood Cr of ≥ 5.5 μg/L had the disease. The link is very clear in animals, i.e., Cr-deficient animals have impaired glucose tolerance & atherosclerotic plaques in their aortas.

B. ↑ scientific evidence that when Cr is added to the diet, blood cholesterol ↓ and incidence of atherosclerosis ↓.
C. Although the requirement is not well established, probably quite few people are not getting enough Cr. (One USDA study found that 90% of the diets examined did not supply 50 μg/d!)

4. **Chromium & Metabolism (NRC, 1997)**

A. Carbohydrate:

1) Cr potentiates the action of insulin via the GTF (contains nicotinic acid, glycine, glutamic acid, and cysteine, as well as Cr . . . but the exact structure of the native complex has not been determined).
2) Increase glucose uptake, glucose use for lipogenesis, glucose oxidation to carbon dioxide, and glycogenesis with the addition of Cr to animal tissues.
3) Normalization of glucose metabolism in humans afflicted with a variety of disorders (e.g., diabetes-like symptoms) with Cr supplementation.
4) A decreased sensitivity of peripheral tissues to insulin may be the primary biochemical lesions in Cr deficiency.
5) Cr can potentiate the activity of insulin, but does not substitute!

B. Lipids:

1) Cr may be necessary for normal lipid metabolism and for minimizing rates of atherogenesis because rats & rabbits fed low-Cr diets had greater concentrations of serum cholesterol and aortic lipids and exhibited greater plaque formation . . . Cr supplementation reduced cholesterol concentrations.
2) With Cr supplementation, increases in HDL cholesterol, decreases in total cholesterol, LDLP cholesterol, ana triacylglycerols in humans have been observed . . . But not very consistent!

C. Protein:

1) Because of the role of insulin in amino acid uptake by animals tissues, Cr is predicted to have an effect on protein metabolism.
2) One report indicated that Cr supplementation increased amino acid incorporation into heart proteins and uptake into tissues of rats.

D. Nucleic acids:

1) Cr in trivalent state seems to be involved in structural integrity and expression of genetic information in animals.
2) Cr protects RNA against heat denaturation.
3) Cr seems to be concentrated in the nuclei of animal cells, and has been shown to enhance RNA synthesis in mice in vitro and in vivo.

E. Stress:

1) Cr status seems to be influenced by physiological, pathological, and nutritional stresses.
2) For instance, exercise and trauma can increase urinary Cr in humans, thus contributing to Cr deficiency.
3) Symptoms of Cr deficiency can be aggravated by a low-protein diet, exercise, blood loss, and infection.

4) Supplemental Cr may increase longevity and retards aging by improving immune function and enhancing resistence to infectious diseases . . . e.g., supplemental Cr for market-transit-stressed feedlot calves and periparturient and early-lactation dairy cows improved immune status and health.

BONE AND VITAMINS/MINERALS

BONE IN GENERAL

1. **Composition**

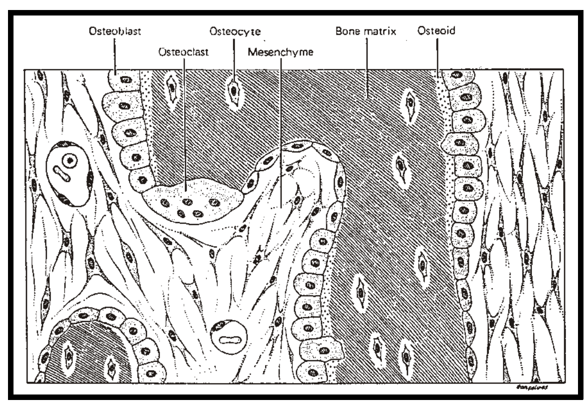
A. Composition of "normal" adult bones: (Maynard et al., 1979)

Item %	
Approximate composition:	
Water	45
Protein	25
Fat 10	
Ash	25
Composition of ash (moisture- & fat-free basis):	
Calcium	36
Phosphorus	17
Magnesium	0.8

B. The composition of bones is somewhat variable according to age, state of nutrition & species.
C. Bones also contain small amounts of Na, K, Cl & F, and traces of others.
D. The ratio of calcium & phosphorus in the bone is about 2:1.

2. **Bone Structure**

- Major constituents? - Bone cells, organic matrix & minerals.
- e.g., See Junqueira & Carneiro (1983).



A. Bone cells:

1) Osteoblasts:

a) Found in active areas of bone formation.
b) Responsible for the synthesis of bone matrix.
c) Most cells eventually rise to osteocytes, while others remain as osteoblasts for a long period of time, and some return to the state of "osteoprogenitor cell" (i.e., slightly differentiated mesenchymal cell).

2) Osteocytes:

a) Mature bone cells found in the bone matrix.
b) Less active vs osteoblasts, and involved in maintenance of bony matrix.

c) During destruction of the matrix (e.g., in the process of remodeling), some osteocytes die, whereas others return to the state of osteoprogenitor cell.

3) Osteoclasts:

a) Multinuclear, giant cells found in sites of bone resorption.
b) A precise role of osteoclasts in bone resorption is not clear, but those cells are responsible for secretion of collagenase, acid & proteolytic enzymes.

B. Organic matrix:

1) Consists of ≈ 95% collagen, which is responsible for hardness & resistance of the bone.
2) Others (≈ 5%) - Amorphous (noncrystalline) ground substances:

a) Ground substances - Fill spaces, act as a lubricant & also serve as a barrier.
b) Contains glycosaminoglycans associated with proteins (mucopolysaccharides) - e.g., Chondroitin 4-sulfate, chondroitin 6-sulfate and keratin sulfate.

C. Inorganic matters:

1) Mostly calcium & phosphorus.
2) Deposited as tricalcium phosphate ($Ca_3(PO_4)_2$) - Amorphous & predominant in immature bones.
3) $Ca_3(PO_4)_2$ undergoes changes to form hydroxyapatite {$3[Ca_3(PO_4)_2] \cdot Ca(OH)_2$ or $Ca_{10}(PO_4)_6(OH)_2$} - Crystalline & predominant in mature bones.

3. **Abnormal Bone Metabolism**

A. Rickets:

1) A disturbance of mineral metabolism in young animals.
2) Calcification of growing bones does not take place normally.

B. Osteomalacia - Similar conditions in mature animals.
C. Osteoporosis:

1) A failure of normal bone metabolism in adults.
2) Differs from osteomalacia, i.e., the mineral content is normal, but the absolute amount of bone is decreased.
☛ Common in humans after the age of 50, especially among ♀!

D. Osteopenia:

1) A general term used to describe bone pathology.

2) Simply means too little bone.

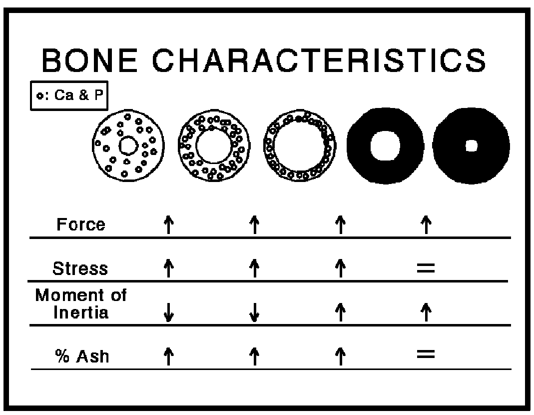
E. Osteosclerosis:

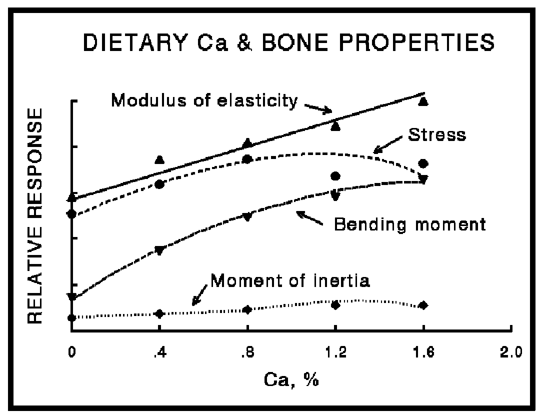
1) Presence of increased amounts of calcified bones.
2) Due to hypoparathyroidism, lead poisoning, etc.

4. **Assessing Bone Mineralization**

◦ *Reference: Crenshaw et al., 1981. Bone strength as a trait for assessing mineralization in swine: A critical review of techniques involved. J. Anim. Sci. 53:827.*

A. Cross section and characteristics of the bone - Figure on the left.
B. Dietary Ca & mechanical properties of the bone - Figure on the right.

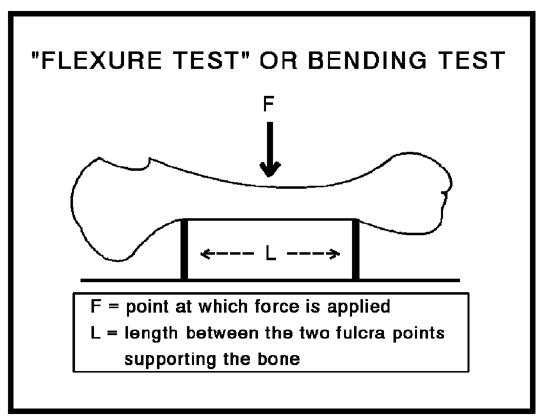




C. A "flexure test" (or bending test):

1) Considers the force, distance, inside & outside diameters, etc.
2) Based on measurements, can calculate:

   Bending moment, stress (or strength), modulus of elasticity & other bone characteristics!



5. **Factors Affecting Bone Metabolism**

A. Parathyroid hormone (PTH):

1) Acts directly on bones to ↑ bone resorption, ∴ ↑ plasma Ca.
2) ↑ reabsorption of Ca in the distal tubule (↓ urinary Ca).
3) ↓ plasma phosphate by ↑ phosphate excretion in the urine.

4) Increase formation of 1,25-dihydroxycholecalciferol.

B. 1,25-$(OH)_2D_3$ (vitamin D):

1) Increase absorption of Ca and phosphate from the intestine.
2) Also, involved in mobilizing Ca & phosphate from the bone.

C. Calcitonin:

1) The exact role is unknown, and does not seem to be involved in homeostasis of Ca, P or others.
2) Hypercalcemia or hypermagnesemia stimulates secretion.
3) ↓ plasma Ca by ↓ bone resorption.
4) ↓ reabsorption of Ca, P & Mg.

☞ The 1° function might be to prevent hypercalcemia after ingestion of a meal?

D. Other hormones:

1) Glucocorticoids - Anti-anabolic effects.
2) Growth hormone - Anabolic (at the epiphyseal cartilage).
3) Estrogen & androgens - Anabolic (↑ Ca & P in the body, and involved in formation of spongy bones).
4) Thyroid hormones - Normal concentrations/activities are anabolic, whereas the excess may have negative effects.

E. Vitamin A:

1) Has a role in normal development of bones via a control over osteoblast & osteoclast activities.
2) Involved in the synthesis of mucopolysaccharides, which are components of cartilage & bones.

☛ The vitamin A deficiency can lead to disorganized bone growth & irritation of joints.

F. Vitamin C:

1) Important in collagen synthesis, thus involved in protein matrix formation.
2) Involved in hydroxylation of Pro & Lys, thus involved in stabilizing, e.g., collagen.

G Manganese (Mn):

1) Required for enzymes involved in the synthesis of chondroitin sulfates (component of mucopolysaccharides in bones & cartilage).
2) Involved in activation of alkaline phosphatase, which is involved in collagen synthesis & transfer of P-group to bone tissues.

H. Zinc (Zn):

1) A component of alkaline phosphatase.
2) A component of collagenase, which is involved in collagen synthesis (∴ in bone matrix formation & remodeling of the bone).

CALCIUM AND PHOSPHORUS

1. **Introduction**

A. About 99% of total body Ca and 75% (80-85% in bones & teeth) of total body P are found in the skeleton - The ratio of Ca & P in the bone is 2.1:1.

B. The bone serves as:

1) Structural framework of the body.
2) A reservoir of Ca and P:

a) The bone is in a dynamic state, i.e., a continuous exchange between the solid & liquid phases, and also between bone & body fluids.
b) Ca & P are readily mobilized when needed, which is especially important for laying hens & lactating sows!

2. **Additional Functions**

A. Calcium:

- Serum Ca - ≈ 60% ionized, 35% bound to protein & 5% citrate, bicarbonate & phosphate complexes.

1) Involved in the development and maintenance of teeth.
2) Involved in a normal blood coagulation - Responsible for the conversion of prothrombin to thrombin, etc.
3) Involved in contraction of skeletal, cardiac & smooth muscles.
4) Involved in regulation of nervous system:

a) Ionic permeability of the membrane.
b) Generation of neuron stimulation.
c) Stimulation of nerve extremities.

5) An activator or stabilizer of enzymes.

☛ (2) through (5) - Usually don't see deficiency symptoms because amounts needed to perform these functions are small, and also there are considerable reserves in bones.

B. Phosphorus:

1) P in other tissues:

   a) In soft tissues & body fluids:

      (1) Mostly organic - Phosphoproteins, nucleic acids, hexose phosphates, energy-rich phosphates (ATP, ADP, creatine-P, etc.), etc.
      (2) Inorganic - Ca-, Mg-, Na-, K- & ammonium-phosphate, etc.

   b) In plasma - 85% phosphate ions ($H_2PO_4^-$, HPO_4^{--}), 10% protein bound & 5% Ca & Mg complexes.

2) Other functions:

   a) Involved in development & maintenance of teeth.
   b) Involved in metabolism of energy, protein & lipid (glycolysis, citric acid cycle, protein synthesis, FA synthesis, etc.).
   c) Component of membranes (phospholipids).
   d) Component of coenzymes (NAD, FAD).
   e) Important buffer (acid-base) - A major intracellular buffer in regulation of urine pH, etc.

☛ The most widely involved mineral in various body functions:

   a) Hardly any physiological function that does not involve P, directly or indirectly!
   b) Unlike Ca, a marginal deficiency of P can reduce rate & efficiency of growth.

3. **Absorption of Ca & P**

A. General:

1) Mostly absorbed from the upper tract (duodenum).
2) Ca by a specific Ca-binding protein (also by a passive diffusion).
3) P, less clear, but probably similar to Ca.
4) Absorption rate for dietary Ca & P is ≈ 30-50%.

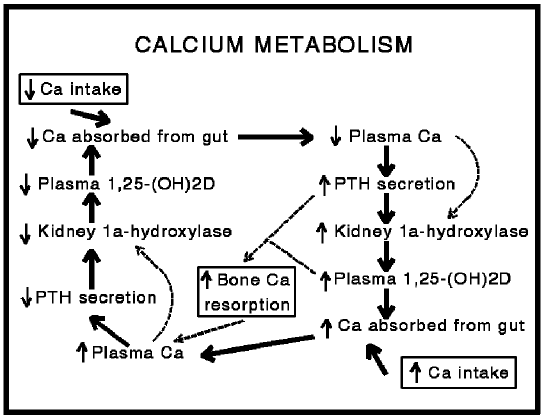
B. Factors affecting absorption:

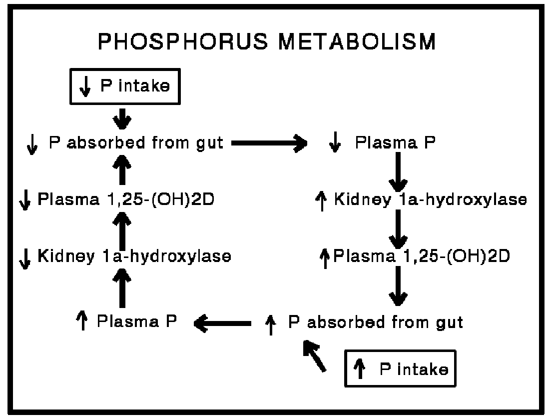
1) Animal's needs.
2) Form of P - Inorganic > organic.
3) Ca:P ratio - Excess Ca can form insoluble tricalcium phosphate, ∴ ↓ absorption of P.
4) Vitamin D - Involved in the synthesis of Ca-binding protein.
5) Excess Fe, Al, Mg can form insoluble phosphates, ∴ ↓ P (& others) absorption rate.
6) Excess fats can ↓ Ca absorption by forming a Ca soap.

7) pH - A lower pH can ↑ absorption rate by ↑ solubility.
8) Presence of chelates ↓ absorption (e.g., oxalate & phytates).

4. **Ca & P Homeostasis**

◦ Redrawn from Horst, 1986. J. Dairy Sci. 69:604:





5. **Excretion of Ca & P**

A. Calcium:

1) Almost 99% of Ca is reabsorbed by the kidneys, thus limited excretion via the urine.
2) Undigested & endogenous Ca are mostly excreted in the feces.

B. Phosphorus:

1) Excreted in both the urine and feces - Via the kidneys & GI tracts equally in pigs, and mainly via the kidneys in poultry.
2) Homeostasis by adjusting reabsorption from renal tubules.

6. **Deficiency of Ca & P**

A. Abnormal bone metabolism (rickets, osteomalacia, etc.).
B. Laying hens - A poor quality shell & incubation quality, and ↑ mobilization of Ca can lead to thin & brittle bones, thus easily fractured.
C. Sows - Paralysis of hind limbs; often seen in high-milking sows.
D. Depressed rate & efficiency of growth - Generally a deficiency of P, not Ca! (Also, likely to reduce production of milk, eggs, etc.)

7. **Fish & Calcium/Phosphorus**

A. General:

1) Calcium - Readily derived from water & adequate amounts in most fish diets:

   a) 0.5 to 1% of body weight (wet-basis).
   b) 99% of Ca in bones & scales with 20-40% of total Ca in scales.

2) Phosphorus - 85-90% of P in bones and scales.

B. Functions and metabolism of Ca & P:

1) Calcium:

   a) One of the most abundant cations in the fish body.
   b) In addition to skeletal tissues, widely distributed in soft tissues.
   c) Other functions are similar to other species.
   d) Unlike terrestrial animals, the bone is not the 1° site of Ca regulation:

      (1) Gas exchange across gills provides continuous access to an unlimited Ca.
      (2) Regulation of Ca influx & efflux by gills, fins & oral epithelia:

         (a) All structures are important in marine fish, with gills being the most important site in both marine & freshwater fish.
         (b) Gills are probably more efficient in freshwater fish.
         (c) The gut is not a major site of Ca absorption in marine fish, which drink water continuously.

   e) Others? (1) Endocrine control of Ca metabolism - ???, (2) some minerals (e.g., Mg, Sr, Zn & Cu) may ↓ Ca absorption, (3) Calcitonin inhibits Ca influx across salmon gills, (4) prolactin stimulates Ca uptake by tilapia, and (5) Vitamin D has no effect on the Ca homeostasis???
   f) Absorbed Ca:

      (1) Deposited in the bone & skin.
      (2) The rate of uptake, deposition pattern & retention by skeletal tissues? Similar for both freshwater & marine water fish, and similar for all species regardless of bone types, i.e., cellular or acellular types.
      (3) Ca exchange - Three time higher in scales vs bones, and scales are the site of labile Ca storage. Cellular bones must also play an important role in the Ca turnover in smooth skin fish (eels & catfish).

   g) Excretion - 1° by gills & kidneys (feces also contain endogenous Ca).

2) Phosphorus:

   a) General:

(1) In addition to being 1° constituent of structural components of skeletal tissues, located in every cell of the body.
(2) Other functions are similar to other species.

b) Metabolism:

(1) Has not been studied extensively compared to Ca.
(2) Feed is the main source because the water content of phosphate is low in both freshwater & seawater.
(3) Absorbed P accumulates mainly in soft tissues (heart, liver, kidney & blood), and limited extent in skeletal tissues.
(4) Regulation of P is considered to be more critical vs Ca, but mechanism(s) has not been elucidated.
(5) Excretion:

(a) ≈ 90% of P is lost via kidneys from the body in marine fish.
(b) Freshwater fish produce more urine, thus more loss via urine - The difference can be demonstrated by comparing freshwater eel & seawater-adapted eel.

C. Deficiency:

1) Calcium:

a) Not detected in carp & catfish, and Atlantic salmon.
b) Rainbow trout, eel, red sea bream & tilapias require a low level for optimum growth.
c) Deficiency may ↓ growth (& feed efficiency) & ash content (under the conditions of Ca-free diet & Ca-free water).

2) Phosphorus:

a) Carp - Signs include cranial deformity, ↓ growth, poor feed efficiency & low Ca & P content of vertebrae.
b) Signs for other fish species include anorexia, poor growth & feed efficiency, skeletal abnormalities, and poor bone mineralization.

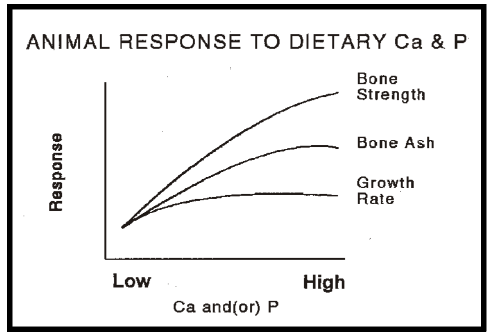
8. **Establishing Ca & P Requirements**

A. Methods used:

1) Growth trial.
2) Balance trial (Ca & P retention) - Difficult to interpret the results because of endogenous Ca & P.

3) Blood Ca & P - May not be useful because of the homeostatic mechanism (especially, Ca).
4) Blood enzymes - e.g., Alkaline phosphatase (↑ or higher with when deficient, and concentrations stabilize when the requirement is met).

5) Characteristics of the bone:



a) For the general response patterns of animals to dietary Ca & P, see the figure.

(1) For the maximum bone strength and ash, animals require higher levels of Ca & P than those required for maximum growth.
(2) Example? Pigs need at least 0.1% higher Ca to maximize bone strength!

b) Effect of Ca & P on growing animals - e.g., Grower-finisher pigs (Cera & Mahan, 1988. J. Anim. Sci. 66:1598)[a]:

	Ca/P level (%) during the finisher phase		
Item	0.45/0.32	0.52/0.40	0.65/0.50
Gain, kg/d	0.70	0.73	0.73
Serum mineral, mg/dL:			
Ca	11.41	10.70	10.89
P	7.65	8.87	9.20
Mg	1.88	1.78	1.80
Bone ash, %	57.92	60.00	60.79
Bone bending moment:			
Humerus	435	511	543
Femur	553	686	738

[a]Ca/P levels during the grower phase were 0.52/0.40, 0.65/0.50 & 0.80% Ca/0.60% P.

c) Effects of Ca & P on breeding animals - e.g., Sows (parities 1 to 2. Nimmo et al., 1981. J. Anim. Sci. 52:1330):

	Ca/P level			
Growing, %:	0.65/0.50	0.65/0.50	0.98/0.75	0.98/0.75
Gestation, g/d:	13.0/10.0	19.5/15.0	13.0/10.0	19.5/15.0
No. of ♀ started	23	22	24	22
Reproductive failure	4	3	7	4
Unable to stand	1	5	0	0
Weaned	14	18	17	18
Lost after weaning	2	0	0	1

Total remaining	12	18	17	17
Bone (metatarsal):				
Weight, g	33.4	33.4	35.5	334.7
Length, cm	9.18	9.30	9.46	9.42
Strength, kg/cm^2	437	498	528	549

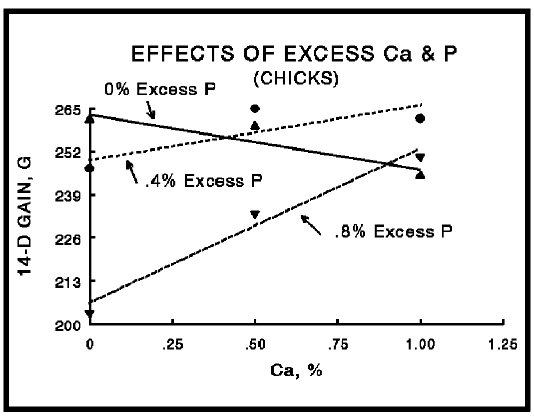
B. Ca and P ratio in pigs:

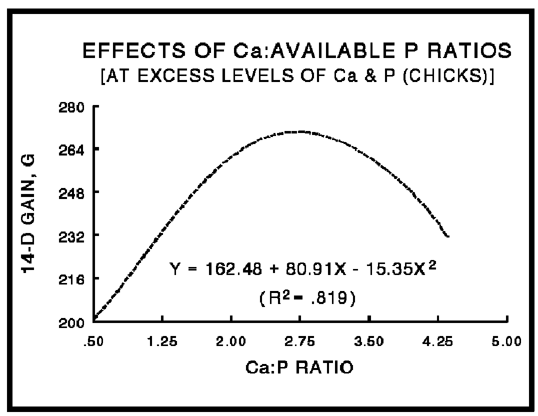
1) Important in establishing the requirement because of interactions.
2) Ideal ratio in feed = "1:1."
3) But, phosphorus is relatively expensive, thus acceptable ratios in swine range from 1.25 to 1.50:1:

a) The most commonly used ratio is 1.3:1.
b) Unacceptable ratio is ≥ 2:1, especially when P level is marginal or the diet is high in phytate P.
c) If P is above the requirement, pigs can tolerate a relatively high Ca:P.

C. Ca:P ratio in poultry:

1) Effect of excess Ca & P on performance of chicks - Figure on the left (Adapted & redrawn from Wedekind & Baker, 1990. Poult. Sci. 69:1156).
2) Ca:available P ratios on performance of chicks -Figure on the right (Adapted & redrawn from Wedekind & Baker, 1990. Poult. Sci. 69:1156).





☛ For poultry, generally Ca to available P ratio of 2 to 1 is recommended!

9. **Availability of Ca & P**

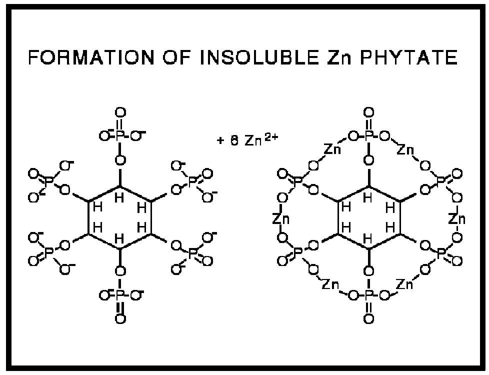
A. Calcium - Bioavailability is less critical because:

1) Ca in most feedstuffs is very low - e.g., Corn = 0.03%. (An exception is alfalfa, which contains ≈ 1.40% Ca.)

2) Most of Ca sources/supplements (calcium carbonate, calcium sulfate, oyster shell, marble dust, etc.) are 100% or close to 100% available.

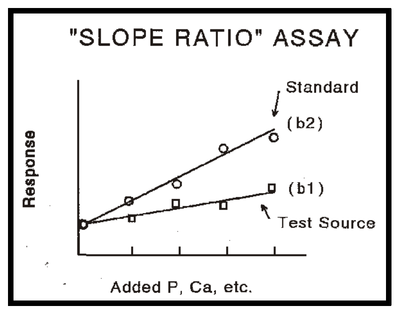
B. Phosphorus:

1) The content in feedstuffs is variable, thus the amount of dietary inorganic P needed to meet the requirement.
2) Also, considerable variations in bioavailability of P in plant feedstuffs.
3) About ⅔ of total P in plant feedstuffs is phytate, which is a storage form of P in seeds.



   a) Phytate can form complexes with Zn, Cu, Co, Mn, Fe, Ca, etc.
   b) Formation of insoluble zinc phytate - Redrawn from Georgievskii et al., 1982. In: Georgievskii et al.
   c) Can be utilized after hydrolysis by phytase.
   d) Phytase is present in some feeds (relatively high in wheat, barley & rye), and also produced by some microbes.
   e) Ruminant species contain organisms capable of hydrolyzing phytate in the rumen.
   f) Nonruminant species - Considerable variations in their ability to hydrolyze phytate.

4) Determination of bioavailability:



   a) Often "slope-ratio assay" is used - See the figure.
   b) Bioavailability

$$= \frac{\text{b (Test source)}}{\text{b (Standard source)}}$$

5) Bioavailability of some feedstuffs: (NRC, 1988)

Feedstuff	Avg., %	Range, %
Alfalfa meal	100	
Barley	31	
Bone meal, steamed	82	
Corn	15	9-29
Corn, high moisture	49	42-58
Cottonseed meal	21	0-42
Defluorinated rock phosphate	87	83-90
Dicalcium phosphate	100	
Fish meal	100	
Meat & bone meal	93	
Oats	30	23-36
Peanut meal	12	

Rice bran	25	
Sorghum	22	19-25
Sorghum, high moisture	43	42-43
Soybean meal	38	36-39
Soybean meal, dehulled	25	18-35
Wheat	50	40-56
Wheat bran	35	
Wheat middlings	45	34-55

6) Supplemental P sources - Most commonly used sources such as monosodium phosphate, mono- and dicalcium phosphates are 95-100% available.
7) Phosphorus sources for fish:

   a) Phytate P (≈ 67% of grain P) has similar effects on fish, i.e., poor availability. (Also, phytic acid can form insoluble salt with Ca in the digestive tract.)
   b) Fish meal - 40 to 75% available in fish having "stomach."
   c) Inorganic P (e.g., Na or mono-Ca P) sources are highly available, but the availability of tri-Ca P is low compared to mono- or di-Ca P.

10. **Ca & P Requirements (%)**

A. Requirements: (Also, see appropriate "Nutrition & Feeding" sections.)

Animal	Ca	P	Available P
Poultry (NRC, 1994):			
Immature chickens	0.80-2.00		0.30-0.40
Laying hens	2.71-4.06		0.21-0.31
Broilers	0.80-1.00		0.30-0.45
Turkeys, growing	0.55-1.20		0.28-0.60
Turkeys, laying	2.25		0.35
Swine (NRC, 1998):			
3-120 kg	0.45-0.90	0.40-0.70	0.15-0.55
Sows	0.75	0.60	0.35
Boars	0.75	0.60	0.35
Horses (1989)	0.21-0.62	0.15-0.34	
Fish (NRC, 1993):			
Channel catfish	?	0.45	
Trout, salmon & carp	?	0.60	
Tilapia	?	0.50	

B. Factors that influence the requirement & supplementation:

1) The variability of nutrient contents in ingredients.
2) Nutrient availability.
3) Animal performance potential, and the variability in animal response.
4) Energy content of feed.
5) Stress from diseases, overcrowding, poor ventilation, etc.
6) Interactions among ingredients & among nutrients.

7) Adequacy of vitamin D and(or) liver/kidney integrity.

11. **Toxicity**

A. Neither Ca nor P is generally considered toxic - Under normal conditions, Ca & P are absorbed according to the needs, and excess Ca & P are promptly excreted (homeostatic mechanisms).
B. Excess of either one can cause bone disorders, and reduced feed intake, weight gain and efficiency.
C. Excess Ca may cause deficiency of other essential elements such as P, Mg, Fe, I, Zn and Mn, and adverse effects are generally due to interactions!
D. Excess P may cause mild diarrhea, and also interacts with others (e.g., Ca & Mg).
E Maximum tolerance levels: (McDowell, 1992)

Animal	Ca, %	P, %
Cattle, horses & rabbits	2	1
Sheep	2	0.6
Swine	1	1.5
Poultry	1.2	1
Laying hens	4	0.8

OTHER MINERALS IN BONE PHYSIOLOGY

(*Major reasons for including these minerals in this section?)*

1. **Magnesium**

A. Found mostly in the skeleton.
B. Involved in activation of alkaline phosphatase, etc.

2. **Manganese**

A. As a component of enzymes, involved in the synthesis of chondroitin sulfate.
B. Involved in activation of alkaline phosphatase, etc.

3. **Zinc**

A. Interacts with Ca.
B. Component of alkaline phosphatase & collagenase.

4. **Fluorine** - May inhibit excessive demineralization of bones.

MAGNESIUM

1. **General**

A. About 70% of Mg is in the skeleton, and remaining Mg is found within cells of soft tissues.
B. Unlike Ca & P, Mg is not readily mobilized.
C. Remaining 30% in soft tissues, and it is a main intracellular cation along with K.

2. **Functions**

A. Constituent of bones & teeth & important for maintaining the integrity of bones & teeth - $Mg(OH)_2$ are held within the hydration shell of apatite crystal surface.
B. Serving as a cofactor or activator of a number of enzyme systems:

1) An active component of enzymes with thiamin pyrophosphate (TPP) as a cofactor.
2) Activates enzymes involved in phosphorylation, carboxylation & oxidation of pyruvate, etc. and also polymerases (DNA & RNA), ribonuclease & others involved in nucleic acid metabolism.

3. **Deficiency**

A. Poultry - Hyperirritability, convulsion, comatose, death (some times), reduction of egg production and hatchability, etc.
B. Swine - Hyperirritability, muscular twitching, reluctance to stand, loss of equilibrium, tetany, etc. & death.
C. Fish:

1) Carp, catfish, eel & rainbow trout - Aanorexia, ↓ growth, sluggishness & high mortality.
2) Carp - Convulsions & cataracts.
3) Rainbow trout - Calcinosis of kidney, vertebrae deformity & degeneration of muscle fibers & epithelial cells of pyloric cecum & gill filaments.

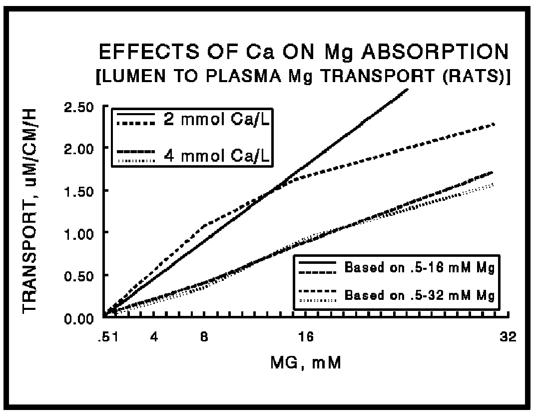
4. **Mg Requirements** (Also, see appropriate "Nutrition & Feeding" sections.)

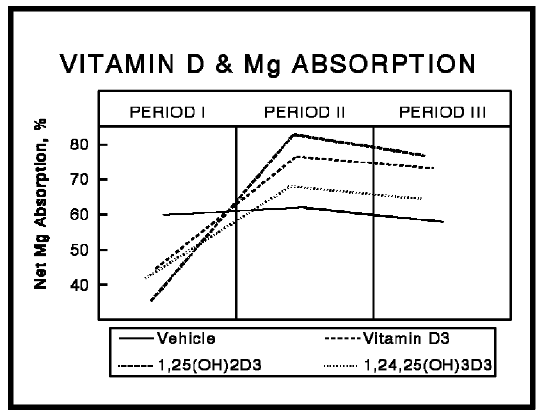
Animal	mg/kg or %
Poultry (NRC, 1994):	
Immature chickens	370-600
Laying hens	420-625
Broilers	600
Turkeys	500
Swine (NRC, 1998):	
All classes	400
Horses (NRC, 1989; %)	0.07-0.12
Fish (NRC, 1993; %):	
Channel catfish	0.04
Rainbow trout	0.05
Pacific salmon	Not tested
Common carp	0.05
Tilapia	0.06

A. Swine - Not well established, and corn-soy diets usually contain enough Mg to meet the requirement.
B. Fish - Diets usually contain adequate levels of Mg (plus active uptake from the environment), thus probably no need for dietary supplementation.

5. **Mg and Ca/Vitamin D**

- Effects of Ca & vitamin D on Mg absorption: (Adapted & redrawn from Hardwick et al., 1991. J. Nutr. 121:13)





6. **Toxicosis**

A. A toxicosis due to ingestion of natural feedstuffs has not been reported, and does not likely to occur unless making a mistake in supplementation process, or water is very high in Mg (≈ 1% or higher).
B. Some toxicity signs include lethargy, disturbance in locomotion, diarrhea, lowered feed intake & performance, and death. (Certain concentrations of Ca & P may protect animals from "Mg toxicosis.")
C. Maximum tolerable levels (NRC, 1980) - 0.50% for cattle & sheep, and 0.30% for poultry & swine.

MANGANESE

1. **General**

A. Involved in normal growth, reproduction and skeletal development.
B. Distributed widely throughout tissues & fluids:

   1) Present in a small amount.

2) Although there are, generally, no notable concentrations in any particular location, it is fairly high in bones. (Also significant amounts can be found in liver, muscle, kidneys, gonadal tissues & skin.)
3) In tissues, concentrated more in mitochondria vs cytoplasm or other organelles.
4) There seem to be little variations among species or with age.

C. Coordination chemistries of Mn^{2+} and Mg^{2+} are similar, thus may replace each other as a activator of various enzymes.

2. **Functions**

A. Bone tissue:

1) Mn is required for enzymes involved in the synthesis of chondroitin sulfate (component of mucopolysaccharides in bone matrix and cartilage).
2) Activate alkaline phosphatase, which is involved in formation of collagen & transferring phosphate to the organic base of bone tissues.
3) Activate many enzymes (or may be acting as a cofactor?) involved in carbohydrate, lipid and protein metabolism:

a) Examples include arginase, hexokinase, pyruvate carboxylase, and isocitrate dehydrogenase.
b) Some enzymes with specific needs for Mn include arginase, pyruvate carboxylase & superoxide dismutase.

3. **Deficiency**

A. Poultry - Impaired growth & development, perosis or slipped tendon, lower egg production & shell strength, poor hatchability, etc. (Perosis is also associated with choline & biotin, and this condition is aggravated by excess Ca & P.)
B. Swine - Abnormal skeletal growth, increased fat deposition (Mn has a specific lipotropic effect), impaired reproductive performance and milk production, etc.
C. Fish - ↓ growth & skeletal abnormalities in rainbow trout, carp & tilapia.

4. **Mn Requirements** (Also, see appropriate "Nutrition & Feeding" sections.)

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	28-60
Laying hens	17-25
Broilers	60
Turkey	60
Swine (NRC, 1998):	
Growing swine	2-4
Sows & boars	20

Horses (NRC,1989; DM)	40
Fish (NRC, 1993):	
Channel catfish	2.4
Rainbow trout	13
Pacific salmon	Required, but not determined
Common carp	13
Tilapia	Required, but not determined

5. **Mn and Ca/P**

- Manganese utilization in chicks fed various sources of Ca & P in excess[a]: (Wedekind and Baker, 1990. Poult. Sci. 69:977)

	Amount added				
Source	Mn, mg/kg	Ca, %	P, %	Gain, g	MN availability, %
None	0	0	0	269	
None	500	0	0	258	
None	1,000	0	0	255	97.3
$CaCO_3$	1,000	1.0	0	238	87.5
$CaCO_3 + K_3PO_4$	1,000	1.0	.88	204	36.5
$CaCO_3 + K_2HPO_4$	1,000	1.0	.88	240	33.5
$CaCO_3 + KH_2PO_4$	1,000	1.0	.88	261	37.4
KH_2PO_4	1,000	0	.88	203	45.0
Dical	1,000	1.0	.88	258	52.8
De-F rock PO_4	1,000	1.0	.56	279	55.9

[a]The basal diet contained 1.1% Ca, 0.51% available P & 37 mg Mn/kg; Estimated the availability based on total tibia Mn & supplemental Mn intake.

6. **Toxicosis**

A. Although some metabolic alterations may occur (e.g., effects on metabolism of Cu, Ca, P & Fe), generally, 1,000 ppm or less has no adverse health effects on most species.

☛ One of the least toxic trace elements for poultry & mammals!?

B. With above 2,000 ppm, may see growth retardation, anemia, gastrointestinal lesions & neurological signs.

C. Maximum tolerable levels - 1,000 ppm for sheep & cattle, 2,000 ppm for poultry, and 400 ppm for swine.

ZINC

1. **Functions**

A. Component of many metallo-enzymes - e.g., Alkaline phosphatase, collagenase (bone collagen), dehydrogenases (alcohol, malic, lactic, etc.), carbonic anhydrase, aldolase, RNA & DNA polymerases, thymidine kinase, carboxypeptidase, etc.
B. Activates many enzymes - e.g., Glycylglycine dipeptidase, arginase, dipeptidases, tripeptidase, His deaminase, enolase, oxalacetate dehydrogenase, lecithinase, etc.
C. Has a wide range of functions/effects:

1) Growth rate - Associated with nucleic acid biosynthesis, amino acid utilization or protein synthesis, etc.
2) Skin & wound healing - Skin is rich in Zn, and deficiency can lead to parakeratosis, scaling/cracking, loss of hair & dermatitis.
3) Immune response - Essential to the integrity of the immune system.
4) Water & cation balance - Early signs of deficiency in most species are dehydrated appearance, elevated hematocrit & diarrhea.
5) Others - Development of sex organs, reproductive functions, bone and blood formation, metabolism of nucleic acids, proteins & carbohydrates, etc.

D. Other roles of Zn?

1) Its relationship with vitamin A:

a) Zn deficiency reduces retinol-binding protein (Mobarhan et al., 1992. Int. J. Vit. Nutr. Res. 62:148), which influences mobilization of vitamin A.
b) Thus, Zn may aid in maintaining normal concentration of vitamin A in plasma, which in turn maintains normal functions of epithelial tissues.

2) Protection of membranes - Zn has antioxidative effect in protecting sulfhydryl group in the membrane.
3) Prostaglandin metabolism - Affects metabolites of PG.
4) Lipid metabolism - Zn deficiency ↓ incorporation of glucose into FA.
5) Microbial growth - Microorganisms need Zn for growth.
6) Behavior & learning ability - Severe maternal Zn deficiency has severe consequences in learning abilities & emotional responsiveness.

2. **Deficiency**

A. Poultry - Delayed growth, unnatural feather formation, shorter & thicker long bones of the legs & wings, lower egg production & hatchability, etc.
B. Swine - Parakeratosis (hyperkeratinization of skin), reduced rate & efficiency of growth, reduced testicular development in boars, small litters, small pigs, etc.
C. Fish:

1) A widespread occurrence of cataracts in rainbow trouts (1973-1974) was traced back to Zn unavailability in white fish meal.

2) Other signs may include ↓ growth, high mortality, erosion of fins & skin, short body dwarfism in rainbow trout, and ↓ growth, feed intake, bone Zn & Ca in catfish.

3. **Zn Requirements** (Also, see appropriate "Nutrition & Feeding" sections.)

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	33-40
Laying hens	29-44
Broilers	40
Turkeys	40-70
Swine (NRC, 1998):	
Growing pigs	50-100
Sows & boars	50
Horses (NRC, 1989; DM)	40
Fish (NRC, 1993):	
Channel catfish	20
Rainbow trout	30
Pacific salmon	Required, but not determined
Common carp	30
Tilapia	20

- Supplements - Oxide, carbonate, sulfate & chloride salts are highly available sources, but sulfide salt is a poor source.

4. **Zn, Ca & Phytate**

A. Phytate binds Zn and reduces its availability.
B. High dietary Ca also reduces absorption of Zn, thus Zn requirement is directly proportional to dietary Ca.
C. Phytate, Ca and Zn (growing rats): (Unknown source)

Phytate, mg/kg	Ca mg/kg	Zn mg/kg	Molar ratio[a]	4-wk Gain, g
10,000	16,000	2	197.8	8.8
10,000	16,000	15	26.3	12.5
4,000	16,000	15	10.5	15.3
4,000	16,000	70	2.3	37.5
4,000	16,000	125	1.3	48.5

[a]Molar ratio = (Phytate)(Ca)/Zn

1) Should not exceed 2.0 (maximum) for optimum performance.
2) In typical corn-soy diets (.75% Ca & 75 ppm Zn), the ratio is ≈ 1.80.

5. **Toxicosis**

A. Generally no adverse physiological effects at < 600 ppm.
B. Supplemental Zn at > 1,000 ppm caused some adverse effects in most studies - signs include GI tract distress, ↓ feed intake & weight gain, anemia, reduced utilization of Ca & bone ash, ↓ tissue concentrations of Fe, Cu & Mn, damage to pancreas, non-viable newborn, etc.
C. Maximum tolerable levels - 300 ppm for sheep, 500 ppm for cattle & 1,000 ppm for swine & poultry.

FLUORINE

1. **General**

A. Generally classified as a toxic element, and excessive accumulation in bones & teeth can result in:

1) Bones - Thick & soft bones, reduced breaking strength (low ash content), etc.
2) Teeth - Chalky and brittle teeth, and an enamel becomes pitted & stained (yellow to black) & may chip off (mottling).

B. Small amounts are beneficial in:

1) Development of a dental caries-resistance - 1-2 ppm in water may have beneficial effects. (Addition of 0.7-1 ppm is a common practice in many municipalities.)
2) Inhibit an excessive demineralization of bones (especially in aged).

C. Concentrations in bones & teeth:

1) Normal (dry, fat-free basis) - 300-600 ppm in bones & 200-540 ppm in teeth.
2) After high F intake, can expect 3,000 to 4,500 ppm in bones.

a) Generally, F toxicosis occurs when the F content in bones exceeds 5,500-7,000 ppm.
b) "Saturation" point is ≈ 15,000 to 20,000 ppm.

D. Classification of dental fluorosis: (NRC, 1974)

Score	Description
0	**Normal** - smooth, translucent, glossy white enamel; tooth has a normal shape.
1	**Questionable effect** - slight deviations; may have enamel flecks, but is not mottled.
2	**Slight effect** - slight mottling of enamel; best observed as horizontal striations with transmitted light; may be slightly stained but no increase in normal rate of wear.
3	**Moderate effect** - definite mottling; large areas of chalky enamel or generalized mottling of entire tooth; tooth may have slightly increased rate of wear and may be stained.
4	**Marked effect** - definite mottling, hypoplasia, and hypocalcification; may have pitting of enamel; with use, tooth will have increased rate of wear & may be stained.

5 **Severe effect** - definite mottling, hypoplasia, and hypocalcification; with use, tooth will have excessive rate of wear, and may have eroded or pitted enamel. (Tooth may be stained or discolored.)

E. Other symptoms associated with F toxicosis:

1) Low levels - Anorexia & reduced performance (secondary to dental & skeletal damages?), unthriftiness, dry hair, thick, nonpliable skin, etc.
2) High levels - High-F content of blood & urine, restlessness, stiffness, excessive salivation, nausea, vomiting, urinary & fecal incontinence, clonic convulsions, necrosis of GI mucosa, weakness, severe depression & cardiac failure.
3) Difficult to predict possible/potential problems because:

    a) No histologic or functional changes in blood or soft tissues that can be used to assess the status.
    b) The severity of the problem is influenced by the form, duration of ingestion, general nutritional status, species, age, other dietary components, etc.

2. **F & Animals**

A. According to a recent pig research:

1) ≈ > 132 ppm may resulted in reduced feed intake & weight gain.
2) ≈ > 7 ppm - Seems to have detrimental effects on the integrity of bones.

B. The fluoride content in some phosphate compounds:

1) Defluorinated (e.g., mono- & dicalcium phosphate) - 0.12 to 0.18% F.
2) Soft rock phosphate - 1.2% F.
3) Ground rock phosphate - 3.7% F.

C. Use of phosphates in the diet:

1) Raw rock phosphate (3% F) at 1.5% of the diet provides 450 ppm F.
2) Defluorinated phosphate (0.18% F) at 1.5% of the diet provides 27 ppm F.

D. Maximum tolerable levels:

Young & mature cattle	40 to 50 ppm
Finishing cattle	100 ppm
Horses & rabbits	40 ppm
Breeding sheep	60 ppm
Finishing sheep	150 ppm
Swine & turkey	150 ppm
Chickens	200 ppm

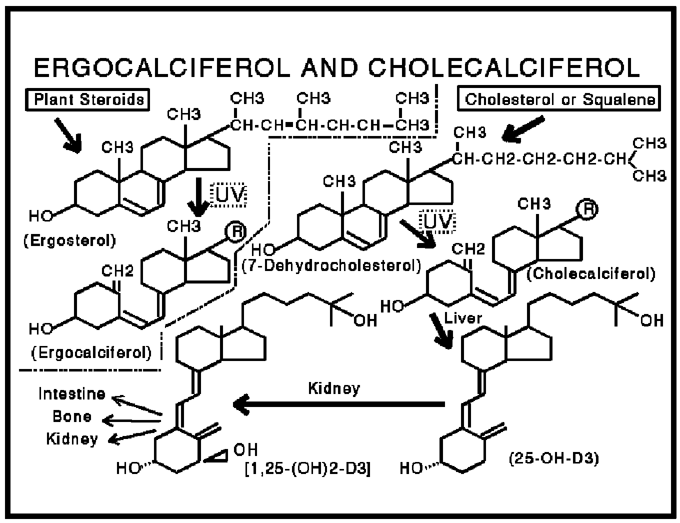
VITAMIN D

1. Introduction

A. Often referred to as a sunshine vitamin:

1) In the total confinement facility (swine & poultry), little or no exposure to the natural sunlight, ∴ must be supplemented.
2) Even those on pasture/outside lots, may develop deficiency symptoms during winter months.

B. A general function of the vitamin is to elevate plasma Ca & P for normal mineralization of bones & also for other body functions.
C. Two major natural sources or provitamins - Cholecalciferol (D_3 - animal sources) & Ergocalciferol (D_2 - plant sources).
D. The most potent vitamin D metabolite is 1,25-dihydroxy-D_3. (Based on the mode of action, "1,25-dihydroxy-D_3" may be considered as a hormone?)



2. Structure & Metabolism

A. Ergo- & cholecalciferol: Adapted & redrawn from McDowell, 1989.
B. Vitamin D and Ca & P:

1) Intestine:

a) Two forms of vitamin D-dependent CaBP are known (MW of 27,000 & smaller one, MW of 9,000).
b) But, a precise role of CaBP on transfer of Ca is unclear!

(1) May be inducing synthesis of protein(s) that involves in transfer of Ca!?
(2) Vitamin D may alter membrane fluidity, thus ↑ Ca transport rate!?

2) Effects on the bone:

a) ↑ mobilization of Ca and P to the ECF, but little is known about the process.
b) 25-(OH)D (major metabolite in bones) & 24,25-$(OH)_2$D [found in a constant proportion with 25-(OH)D in bone] may have unique actions on the bone (e.g., promoting "normal" development of the bone?).

3) Effects on other organs/tissues - Poorly understood:

a) ↑ renal reabsorption of Ca & P - Less important for Ca since most of Ca is reabsorbed in absence of vitamin D, but quantitatively important for P.
b) May act on parathyroid glands to regulate PTH secretion.

3. **Functions**

A. 1,25-$(OH)_2D_3$ stimulates the synthesis of Ca-binding proteins in the gut mucosa, which facilitate absorption of Ca, P & Mg.
B. Maintains the homeostasis of Ca/P along with PTH & calcitonin in the bone & kidneys.
C. Current view:

1) Conversion of D_3 to 25-$(OH)D_3$ in the liver.
2) Conversion to 1,25-$(OH)_2D_3$ in the kidneys.
3) 1,25-$(OH)_2D_3$ - Transported to the intestine & bone.
4) 1,25-$(OH)_2D_3$ - Unmask a specific DNA which is transcribed into the mRNA.
5) Synthesis of a protein (or proteins), which appears at the brush border as an ATP-requiring transport system. (Ca-binding protein & others.)
6) Thus, enhancing absorption of Ca & P (also, Mg).

4. **Deficiency**

A. Similar to the Ca-P deficiency in land animals.
B. Fish -Get relatively little UV light from the sun because of shallow depth of penetration of these rays in natural water, and dietary needs has been established for at least two species by feeding vitamin D deficient diets:

1) Channel catfish - ↓ weight gain & ↓ body ash, Ca & P (fed for < 16 wk).
2) Rainbow trout - ↓ weight gain, tetany in white muscle & structural changes in muscle fibers.

4. **Vitamin D Requirements** (1 IU = 0.025 µg of vitamin D_3) (Also, see appropriate "Nutrition & Feeding" sections.)

Animal	ICU/kg	IU/kg
Poultry (NRC, 1994):		
Immature chickens	190-300	
Laying hens	250-375	
Broilers	200	
Turkeys	1,100	
Swine (NRC, 1998):		
3-120 kg		150-220
Sows & boars		200
Horses (NRC, 1989; For those not exposed to sunlight, DM)		300-800
Fish (NRC, 1993):		
Channel catfish	500	
Rainbow trout	2400	
Others	Not tested	

A. Vitamin D_3 may be 30 times more effective than D_2 in poultry - Eliminates D_2 rapidly via bile.
B. Similarly, D_2 is poorly utilized or not at all by fish - e.g., D_3 was utilized ≈ 3 times more efficiently than D_2 by rainbow trout.
C. Recent data indicate that pigs, ruminants & others also utilize D_3 more efficiently.
D. Natural feeds are generally low or devoid of vitamin D, thus needs to be supplemented.
E. Factors influencing requirements? - Sunlight, amount and ratio of dietary Ca and P, availability of Ca & P, species, physiological factors, and others.

5. **Supplementation/Supplements**

A. Commercial supplements are stabilized or protected by coating (e.g., gelatin, starch, sugars & antioxidants).
B. In the original unopened container with good storage conditions, 90-100% retention of the vitamin activity can be expected up to one year.
C. Stability can be ↓ by moisture, minerals, light, oxygen, heat, rancid fat & pelleting.
D. Vitamin D stability: [Coelho, 1991. Feed Management 42(10):24]

Condition	Retention, %
In vit-TM premix (½ → 6 mo)	96 → 65
Pelleting - 140°F/3 min → 220°F/3 min	97 → 89
Extrusion - 230°F/3 min → 330°F/3 min	95 → 83
In feed (Avg. of the industry - ½ → 6 mo	93 → 55

6. **Toxicity**

A. Signs in swine include anorexia, stiffness, lameness, arching of the back, polyuria, etc.
B. Postmortem examination reveals extensive mineralization in cardiovascular systems, kidneys, respiratory tracts, salivary glands, GI tracts, etc.
C. Safe upper dietary levels of vitamin D_3 (IU/kg): (NRC, 1987)

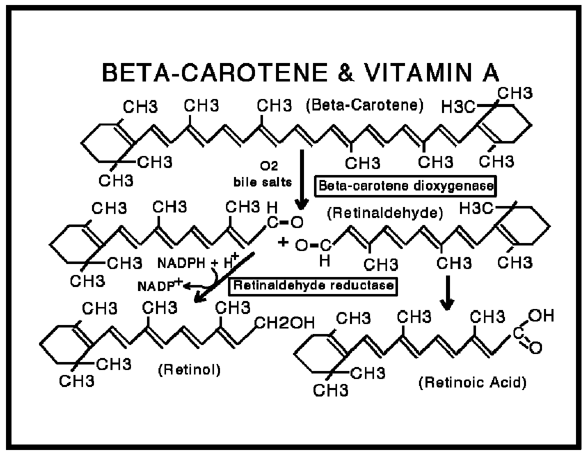
		Exposure time	
Species	Requirement	< 60 d	> 60 d
Birds:			
Chicken	200	40,000	2,800
Turkey	900	90,000	3,500
Swine	220	33,000	2,200
Fish:			
Catfish	1,000	20,000	
Trout	1,800	1,000,000	
Horse	400	2,200	
Sheep	275	25,000	2,200
Cattle (cow)	300	25,000	2,200

VITAMIN A

1. Introduction

A. From a practical standpoint, may be considered as the most important vitamin because all animals require supplementation.
B. Necessary for support of growth, health and life of higher animals.
C. Vitamin A itself does not occur in plants as such:

1) Occurs in plants as carotenoid pigments (provitamin A).
2) Identified over 80 carotenoids with ≈ 15 having vitamin A activity. (☞ According to some, there are over 600 carotenoids in nature with < 10% having provitamin A activity!)
3) The most important one is β-carotene:



a) Variations among species in their ability to convert carotene to vitamin A.
b) In pigs, it might be only 25-30% [much higher in other nonruminant species such as poultry & rats, and also fish (especially channel catfish)].

D. Animals can store large amounts of vitamin A in the liver - e.g., mature sows completed three normal pregnancies without vitamin A supplement in one study (showed signs of deficiency in the fourth).

2. Structures

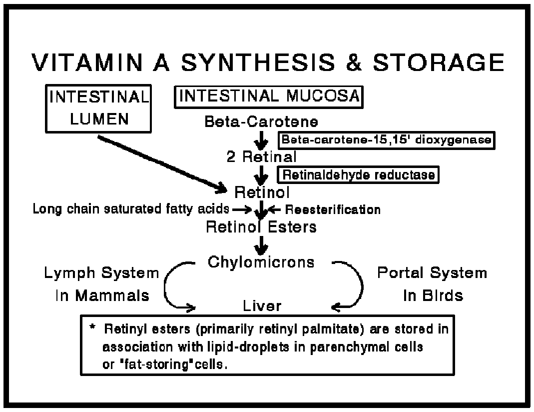
◦ β-Carotene and vitamin A: (Redrawn from Martin et al., 1983)

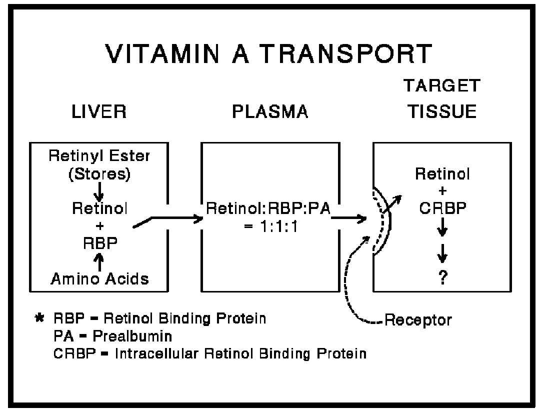
A. Retinol (alcohol) - Probably serving as a sterol hormone?
B. Retinal (aldehyde) - Precursor of a visual pigment, rhodopsin.
C. Retinoic acid - Supports normal growth & differentiation, but not a visual pigment precursor & can't support normal function of the reproductive system in male or females.

3. Biosynthesis, Transport & Storage

A. Over 90% of vitamin A is stored in the liver with remainder in the kidneys, lungs, adrenal & others.

B. Liver can store enough to protect animals for a long period of dietary scarcity.
C. Vitamins E & D might be using the same transport mechanism, thus excess of one of these (especially, vitamin A) may cause deficiency of others.





4. **Deficiency/Functions**

- Metabolic functions of vitamin A have not been completely elucidated!

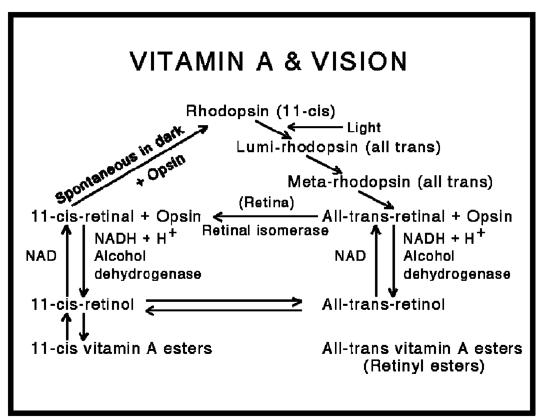
A. Defects in bone growth (disorganized bone growth & irritation of joints):

1) Vitamin A affects the activity of osteoblasts and osteoclasts.
2) Involved in mucopolysaccharide synthesis.
3) Changes in bones may be responsible for muscle incoordination & other nervous symptoms associated with vitamin A-deficient animals?

B. Abnormal epithelial tissues:

1) Mucus membranes protect respiratory, GI and uro-genital tracts.
2) Vitamin A deficiency can cause damages to mucus-secreting cells of epithelium (keratinization), which can lead to ↑ incidence of infections, diarrhea, kidney & bladder stones, etc.
3) Vitamin A is stabilizing membranes? - May be acting as a cross-linkage agent between lipid & protein in the membranes!
4) Involved in a normal cell differentiation?
5) Involved in the synthesis of mucopolysaccharides.

C. Impaired vision - The role of vitamin A in vision: (Adapted & redrawn from McDowell, 1989)



- Impaired vision is due to a failure of rhodopsin formation, which can lead to night blindness and also total blindness!

D. Reproduction problems:

1) Vitamin A deficiency can lead to a failure of spermatogenesis, resorption of fetus, abortion, retained placenta, reduced hatchability, etc.
2) Possible reasons?

a) Probably the results of failure to maintain normal epithelium?
b) Direct effects - Effects of vitamin A on cell differentiation & proliferation, transcription of specific genes, etc.?
c) Indirect effects - Production of steroid hormones, enhancing the immune status, etc.?

E. Deficiency signs in fish:

1) Salmonids - ↓ growth rate, light skin color, pathological conditions of the eye characterized by exophthalmos, hemorrhagic eyes, eye lens displacement, thinning of cornea, degradation of the retina, etc.
2) Channel catfish - Exophthalmos, edema & kidney hemorrhage.
3) Common carp - Light skin color, fin & skin hemorrhages, exophthalmos & deformed gill opercula.

F. β-Carotene:

1) May have a role in reproduction that is independent of vitamin A - A higher intensity of estrus, ↑ conception rate, ↓ embryonic mortality, heavier birth & weaning weights have been observed with β-carotene supplementation.
2) Also, it has been suggested that it is an inhibitor of some type of cancers in humans?

☞ β-carotene might be serving as an antioxidant against lipid peroxidation, thus having beneficial effects on reproductive performance?

5. **Vitamin A Requirements** (1 IU = 0.30 μg of retinol or 0.55 μg of vitamin A palmitate) (Also, see appropriate "Nutrition & Feeding" sections.)

Animal	IU/kg
Poultry (NRC, 1994):	
Immature chickens	1,420-1,500
Laying hens	2,500-3,750
Broilers	1,500
Turkeys	5,000
Swine (NRC, 1998):	
Growing pigs	1,300-2,200
Sows	2,000-4,000
Boars	4,000

Horses (NRC, 1989)	2,000-3,000
Fish (NRC, 1993):	
Channel catfish	1000-2000
Rainbow trout & pacific salmon	2500
Common carp	4000
Tilapia	Not tested

6. **Sources/Supplementation**

A. Rich sources - Fish oils (e.g., swordfish liver oil contains 250,000 IU/g).
B. Factors detrimental to stability include long storage, high temperature & humidity, pelleting, extrusion, presence of trace minerals, etc. (☞ Vitamin A might be a least stable vitamin among the vitamins commonly supplemented!)
C. Vitamin A palmitate (synthetic):

1) Esterified with palmitate to increase stability.
2) Also encapsulated in gelatin beadlets for further protection.
3) But, still very unstable, thus usually fortified with several-fold levels to compensate for potential losses during the storage.

7. **Hypervitaminosis**

A. General:

1) Common reactions to massive doses of vitamins include general malaise, anorexia, nausea, hyperirritability, peeling skin, muscular weakness, twitching, convulsions, paralysis and death.
2) Chronic toxicity (generally with intake of 1,000 times the requirement for a long time, but may be observed with 10 times?) - Skeletal malformation, spontaneous fractures, internal hemorrhage, loss of appetite, slow growth, loss of weight, skin thickening, increased blood clotting time, etc.
3) Vitamin A toxicity:

a) Signs in fish include enlargement of liver and spleen, abnormal growth, skin lesions, epithelial keratinization, hyperplasia of cartilage in the head, abnormal bone formation, etc.
b) Because of the storage capacity of the liver (which offers protection to some degree), probably require feeding an unusually high level for a long period to induce the vitamin toxicity.

B. Upper safe levels: (NRC, 1987)

1) Presumed upper safe levels - 4-10 times the requirement for nonruminant species, and ≈ 30 times for ruminant species.
2) Usually, can expect toxicity signs by feeding over 100 times the requirement.

3) Some examples: (chronic intake)

Animal	Requirement, IU/kg diet	Safe level, IU/kg diet
Chicken, growing	1,500	15,000
Chicken, laying	4,000	40,000
Swine, growing	2,000	20,000
Swine, breeding	4,000	40,000
Cattle, feedlot	2,200	66,000
Goats	1,500	45,000

VITAMIN C

1. Introduction

A. Scurvy is a disorder associated with inadequate vitamin C intake:

1) Scurvy has been known since the ancient times (as early as 1550 B.C.?!).
2) Potentially fatal - Signs include anemia, weakening of collagenous structures (bone, cartilage, teeth, connective tissues), swollen, bleeding gums with loss of teeth, hemorrhages in various tissues, delayed healing of wounds, fatigue & lethargy, rheumatic pains in the legs, degeneration of muscles & skin lesions.

B. Vitamin C can be synthesized by almost all species, except primates & few others (guinea pigs, many fishes, etc.):

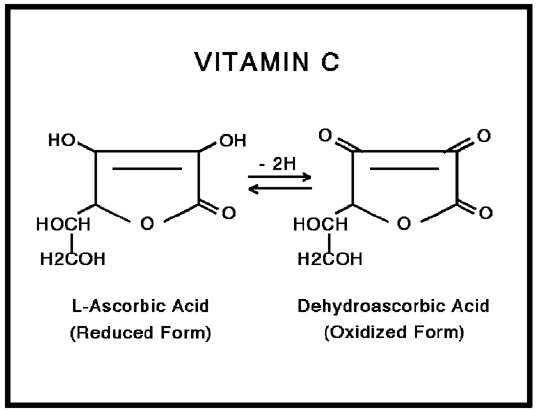
1) Biosynthesis by the glucuronic acid pathway in the liver of mammals & kidney of other vertebrates - D-glucose → D-glucuronic acid → L-gulonic acid → L-gulono-γ-lactone → L-ascorbate.
2) Humans, primates, guinea pigs, fruit bats, some birds and certain fish & insects lack "L-gulono-γ-lactone oxidase," which is responsible for conversion of L-gulono-γ-lactone to 2-oxo-L-gulono-γ-lactone (which is transformed spontaneously into the vitamin).

C. Suggested beneficial effects of megadoses (2.3 g to 9-10 g/day) for humans include: [Pauling, 1971. Vitamin C and the Common Cold; Pauling, 1974. Am. J. Psychiatr. 131:1251; Jaffe, 1984. In: Machlin (Ed.) Handbook of Vitamins]

1) Prevention & reduction of severity of a common cold.
2) Prevention of cancer & prolonged life of cancer patients.
3) Lower serum cholesterol & severity of atherosclerosis.
4) Increase wound repair & normal healing processes.
5) Increase immune response for prevention and treatment of infections.
6) Control of schizophrenia.
7) Inactivation of disease viruses.

2. **Structure** (Redrawn from McDowell, 1989)

- 1 IU = 0.05 mg of L-ascorbic acid, which is equivalent to ≈ 1 ml of lemon juice.



3. **Functions**

◦ The exact role in the living system is not clearly known, i.e., to date, a coenzyme form has not been reported.
◦ Functions are probably related to its reversible oxidation and reduction characteristics.

A. Collagen biosynthesis:

1) The most clearly established role of vitamin C.
2) Involved in hydroxylation of Pro and Lys: OH-Pro - Gives a greater stability (H-bonding), and OH-Lys - Involved in the formation of cross-links.
3) Also, may protect hydroxylase enzymes!

B. Other functions?

1) Involved in the electron transfer (NADH & cytochrome b_5).
2) Involved in metabolic oxidation of excess Tyr.
3) Enhances absorption of minerals, and also mobilization (e.g., Fe).
4) Involved in the synthesis of carnitine, and also norepinephrine.
5) Has a stimulating effect on phagocytic activity of leukocytes.
6) Is a natural inhibitor of nitrosamines (carcinogens).
7) Is a powerful antioxidant, and spares vitamin E & enhance immune responses.
8) Involved in activation, inhibition or ↑ activity of enzymes.
. . . , etc.

4. **Deficiency**

A. Ascorbate-synthesizing animals:

1) Under practical situations, not likely to see vitamin C deficiency.
2) Under certain conditions (stress, infectious diseases, etc.), may develop deficiency symptoms (scurvy-like symptoms).

B. Fish:

1) Highly sensitive to dietary deficiency, especially young fish.
2) Curvature of spinal column is a prominent, early sign of deficiency in finfishes.

3) Rainbow & brook trout, coho salmon, tilapia, channel catfish & young carp - Scoliosis & lordosis (lateral & vertical curvature of spinal column, respectively).
4) Channel catfish - Signs include deformed spinal columns, external & internal hemorrhages, erosion of fins, depigmented vertical bands around midsection, distorted gill filament cartilage & ↓ rate of wound healing.
5) Black death in shrimp - A condition characterized by melanized hemocytic lesions distributed throughout the collagenous tissues.
6) The deficiency also ↓ resistance to bacterial diseases.

5. **Vitamin C Supplementation (e.g., Swine)**

A. Has resulted in very inconsistent response:

1) Improved performance of pigs in some experiments, but no response in others (vitamin C used ranged from 150 to 5,000 ppm in those studies).
2) Reported a rapid cessation of naval bleeding & rapid growth of pigs by vitamin C supplementation of the sow diet (1 g/day), but observed no response in subsequent experiments.

B. Probably, a routine vitamin fortification of swine diets is not necessary.
C. But, in some situations, supplementation might be beneficial - e.g., Deficient in other nutrients (vitamin E, Se, protein, Fe, etc.), highly productive animals, transporting a long distance or handling animals extensively, adjusting to a new environment, ambient temperatures (too high or too low), diseases & parasite infestations, etc.

6. **Vitamin C & Fish**

A. Dietary requirement: (NRC, 1993)

Channel catfish	25-50 mg/kg
Rainbow trout, pacific salmon & tilapia	50 mg/kg
Common carp	Required, but not determined

B. Supplementation:

1) Commercial ingredients - Almost devoid of vitamin C, thus must be supplemented.
2) Vitamin C is highly sensitive to oxidative destruction during processing & storage:

a) 25% destruction during steam pelleting & 50% loss during extrusion process.
b) ½ life of L-ascorbic acid in feed is ≈ 2.5 mo under warm weather conditions.
c) Phosphate & sulfate conjugates are much more stable vs L-ascorbic acid.

7. **Vitamin C for Humans?**

A. Three levels of daily intake:

1) "5 to 10 mg" can prevent scurvy.
2) "100 to 250 mg" can achieve a saturation in the blood.
3) "1000 to 10,000 mg:"

   a) May produce favorable mega-vitamin effects.
   b) Pauling suggested 2.3 g/day for optimum health, and 9-10 g in presence of some ailments.

      ☛ Personally, he'd taken 10 g/day based on the fact that many species produce 10 g of ascorbic acid/day/70 kg BW.

B. Annual vitamin C consumption in the US:

1) ≈ 1 kg/year, i.e., 2,740 mg/person/day.
2) But, mostly used by the food industry for enrichment of canned vegetables, fruits and beer (adding color, flavor, etc.).

C. Requirements: (RDA, 1989)

Item	mg/d
Children	35-50
Adult	60
Pregnant	70
Lactating	90-95

D. Sources: (McDowell, 1989)

Food	mg/100 g (as-fed)
Cauliflower, raw	50-90
Peppers, raw	100
Spinach	10-60
Apple, unpeeled	10-30
Grapefruit	35-45
Lemons	80
Limes	250
Oranges	40-60

D. Toxicity - Generally safe, but a consumption of > 4-10 g/d for a prolonged period may results in kidney stones, iron overload or hemochromatosis & other disorders in some people.

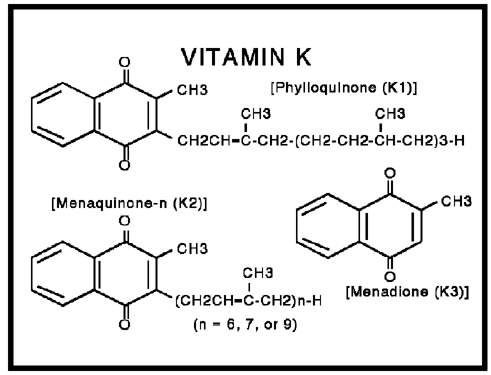
CIRCULATION & VITAMIN/MINERALS

VITAMIN K

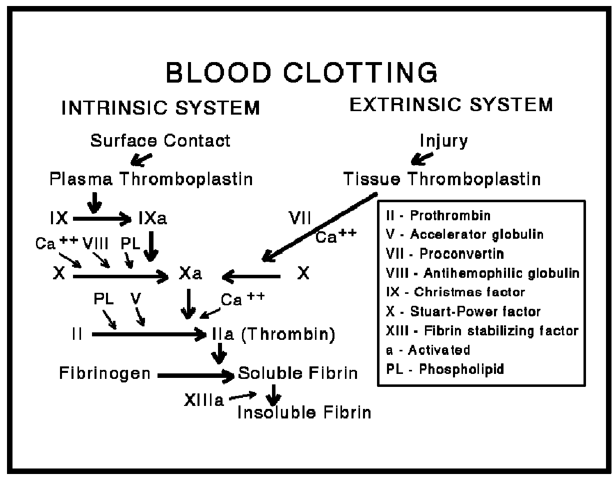
1. **Introduction**

   A. The last fat-soluble vitamin to be discovered.
   B. Previously referred to as a coagulation vitamin, antihemorrhagic vitamin & prothrombin factor.
   C. Can be synthesized by intestinal microorganisms, but deficiency signs have been observed under field conditions.
   D. Poultry (and to a lesser degree, pigs) may be susceptible to deficiency:

      1) Limited ability to synthesize vitamin.
      2) Extensive use of antimicrobial agents.



2. **Structures**: Redrawn from Martin et al. (1983) - There is no "standard" unit for vitamin K, but usually in "mg menadione/kg!?"

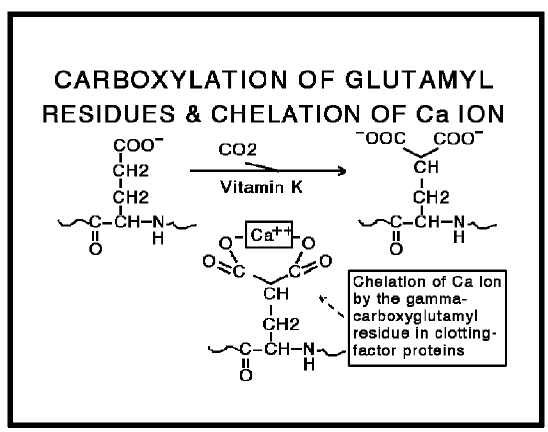


3. **Functions**

   A. Functions in the blood clotting mechanism, and is essential for synthesis of: 1) Factor II (prothrombin), 2) Factor VII (proconvertin), 3) Factor IX (thromboplastin), and 4) Factor X (Stuart factor).
   B Scheme involving blood clotting: (Redrawn from McDowell, 1989)

      1) Proteins are synthesized in the liver as inactive precursors:

         a) Protein are activated by carboxylation of specific glutamyl residues by carboxylase, and vitamin K is a component of carboxylase.
         b) γ-Carboxyglutamyl (Gla) residue chelates Ca ion, which is essential for the blood clotting mechanism.



2) Carboxylation of glutamyl residue & chelation of Ca ion: (Redrawn from Martin et al., 1983)

C. γ-Carboxyglutamyl residues:

1) Also identified in a number of proteins in the bone, kidney, lung, placenta, skin & spleen.
2) Thus, may have some other functions?!

4. **Deficiency**

- Essentially, an impairment of blood coagulation!

1) Low prothrombin levels (factor II).
2) Increased blood clotting time.
3) Hemorrhaging - Subcutaneous & internal hemorrhages in severe cases.
4) Anemia.

5. **Requirements/Supplementation**

A. Most species:

1) Generally met by feed sources & microbial synthesis in the hind gut, but may or may not be absorbed efficiently.
2) Possible exceptions:

a) Use of sulfonamides & other antibiotics - ↓ microbial synthesis of the vitamin. (Also, ↓ synthesis of B-vitamins!)
b) Presence of molds in feeds - May produce antagonists such as dicumarol.
c) Limited access to feces, i.e., the use of slotted floors & cages.

3) Thus, as an insurance, diets are usually supplemented.

B. Vitamin K requirements:

1) Poultry (NRC, 1984) - 0.47-0.50 mg/kg for immature chickens & broilers, 0.40-0.60/kg for laying hens, and 0.5-1.75 mg/kg for turkeys.
2) Swine (NRC, 1998) - 0.50 mg menadione/kg for all classes of swine.
3) Horese (NRC, 1989) - No estimated requirements.
4) Fish (. . . Quantitative requirements have not been established!):

a) Intestinal synthesis of vitamin K has not been fully evaluated in fish.
b) Channel catfish & trout - Need vitamin K for normal blood coagulation, but growth rate is not affected by dietary deletion of the vitamin.

c) 0.5 to 1 mg of menadione/kg may be sufficient for fingerling trout, and 10 mg/kg has been suggested for trout & salmon.
d) Fish meal & alfalfa are good source of vitamin K.

C. Sources - Water-soluble menadione (vitamin K_3) salts:

1) Menadione Na bisulfite (MSB)
2) Menadione Na bisulfite complex (MSBC)
3) Menadione dimethyl-pyrimidinol bisulfite (MPB)
☞ Vitamin K activity - 50, 33 & 45% of menadione (synthetic form) for MSB, MSBC & MPB, respectively.

IRON

1. **General**

A. As a constituent of Hb, Fe plays a central role in life processes.
B. Occurs as "iron-porphyrin" nucleus, heme:

1) Not only in Hb, but also in Mb, cytochromes, peroxidase, catalase & other enzymes.
2) Thus, Fe is a constituent of oxygen carriers & oxidation catalysts or enzymes.
3) Examples of heme compounds:

Heme compounds	Function
Hb (erythrocytes)	Oxygen transport
Mb (skeletal muscles)	Oxygen transport
Cytochrome oxidase (heart muscle)	Electron transfer
Cytochrome C (heart muscle)	Electron transfer
Peroxidase	Peroxide decomposition
Succinate dehydrogenase (heart)	Electron transfer
Reduced NAD dehydrogenase (heart)	Electron transfer

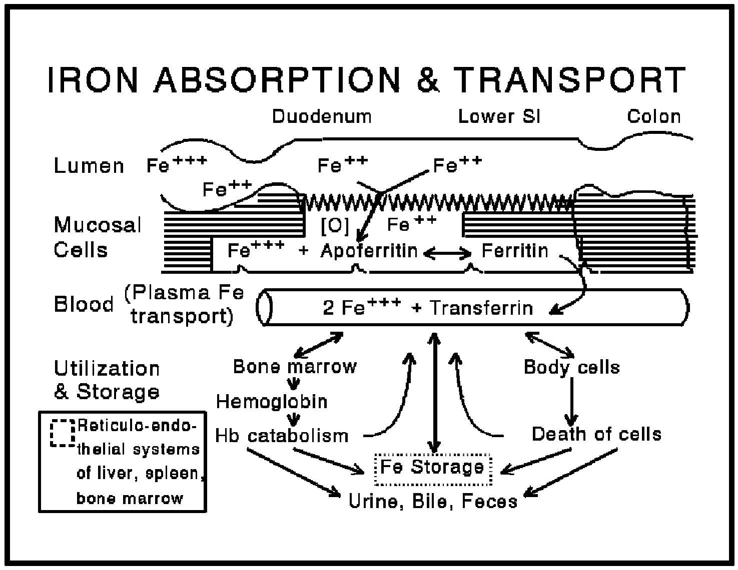
C. Iron metabolism: (McDowell, 1992)

1) Absorption:

a) Fe in ferrous state (Fe^{++}) is absorbed much more efficiently than that in "ferric" state (Fe^{+++}).

▹ Vitamin C (& others) can reduce Fe from 3^+ to 2^+, thus having beneficial effects on Fe absorption.

b) Generally, Fe is poorly absorbed, but the efficiency increase in the deficient state - e.g., Only 7-10 % in Fe-adequate rats vs ≈ 80% in Fe-deficient rats.



2) Once absorbed, Fe is not readily lost from the body:

   a) e.g. - Fe released from Hb → liver → secreted into the bile → reabsorbed & used again. (Retained with a great tenacity!)
   b) Exception - hemorrhages!

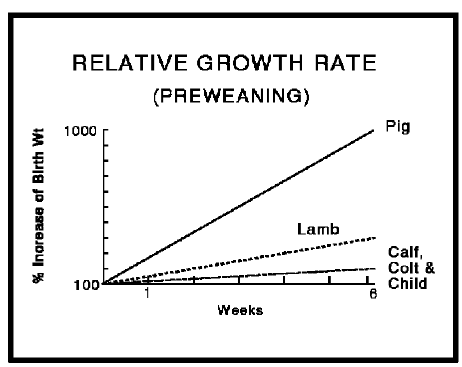
3) Fe is stored as: a) "Ferritin & hemosiderin" in the liver, b) "Transferrin" in serum, c) "Uteroferrin" in placenta, and d) "Lactoferrin" in milk.
4) Excretion - Feces (1° unabsorbed Fe) & urine, and also a continual loss in sweat, hair & nails.

D. Fish:

1) Relatively little information on absorption/metabolism of Fe, but probably similar to other species.
2) Absorption of Fe takes place across the gill, but the intestinal mucosa is the major site.
3) Dissolved Fe (e.g., ferrous sulfate) in water may serve as a source in certain warm-water fish, but may precipitate out as ferric hydroxide.

E. Natural feed ingredients usually supply enough Fe to meet the postweaning requirements of pigs & poultry, and Fe-deficiency is unlikely to occur under practical conditions in fish.

2. **Iron Deficiency Anemia in Nursing Pigs**



A. Reasons?

1) Low body storage in newborn pigs - Born with only about 40-50 mg of Fe, and with the daily requirement of 7-16 mg/day, deplete rapidly!
2) Low Fe content in sow's milk - About 2 ppm in colostrum & 1 ppm in milk, thus piglets receive only about 1 mg/day from milk!
3) Rapid growth rate vs other species - See the figure.

4) No access to iron sources (e.g., soil) in the confinement.

B. Fe deficiency:

1) Characterized by pale mucous membranes (around eyes, ears, nose & mouth).
2) Slow growth, rough hair coat, wrinkled skin, and may be listless.
3) Labored breathing or "thumps" (spasmodic jerking of the diaphragm muscles), and sudden death from anoxia.
4) More susceptible to infectious diseases.

C. Hb or hematocrit levels - The best index of the Fe status in pigs:

	Normal	Anemic
Hb, g/100 ml	12	5
Hematocrit, % RBC	35	17

D. Prevention of baby pig anemia:

1) Treatment of sows with oral or injectable Fe during gestation:

- Injection of 22 mg Fe-dextran/kg BW (divided among 5 injections at d 40, 45, 50, 55 & 60 of gestation): (Ducsay et al., 1984. J. Anim. Sci. 59:1303)

Item	Control	Treated
Fetal liver:		
Fe, mg/g DM	1.3	1.2
Total Fe, mg	3.7	3.5
Placenta:		
Uteroferrin, mg/g	1.6	2.4
Uteroferrin, mg	287	427
Allantoic:		
Fe, μg/ml	5	7
Fe, mg	204	1,327

- No appreciable effect on body stores of newborn pigs!

2) Treatment of sows with Fe during lactation:

- Hemoglobin levels in young pigs (g/100 ml): (Univ. of Kentucky data)

Treatment	Birth	Wk 1	Wk 3
None	9.2	7.7	5.9
Pigs injected	9.0	9.3	9.1
Sows fed 700 ppm Fe	9.6	8.4	8.9

- ▹ No effect on the Fe content of milk!

☛ Thus, limited placental & mammary transfer of Fe in pigs, and it is a common practice to inject pigs with 100-150 mg of Fe as Fe-dextran or Fe-dextrin at 1-3 days of age.

3. **Iron Requirements/Supplementation**

A. Requirements: (Also, see appropriate "Nutrition & Feeding" sections.)

Animal	mg/kg
Poultry (NRC, 1994):	
Immature chickens	56-80
Laying hens	38-56
Broilers	80
Turkeys	50-80
Swine (NRC, 1998):	
3-120 kg	40-100
Sows/boars	80
Horses (NRC, 1989; DM)	40-50
Fish (NRC, 1993):	
Channel catfish	30
Rainbow trout	60
Pacific salmon	Not tested
Common carp	150
Tilapia	Not tested

B. Bioavailability:

1) Ferrous sulfate ($FeSO_4$) - Highly available.
2) Ferrous carbonate ($FeCO_3$) - Variable.
3) Ferrous oxide (FeO) - Poorly available.
4) Ferric oxide (Fe_2O_3) - Totally unavailable.

☛ Others such as ferrous ammonia sulfate, ferrous chloride, ferrous fumarate, ferrous gluconate, ferric chloride, ferric citrate, ferric choline citrate & ferric sulfate are available, but not commonly used!

4. **Fe Toxicity**

A. Excess Fe (pigs):

1) 600 mg Fe/kg BW - Develop toxic signs within 3 h (incoordination, shivering, heavy breathing, convulsion, diarrhea, etc.).
2) Injection of > 200 mg Fe/day - May increase bacterial growth, thus become susceptible to infections & diarrhea.

C. Toxicity in general:

1) Chronic - Reduced feed intake, growth rate and feed efficiency.
2) Acute - Anorexia, diarrhea, hypothermia, shock, metabolic acidosis, vascular congestion of various organs & death.

D. Maximum tolerable levels - 500 ppm for sheep, 1,000 ppm for cattle & poultry, and 3,000 ppm for swine.

COPPER

1. **Deficiency/Functions**

A. Anemia:

1) Can result from poor Fe mobilization, abnormal hemopoiesis, etc.
2) Cu enhances transport of Fe, and catalyzes incorporation of Fe into Hb.

☛ Ceruloplasmin has ferrioxidase activity - Can be involved in conversion of ferrous (Fe^{2+}) to ferric Fe (Fe^{3+}), which can be incorporated into transferrin.

3) Can also assists the maturation, and perhaps, the retention of erythrocytes!?

B. Abnormal bone development:

1) "Bowing" of the leg, spontaneous fractures & others (low osteoblastic activity).
2) Cu is involved in the collagen synthesis - A component of lysyl oxidase, thus, Lys to allysine → desmosine & isodesmosine → cross-linking of collagen?

C. Cardiac and vascular disorders - e.g., Aortic rupture in turkeys, and falling disease in cattle (heart failure, atrophy of myocardium, etc.).

1) A component of lysyl oxidase, and involved in elastin synthesis (cross-linking).
2) Ceruloplasmin (6 Cu/molecule) - Inhibiting peroxidation?
3) A component of superoxide dismutase, which converts superoxide to hydrogen peroxide & oxygen?

D. Abnormal pigmentation (not in pigs) - Due to loss or lack of melanin synthesis:

1) Possibly due to a ↓ activity of tyrosinase (polyphenyl oxidase, which contains Cu).
2) Tyrosinase is involved in conversion of Tyr to dopa (dihydroxy-Phe), and dopa is converted to melanin.

E. Also, Cu is a component of many oxidases and other enzymes, and a activator of a number of enzymes, thus likely to be involved in the CNS functions, reproduction, immune system, lipid metabolism, etc.

2. **Requirements/Toxicity**

A. Requirements: (Also, see appropriate "Nutrition & Feeding" sections.)

Animal	mg/kg
Poultry (NRC, 1984):	
Immature chickens	4-5
Laying hens	?
Broilers	8
Turkeys	6-8
Swine (NRC, 1998):	
Growing	3-6
Adults	5
Horses (NRC, 1989; DM)	10
Fish (NRC, 1993):	
Channel catfish	5
Rainbow trout & common carp	3
Others	Not tested or determined

B. Toxicity:

1) Signs include loss of appetite, ↑ thirst, apathy, ↑ breathing rate, intensified heart beat, jaundice, hemolysis, necrosis of liver & death.
2) Maximum tolerable levels:

Sheep	25 ppm
Cattle	100 ppm
Chickens & turkeys	300 ppm
Rats	1,000 ppm
Swine	250 ppm

3. **The Use of Copper as a Growth Stimulant**

A. A high dietary level of Cu (100-250 ppm) has antimicrobial activity, and acts like an antibiotic.
B. Widely used as a growth promotant for pigs in the U.K. and Europe.
C. Dietary copper supplementation?

1) Effect of Cu on performance of starter pigs (a summary of seven 7 28-d studies with 4-wk old pigs): (Cromwell, Univ. of Kentucky)

Cu, ppm:	0	125	250	500

ADG, g	245	291	305	236
G:F	.49	.52	.54	.45
Liver Cu, ppm	23	24	191	349

2) The most effective supplementation seems to be 250 ppm Cu.

D. Dietary copper and age of pigs:

1) A summary of 12 starter and 18 grower/finisher experiments: (Cromwell. Pers. Comm.)

Item	0	250	% ↑
Starter:			
ADG, g	227	286	26
G:F	.49	.54	9
Grower:			
ADG, g	659	714	6.9
G:F	.36	.37	3.6
Finisher:			
ADG, g	714	736	3.1
G:F	.31	.32	2.5
Liver Cu, ppm (DM)	22	244	

2) Dietary Cu supplementation is the most effective during the starter phase.

E. Sources:

1) Copper oxide & sulfide - Totally unavailable.
2) Copper sulfate - Available and most commonly used. (☞ 2 lb of $CuSO_4 \cdot 5H_2O$/ton of diet provide 250 ppm Cu.)
3) Copper carbonate & chloride, sequestered copper & chelated copper Met are all effective, but costly.

F. Relationship between Cu & Fe:

1) When using 250 ppm Cu, may have to provide ≈ 50% more dietary Fe (≈ 150 ppm), or even more?
2) Supplemental Cu and Fe on performance & hematology of weanling pigs: (Dove & Haydon, 1991. J. Anim. Sci. 69:2013)

	5 ppm Cu			250 ppm Cu		
+ Fe, ppm[a]:	100	200	300	100	200	300
Hematocrit, %[b]	37.2	39.9	40.5	39.9	39.3	41.4

Hb, g/dL[b]	10.6	11.2	10.8	11.2	11.3	11.9
Plasma Fe, µg/dL[b]	245	248	233	218	233	241
Gain, g/d[c]	320	360	330	410	400	430
Feed:gain[c]	1.62	1.54	1.65	1.55	1.59	1.59

[a]Basal diet contained 169 ppm Fe & added 50, 100, 150, 200, 250 & 300 ppm; [b]Cu x Fe interaction, $P = 0.05$ to 0.06; [c]Effect of Cu, $P < 0.01$.

G. Mode of action?

1) Not well defined, but probably similar to the action of antibiotics - Unclear, but some suggestions?

a) Metabolic effects - Direct influences on metabolic processes such as ↓ FA oxidation, ↑ protein synthesis, etc.
b) Nutritional effects (cannot separate completely from the metabolic effect):

(1) May be ↓ undesirable microbes & ↑ desirable microbes, i.e., ↑ the population of microbes that synthesize vitamins & amino acids.
(2) Inducing changes in the GI tract - e.g., Thinner wall of the gut, thus may ↑ absorption rate & ↓ energy expenditures.

c) Disease controlling effects.

2) Effect of Cu is "additive" to antimicrobial agents.

H. Some concerns regarding the use of high levels of copper:

1) Toxicity in pigs - The optimum level for growth promoting effect & toxicity level are similar!
2) Adverse effects on humans - e.g., Consumption of high-Cu liver.
3) Rapid deterioration of galvanized metals (buildings & equipment).
4) Reduced microbial decomposition of wastes in lagoons.
5) Can be an environmental pollutant.

PIG NUTRITION AND FEEDING

- *References: Chiba (2004; http://www.ag.auburn.edu/~lchiba/swineproduction.html) & NRC (1998). Also, see Chiba (2000) in Theodorou and France (2000).*

REPLACEMENT BOARS AND GILTS

1. **Replacement Boars**

A. Some considerations:

1) Consider buying a strong boar in a good body condition (including sound feet and legs) from a reliable seedstock producer (. . . known genetics and herd health) - Selection should be based on the performance record rather than placing too much emphasis on how they look.
2) Purchase boars (5.5 to 6 mo. old) at least 60 days before being used - Should not use boars before they are 7.5 to 8 mo. old.
3) Isolation - Isolate all new boars a minimum of 28 days for treatment for parasites, vaccinations, acquisition of immunity for microorganisms on the farm, and evaluation of sexual behavior (& possibly semen too).
4) In the confinement system, a boar should be housed individually, and provide 35 to 50 ft^2/pen or use 28 in. x 7 ft. stalls.
5) In non-confinement system, should have 20 ft^2 of shelter and dry sleeping area. Better to house boars individually, but if not possible then: a) boars must be reared together, and b) should provide 20-24" of feed space/boar, and one waterer/3 boars.

B. How should we feed?

1) The newly purchased boar has less appetite for the first few days because of the changes in the environment and other factors, thus, may want to obtain a bag of feed from a supplier!
2). Feed sparingly, i.e., feed ≈ 2 lb the first day and increase gradually, and feed to maintain a proper body condition, which can be done by feeding 4 lb/day.

2. **Replacement Gilts**

A. Some considerations:

1) Selecting gilts?

a) At birth - Ear notch at least twice as many gilts as will be needed, and keep records, and may want to foster barrows in large litters (. . . does not mean that gilts should be selected from small litters though!).
b) At weaning - Remove gilts from a list if their sows did not milk well.

c) Finishing phase - Make a final selection at 175 to 200 lb based on growth rate, backfat, mammary & skeletal systems and vulva development.

2) Early puberty

a) Most gilts reach puberty at 6-8 mo of age (avg., ≈ 200-220 days) - They should reach puberty (1st estrus and ovulation) at an early age.
b) Gilts should express one or more estrous cycles before the breeding age (7-9 mo) because may be able to increase ≈ 2 pigs/litter by breeding at 2nd estrus vs. 1st estrus!
c) Factors affecting puberty? - Genetics, season of the year (winter- and spring-born gilts tend to have delayed expression of the 1st estrus), confinement, etc.

3) Stimulate gilts or induce estrus?

a) Stimulation should precede the breeding period by 3 to 4 wk.
b) Regrouping and relocation:

(1) Gilts should weigh ≈ 200 to 230 lb (5-5½ to 6 mo of age), and start restricting energy intake by feeding 5-6 lb/day.
(2) If possible, relocate to the outside. Relocation seems to be the most important component of "transport phenomenon," and relocation within the confinement is less effective vs. moving to the outside.

c) Perhaps, use PMSG (**P**regnant **M**are **S**erum **G**onadotropin - similar to FSH) and HCG (**H**uman **C**horionic **G**onadotropin - similar to LH) to induce estrus in gilts that have not cycled.
d) Allow a fence-line contact/supervised direct mingling with a sexually active, mature boar for 15-30 min/day. Check gilts for estrus with the main criterion being a standing reaction to the pressure applied to the back with the presence of a boar.

B. How should we feed?

1) Most gilts are developed to 175-200 lb by self-feeding grower-finisher diets.
2) Should restrict energy intake after 175-200 lb, which can save feed costs and avoid unneeded weight gain to avoid a reduction in the longevity and unsoundness problems!
3) Restrict the energy intake by hand feeding 5-6 lb of balanced diet/day. Should adjust feed allowance because: a) require 10% less feed (≈ 0.5 lb less/day) in the confinement, and b) require 25% more feed (≈ 1 lb more/day) during the cold weather.
4) Flushing or high-energy feeding - End "restricted-feeding" and increase feed intake by 50 to 100% 7-10 days before breeding, which can maximize the ovulation rate!

5) A practical feeding approach?: a) Feed a grower diet until making a final selection at 175-200 lb, and, then, b) feed a lactation diet (5-6 lb/day) thereafter?

BOARS AND SOWS AT BREEDING

1. **Feeding Boars?**

A. When to feed?

1) They have a tendency to stop and eat spilled feed in the alley and miss sows in a "standing reaction" because of the delay!
2) Thus, boars should be fed before being used in the hand mating system.

B. How much?

1) Before the breeding period (within 2 weeks), feed 5-6 lb of a well-balanced 14% CP diet to young boars and 4-5 lb to older boars in a good body condition.
2) During the breeding period? - Depends on the work load, but increase the amount some?
3) After the breeding period? - Depends on a body condition and the idle period, but generally 4 lb of a well-balanced 14% CP diet should be sufficient.

Energy intake & return to estrus (Reese et al., 1982)

Intake	Weight change, kg	Return to estrus 7 d	14 d	21 d	70 d
8 Mcal	- 21	**50.0**	63.9	63.9	86.1
16 Mcal	-.6	**94.3**	94.3	97.1	100.0

* The 1988 NRC requirement = 17 Mcal/day.

2. **Nutrition During Lactation and Return to Estrus**

A. Effect of energy intake [Reese et al., 1982. JAS 55:590] - Sows must consume adequate energy for early return to estrus!
B. Effect of protein intake [Brendemuhl et al., 1987. JAS 64:1060] -Sows must consume adequate protein for early return to estrus!
C. Thus, both are important during the lactation period!

Effect of protein intake: (Brendemuhl et al., 1987)

Protein intake	Wt ▵, kg	Return to estrus 7 d	14 d	35 d
380 g/d	- 23	**63.1**	75.7	85.4
760 g/d	- 12	**82.3**	87.5	93.6

* The 1988 NRC requirement = 689 g/day.

3. **Effect of Flushing After Weaning?**

A. Flushing or high energy feeding 7-10 days before breeding (↑ feed intake by 50-100%) is commonly used to ↑ ovulation rate in gilts.
B. Effect on younger & older sows - See the data on "flushing & age of sows (Levis, 1986)."
C. Effect of body condition of sows - See the data on "Flushing and body condition (Levis, 1986)."

Flushing and age of sows: (Levis, 1986)

Item	Contr.	Flush.	Diff.
Return to estrus (day):			
Parity 1	7.6	6.4	+ 1.2
Parity 2-5	5.6	5.2	+ .4
Parity 5+	5.5	5.3	+ .2

Flushing & body condition (Levis, 1986):			
Item	Contr.	Flush.	Diff.
Return to estrus (day):			
V. good	6.2	5.5	+ .7
Good	6.4	5.8	+ .6
Poor	7.6	6.7	+ .9
Pigs born alive:			
V. good	10.8	10.6	- .2
Good	10.6	10.9	+ .3
Poor	10.4	11.2	+ .8

- The Bottom Line?

  1) Primiparous sows respond to flushing, but not sows in a good body condition. (Usually, return to estrus 4-8 d after weaning, thus, insufficient time to show response in the ovulation rate!?)
  2) Feeding extra feed to very thin sows may be justified because of benefits in return to estrus and ovulation rate!
  3) Older sows weaned in a good body condition? - Feeding 4 lb/day is adequate!?

4. **Antibiotics at Breeding Time?**

- For a herd with some history of breeding problems (. . . Causes? Unknown!), antibiotics may improve breeding performance, but should discontinue the use within two or three weeks after breeding.

5. **To Avoid Failure to Recycle After Weaning (e.g.)**

A. Some nutritional considerations: (1st litter sows?)

  1) During gestation, feed gilts so that they are still gaining weight (i.e., "net" body weight gain).
  2) Feed a high energy diet during the first lactation.
  3) Avoid high farrowing house temperatures (> 80°F) because they can reduce feed intake!
  4) Not to reduce feed on thin sows before weaning.
  5) Feed thin sows about 8 lb daily after weaning (especially, 1st litter sows).
  8) Check the adequacy of feeding program by weighing sows at the mating time, end of the gestation phase, and weaning time.

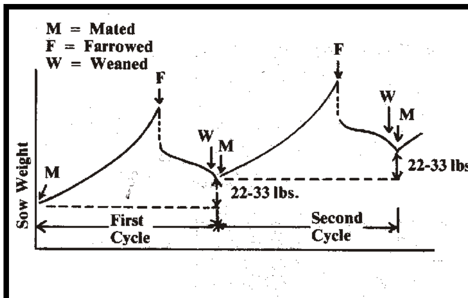


Figure 5. Example of sow weight changes during first two reproductive cycles.

B. Weight gain of sows - See the figure (Levis et al. NE Swine Repro. Mgt.):

  1) Sows continue to mature until about 5th litter.
  2) If sows are gaining about 22 to 33 pounds (from weaning to weaning) during each of 4 to 5 cycles, they are probably in a proper body condition!

GESTATING SOWS/GILTS

1. **Feeding in General**

A. Common feeding scheme:

1) Feed 4 lb of corn-soy diet containing 12.0-12.9% CP, 0.75% Ca, & 0.60% P/day.
2) Sows should be consuming 218-253 g CP, 9.4-11.4 g Lys, 13.9 g Ca, and 11.1 g P/day.
3) For thin sows (especially 1st litter sows), feed 5-6 lb/day of a corn-soy diet.

B. Adjusting feed?

1) "Bulky ingredients" - Must adjust the amount of feed offered to satisfy the required daily energy needs.
2) "Confinement" - Can be maintained in a proper condition with 0.5 lb/day less feed vs. outside because of less physical activity and relatively constant ambient temperatures regardless of the season.
3) Outdoors - Should increase feed offered by ¾ lb/day for each 20°F ↓ below the 70°F, and for thin sows, feed 1¼ lb more/day.

C. Restriction of energy intake after breeding

1) Flushing should be terminated because it: a) is costly & 2) may lead to increased embryonic loss. But, it should not be automatic . . . depends on other factors!
2) Be sure to provide an adequate amount of all other pertinent nutrients.

3. **Ways to Accomplish Restricted-Feeding?** (Make sure that each sow gets her share of feed!)

A. Individual hand-feeding:

1) Females are maintained in individual stalls, or maintained in pens but fed individually using feeding stalls - Can feed according to individual needs and also no competition for feed.
2) Feeding stalls - Should be designed to allow a group of sows to be locked in, and should not exceed 16-18 inches in width to prevent smaller gilts from turning around.

B. Group hand feeding - Feed in a group in a common trough or on a concrete slab:

1) Not preferred because of no control over sow weight and condition, i.e., no control over individual's feed intake vs. its needs.
2) The variation can be reduced by providing extra feeding space and(or) grouping females according to their age, size, and aggressiveness.

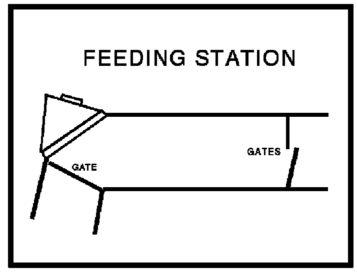
C. Interval feeding - Sows are allowed to consume 2 or 3 d of feed in one day, then wait!

1) Can adjust feed intake by controlling the time on the feeder (2 to 12 hr) or the time off the feeder (2 or 3 days). For gilts, every 3rd day feeding is not recommended.
2) If the time on the feeder is restricted, should provide one feeder hole per sow.

D. Self-feeding high-fiber diets - Generally, not recommended!

1) Can use corn stalks, straw, corn cobs, etc., but sows tend to overeat, thus, over-conditioned an feed costs also increase.
2) A variation of this would be to, e.g., feed silage, whole plant pellets, alfalfa, and others on a "free-choice" basis. Ensuring an adequate intake of the supplement can be a problem though!

4. **Electronic Feeders**



A. Have been developed and being used in Europe possibly because out of necessity? (e.g., High cost of feeds and pressures from the animal welfare group on the use of gestation crates!)
B. See Porcode 1(1):3 & NHF/Feb. pp 98-102 (1989):

1) Sows are housed in a group - One feeding station can serve about 50 sows, and any open buildings can be used (thus, the facility costs can be quite low!?).
2) Identification - Each sow wears an electronic responder (neck collar, ear tag, or implant), and information is stored in the computer that runs the feeder.
3) As a sow enters the feeder, computer reads her No. and meters out feed (and possibly water) based on her preset daily allowance and the amount that she's already consumed.

C. The results of preliminary studies at the U.S. Universities? - Positive results in some studies, but not in others!

5. **Some Q&A on Managing Gestating Females**

A. "*Should we increase feeding level toward the end of gestation?*" - Additional 2-3 lb in the late gestation (about 3 wk before parturition) can increase birth and weaning weights, and may increase pig survival rate. Perhaps, more beneficial for primiparous & thin sows!
B "*What are the effects of feeding fats to sows during the late gestation?*"

1) Feeding fats 1-2 wk before farrowing may increase energy reserves of pigs and fat content of milk, thus, may increase baby pig survival rate and weaning weight.
2) Can be done by feeding 5% fat for 2 wk or 10% fat for 1 wk, or top dressing with ¼ lb of melted fat/dried fat or 1 lb of ground soybeans for 2 wk before parturition. (To see beneficial effects, sows should consume 2½ lb of fat before parturition!)

C. "*Can we use raw soybeans for gestating sows?*" - Can perform as well as those fed soybean meal, and may increase birth wt and survival rate of pigs. Soybeans contain 18-19% lipids, so . . .
D. "*Will moldy feed interfere with normal reproduction?*"

1) Moldy grain/feed can reduce litter size and pig vitality at birth, result in the abnormal estrous cycle, and reduce conception rate.
2) Many are not harmful, but difficult to identify those, thus, simply too risky to feed!

E. "*When should we switch from a gestation diet to a lactation diet?*"

1) Start sows on a lactation diet after moving into the farrowing unit.
2) Feed the same amount as in the gestation phase until parturition.
3) Having constipation problems? Feed beet pulp (10%), wheat bran (15%), and other "natural laxative," but should be removed from the diet by the end of the 1st wk. An alternative is "top-dressing" the diet with bulky feed ingredient.

LACTATING SOWS

1. **Lactation Phase**

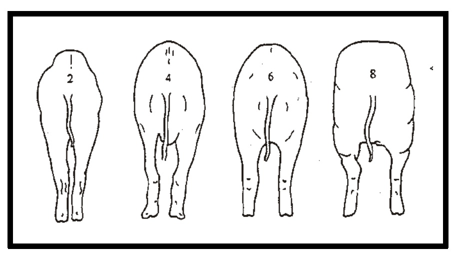
A. Probably, the most important feeding period in the sow's life because most problems in reproduction develop during this phase.

1) Problems? - Lactation failure, downer sows, anestrus, delayed return to estrus, fewer pigs in the subsequent litter, etc.
2) Why? - "Milk production!" A sudden increase in the demand for various nutrients, especially for so called "high-producing" sows!

a) No strict standard, but gilts nursing ≥ 9-10 pigs and sows nursing ≥ 10-11 pigs can be considered as "high-producing" sows.
b) Today's sows are more productive because of: (1) improved genetics, and (2) the use of "white-line, crossbred" sows.
c) Some females can produce 18-20 lb of milk per day, thus, can yield ≈ 1.25 lb fat and 1.0 lb of protein per day (. . . ≈ 6.8% fat ad 5.0% protein in milk).

B. Especially important for primiparous sows (or gilts just had pigs) because they need nutrients for both their own growth and milk production.
C. Unless adequate nutrients are consumed, can result in a depletion of body stores (mostly energy/fat and protein) because sows often use their body reserves to produce milk for pigs.

2. **Body Condition of Sows**



- Various visual condition scoring schemes have been used (e.g., Whittemore, 1987). Generally, classified into: 1) "Too thin" - Hips & backbone are somewhat prominent, 2) "Good" - Hips & backbone are not visible, and 3) "Too fat" - Hips & backbone cannot be felt.

3. Requirements During Lactation

A. The NRC (1998) daily requirements are based on sow wt. change and pig wt. gain.
B. The requirements change according to: 1) body size & reserves at the beginning of lactation, 2) the number of pigs nursing, 3) milking ability, 4) feed intake capacity, and 5) environment.
C. An example of changes in the requirement - See Stahly et al. (1990).

Daily nutrient requirements: (NRC, 1998)

Item	Unit/day
Feed intake, kg	3.56-6.40 (5.25)
Digestible energy, Mcal	12.1-2.2
Crude protein, g	612-1,178
Lysine, g	31.6-61.9
Calcium, g	39.4
Phosphorus, g	31.5

☛ For the optimum performance, energy and nutrients must be adjusted for various factors to ensure adequate intakes!

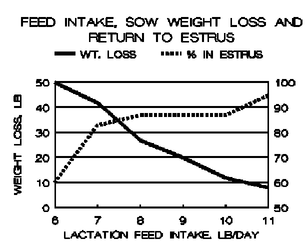
Dietary lysine for high-producing sows during lactation (Stahly et al., 1990)

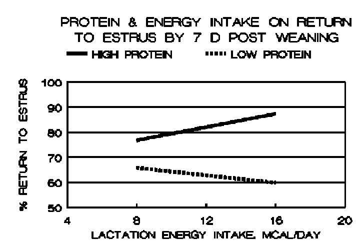
	Lysine, g/day			
Item	20	29	37	47
ME intake, Mcal/d	17.4	17.9	17.5	18.2
Sow wt. loss, lb	43.1	28.6	15.4	9.9
Litter size at weaning	10.5	10.4	10.5	10.8
Avg. weaning wt., lb	12.5	12.8	13.4	14.0
Litter wt. gain, lb	88.2	91.7	98.1	110.2

* Producing ≈ 16 lb milk/d & nursing > 10.5 pigs; The 1988 NRC Lys requirement = 31.8 g/day.

4. Inadequate Intakes During Lactation

A. Energy/protein intake and return to estrus: [e.g., Reese et al.(1982), Nelssen et al. (1985a,b), and Brendemuhl et al. (1987)]





B. Effect of energy intake during lactation on subsequent litter size - Compiled by Reese (1986). Anim. Health & Nutr./Feb. pp 22-35.
C. Inadequate energy and(or) protein intake during lactation:

1) Sows mobilize fat and protein stores for milk production.
2) Results in excessive body weight loss, which can be detrimental to reproductive performance and longevity of sows!

Energy intake during lactation on subsequent litter size[a] (Reese, 1986)

Energy intake, Mcal ME/d	Feed intake, lb/d[b]	Litter size born
< 12	< 8	10.2
12-14	8-10	11.2
> 14	> 10	10.9

[a]Parity ranged from 1-4 & lactation length ranged from 4-8 wk; [b]Corn-soy based diet.

D. Effect of Ca & P (also vitamin D) during lactation?

1) See the data by Nimmo et al. (1981. JAS 52:1330).

2) Lactating sows rely heavily on their skeleton to supply Ca and P for milk production regardless of their intakes.
3) Possible to weaken bones and become susceptible to posterior paralysis (fractured pelvis or vertebrae)and lameness (fractured femur) or stiffness, which are commonly observed within 1-4 days after weaning because of excessive fighting, exercise or activities associated with estrus.

Ca & P during gestation: (Nimmo et al., 1981)

Item	Ca/P, 13.0/10.0 g/d	Ca/P, 19.5/15.0 g/d
No. of sows	23	22
Leg problem (gestation)	5	1
Leg problem (lactation)	2	0

☛ "Repletion" or building-up Ca & P in the bone during gestation is very important!

E. For the optimum reproductive performance, in both short- and long-terms, important to maximize feed intake during lactation!

5. How to Feed Sows During Lactation?

A. During the first few days following the farrowing, many sows have limited appetite, thus may want to increase feed gradually.
B. After few days?

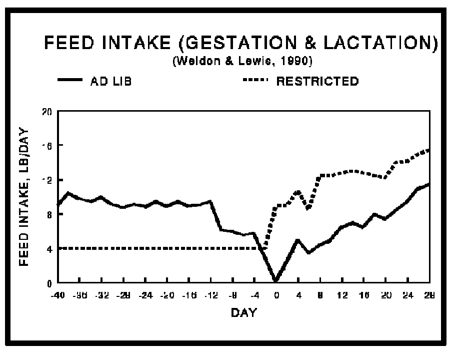
1) Should be on a "full-feed" by the end of the first week.
2) Important to provide fresh water (*ad libitum*).
3) For sows nursing 8 pigs or less, may want to feed 6 lb/day + 0.5 lb/pig.

A practical feeding scheme:

Farrowing	2 lb/day
Day 1	4 lb/day
Day 2	8 lb/day
Day 3	12 lb/day
Day 4	12+ (full-feed)

◦ However, should be allowed to consume more if they want to do so!

6. Factors Affecting Feed Intake During Lactation



A. Temperature - Should keep females cool to avoid the ↓ in feed intake.
B. Eat more if hand-fed twice/day instead of once/day?
C. Switching to cubes or pellets may increase intake?
D. A wet-feeder/mixing with water to increase intake?
E. Feed intake during gestation (Weldon and Lewis, 1990. NE Swine Rep.) - Feeding too much during gestation: a) ↓ feed intake during lactation, b) ↑ feed costs, and c) can lead to various problems during the implantation (early phase) and also parturition because of obesity.

7. Other Nutritional Considerations?

A. Bulky feed ingredients such as alfalfa, what bran, an beet pulp during lactation:

1) Avoid because can: a) limit the energy intake, and b) aggravate a "heat-stress" situation because fibrous ingredients have a relatively higher heat production rate.

2) Exception? Can be used as a laxative. About 10% dietary fiber 3 to 4 d before and after farrowing, or top-dress a regular diet with a bulky feedstuff(s).

B. Dietary fat and baby pig survival

Dietary fat and baby pig survival rate: [Moser & Lewis, 1980. Feedstuffs 52(9):36]

Item	Cont.	Fat	Difference
Born alive	10.0	9.9	-0.1
No. weaned	8.1	8.4	0.3
Survival, %	82.0	84.6	2.6

* Based on 677 to 938 litters; fats/oils during the late gestation & early lactation phases.

1) Producers may lose more than 25% of piglets born before weaning, and majority of losses occur during the 1st few days mostly because of starvation & crushing.

a) Baby pigs - Only ≈ 2% body fat (mostly structural), thus, have low energy reserves.
b) Liver glycogen deplete rapidly within 12-24 h, which can lead to hypoglycemia and ↑ a chance of being crushed.
c) Little hair and fat for insulation and not much energy reserves for heat production, thus, cannot maintain a normal body temperature.

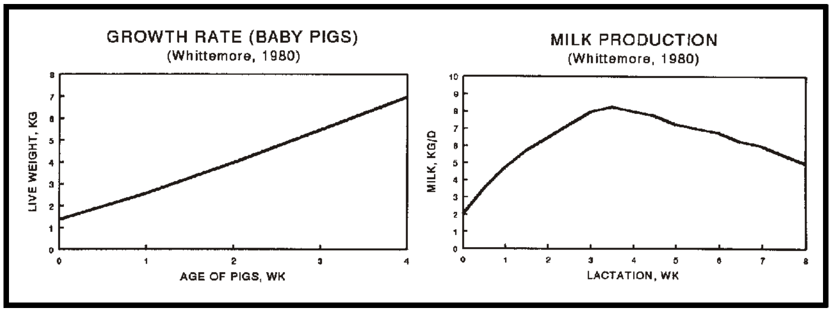
2) To increase survival rate: a) ↑ body reserves of pigs and(or) b) improve the quality of their diet (i.e., milk)! (+ other management practices!)
3) Fats and oils are highly palatable and contain 2.25 times energy vs. carbohydrates/protein, and generally ↑ energy intake during lactation.
5) Dietary fat and baby pig survival rate [. . . see the data by Moser & Lewis (1980)], and respond better if: a) Survival rate of the herd is < 80% (< 80%, 4.1% ↑& > 80%, 0.6% ↑), b) pigs weighing < 1 kg (average) at birth, c) sows consuming < 10 lb of feed/day, and d) used during the summer.
6) Possible reasons for the improvement? - Increase the fat content of milk, milk production, and slight increase in energy reserves of the newborn piglet.
7) For the best result, sows should consume at least 2.5 lb of fats before parturition, which can be done by feeding 10% dietary fat for a week or 5% dietary fat for 2 weeks before farrowing.
8) Drawbacks? - Costly, animal fats are solid at room temperature (thus, must be melted), handling problems with more than 5% in the diet, etc.

SUCKLING BABY PIGS

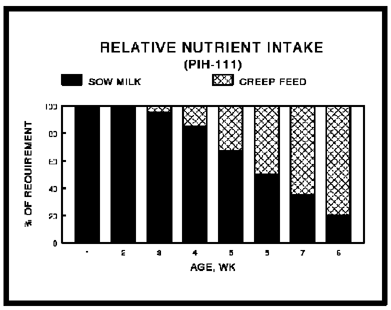
1. **Creep Feeding**

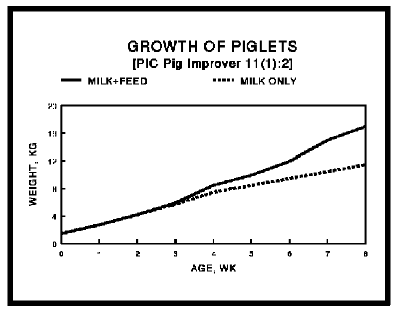
A. Growth rate of pigs and milk production: (Whittemore, 1980)

1) Piglets grow linearly after birth, ∴ the nutrient requirement also ↑ linearly!
2) Milk production peaks at 3rd or 4th week and starts to decline thereafter.
3) Thus, weaning at 3½ to 4 weeks of age or later, piglets need additional nutrients! (If weaning pigs at younger age, the value of creep feed is questionable!)



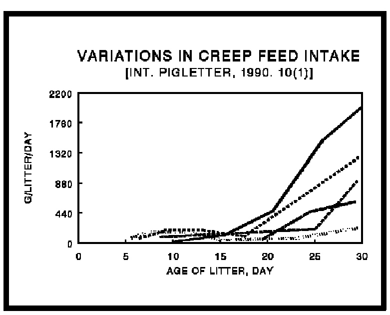
B. Relative intakes and growth of piglets

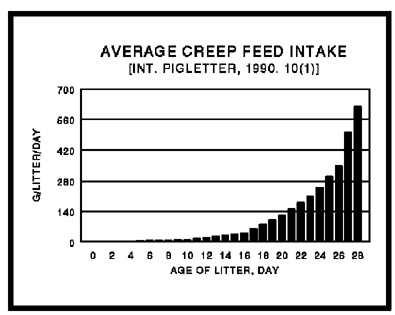




C. Creep feeding and post-weaning scours

1) May cause scours because of allergic reactions/hyper sensitivity to some proteins (& carbohydrates?) in soybean meal - Considerable variations among individuals though!
2) To avoid such problems and benefit pigs, pigs should consume > 400 grams of creep feed before weaning.
3) Creep feed consumption? - Considerable variations in creep feed intake [1990. Int. Pigletter 10(1)] & average creep feed intake [1990. Int. Pigletter 10(1)]:





- Consuming only 10 to 15 g/day before weaning at day 21, but the intake increases to 50 to 60 g/day by day 28!

D. Type of creep feed required (Table)
E. For a successful creep feeding

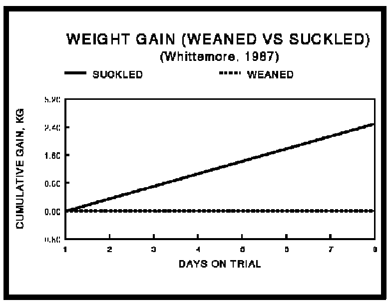
For 3 to 5 kg pigs (NRC, 1998)	
Lysine, %	1.50
Protein, %	26
Calcium, %	.90
Phosphorus, %	.70

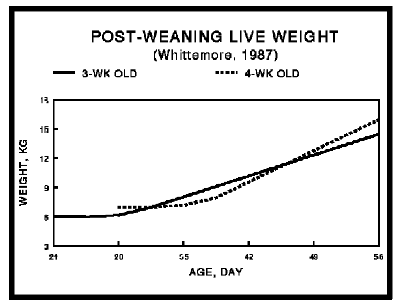
1) Try to provide fresh feed! - a) Change feed frequently, i.e., don't feed too much at once, and b) to encourage intake, feed small amounts in a shallow pan or on the floor several times/day during the first week or so.
2) Use fresh, palatable, and digestible ingredients ("special ingredients" - e.g., milk products, plasma protein, fish meal, oat groats, fats/oil, etc.) - If not, better to buy a complete diet or a base mix with several special ingredients?!

BABY PIGS

1. **Post-Weaning Lag or Growth Check & Stress**:

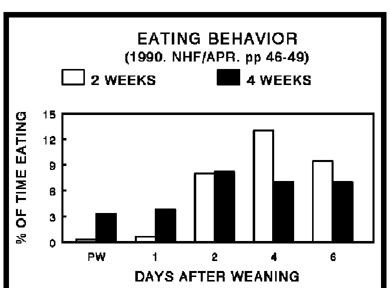
A. Post-weaning weight and weight gain (Whittermore, 1987):

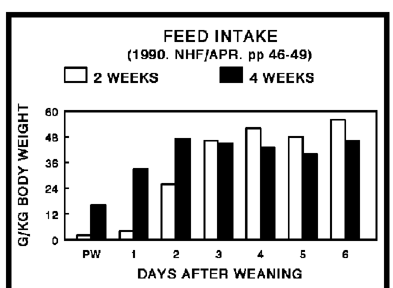


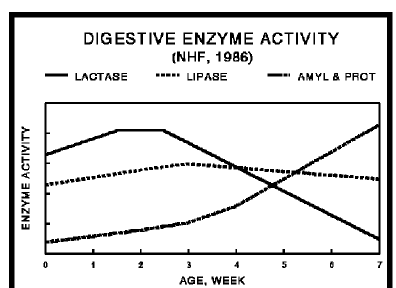


B. Post-weaning stress - Weaning is a traumatic time for suckling piglets, and there are three types of stress: environmental, social, and nutritional.

2. **Try to Reduce "Nutritional Stress" At Weaning Time?**







A. A sudden change to a solid diet at weaning, thus pigs just will not eat during the first day or so. [See "Eating Behavior & Feed Intake." NHF/Apr. pp 46-49 (1990)]
B. Then, may consume a large amount - Mostly undigested, thus end up with diarrhea!?
C. Enzymes - May not be ready for digesting a large quantity of solid feed (especially, corn-soy diets) [See "Digestive Enzyme Activity (1986. NHF/Spr. pp 23-31)"]
D. Important to offer highly palatable/digestible diets, and may want to feed the same creep feed for about 5 d after weaning to reduce nutritional stress - But, costly though!?

3. **Stimulate Feed Intake After Weaning?**

   A. The primary reason for post-weaning lag seems to be "lack of energy intake soon after weaning!" Thus, should make efforts to let pigs eat some feed within 12 hr or so!

   B. Ways to stimulate feed intake:

      1) Hand-feed on the floor several times a day (first 2 or 3 days after weaning) because pigs are reluctant to make a trip to feeder.
      2) Check pigs often (5 to 6 times/day for about week) - Stirring them up can stimulate pigs, thus they may eat more!
      3) For early-weaned pigs (3 wk or younger), adding water to milk replacer, pre-starter diets, or mixture may enhance intake (. . . feed 5 to 6 times/day for about week).

4. **Starter Diets**

   A. Not a long ago, only one starter diet was used for baby pigs, but nowadays, it is common to use a three-phase feeding system. [e.g., Table (Luce and Maxwell, OSU)]

Table 1. Three Phase Feeding System for Early Weaned Pigs.

Phase	*Should Feed:*	*Diet Specifications*
I	First 7 to 10 days for pig weaned at 16 to 21 days. First 3 to 4 days after 22 to 28 day weaning. A pig experiencing postweaning lag.	Pelleted feed (1/8 in. pellet). 18 to 20% crude protein 1.50% total lysine
II	Day 4 to 10 postweaning. A weaned pig that has recovered from post-weaning lag. A weaned pig after it is consuming dry feed.	Feed can be in either pelleted or meal form. 17 to 20% crude protein 1.30-1.40 %* total lysine
III	Week 3 to 5 postweaning. A pig weighing between 25 and 45 lbs. A postweaning pig readily consuming feed.	Grain-soybean meal diet. Feed can be either meal or pellet 17 to 20% crude protein 1.15-1.20 %* lysine.

*High performing pigs may need the higher levels in the range shown

   B. Phase feeding:

      1) Phase I diets are often formulated without soybean meal and they are pelleted.
      2) May ↑ performance during the starter phase.
      3) Some question on the effect of improved performance on overall growth performance and cost effectiveness!

   C. Sometimes, mixing own starter diets may not be cost-effective, especially diets for very young pigs. Thus, may want to buy a complete diet or a base mix containing many special ingredients if you do not have many sows and(or) producing pigs only few times/year!

5. **Type of Ingredients/Diets** - Mostly depending on the weight and(or) age of starter pigs.

   A. 3-week-old or younger ($\approx$ < 15 lb) - Need a complex diet!

   B. 4- to 6-week-old (up to $\approx$ 25 lb) - A semi-complex diet (i.e., a diet containing some milk products) or a corn-soy-based diet.

      ☛ May ↓ the performance slightly, but can be justified economically?!

C. 6-week-old or > 25 lb - Some milk products are recommended, but a simple diet (corn-soy diet) can be used.

6. **Suggested Baby Pig Diets**

Examples - "Diets for young pigs" (NE-SD Swine Nutrition Guide, 1995)[a]:

	Starter 1/ transition[b] (< 15 lb)	Starter 2 (15-25 lb)		Starter 3 (25-50 lb)	
Item	1	1	2	1	2
Ingredients, %					
Corn	31.45	52.50	51.10	65.25	56.90
SBM (44% CP)	8.50	22.90	23.65	30.50	31.05
Soy protein	3.00	-	-	-	-
Dried whey	27.50	15.00	15.00	-	5.00
Plasma proteins	6.00	-	-	-	-
Oat groats	12.50	-	-	-	-
Fish meal	5.00	-	4.00	-	-
Blood meal	-	2.50	-	-	-
Fat (stabilized)	3.00	3.00	3.00	-	3.00
L-lysine·HCl	0.15	0.15	0.15	0.15	0.15
DL-methionine	0.10	0.05	-	-	-
Limestone	0.45	0.60	0.40	0.75	0.70
Dical phosphate	0.80	1.65	1.05	1.60	1.45
Salt	0.10	0.20	0.20	0.30	0.30
Trace mineral	0.15	0.15	0.15	0.15	0.15
Vitamin mix	0.25	0.25	0.25	0.25	0.25
Copper sulfate	0.05	0.05	0.05	0.05	0.05
Antibiotics	1.00	1.00	1.00	1.00	1.00
Calculated analysis, %					
Lysine	1.55	1.25	1.25	1.15	1.19
Protein	22.1	18.9	19.3	19.1	19.3
Calcium	0.90	0.80	0.80	0.75	0.75
Phosphorus	0.80	0.70	0.70	0.65	0.65

[a]SBM = soybean meal; soy protein = soy protein concentrate; dried whey = edible dried whey; plasma proteins = spray-dried plasma proteins; fish meal = select menhaden fish meal; blood meal = spray-dried blood meal.

[b]Provide a total of 4 lb/pig (at least 3 lb after weaning) to pigs > 13 lb at weaning, but < 28 days of age.

7. **Feed Ingredients and Additives**

A. Protein sources in general:

1) Milk products (dried skim milk and whey):

a) Very good ingredients for weanling pigs because: (1) no need for an adaptation period, (2) highly palatable, (3) contain a highly available source of energy, lactose, and (4) "efficient" utilization of milk proteins.
b) Form a "curd" in the stomach by coagulation of milk proteins by "rennin" (or chymosin) produced in the gastric mucosa: (Concentration/activity of rennin ↓ with age!)

(1) A curd can stay in the stomach longer, which can stimulate acid secretion, thus, enhancing the activation of proteases (i.e., pepsin, which is produced as pepsinogen or proenzyme).
(2) Causes stomach to release nutrients very slowly, ∴ better utilization!

2) Soy proteins do not form a curd and acid secretion is very slow, ∴ less enzyme activation, and some components may be harmful to pigs because of, for instance, allergic reactions!
3) Soy protein concentrate (being used by the Food Industry)? - Potentially harmful carbohydrates (raffinose, stachyose, etc., in which galactose is joined by α-1,4-galactosidic linkage) are removed, thus, may improve palatability and availability. But, they are expensive, and pigs' response is very inconsistent!

B. Some protein sources/supplements for baby pigs:

1) Fish meal - Cost and quality of fish products vary greatly, and limit to a maximum of 5% (depending on the quality) because of palatability issue.
2) Dried whey:

a) Most commonly used in starter diets.
b) Because of variations in the quality (Table), try to use only edible grade, which are higher in lysine and lower in ash & salt compared with feed grade, especially for newly weaned pigs.
c) Tan/brown in color means "overheating" and it has less available lysine.

Composition of dried whey:

Item	Low	High	Mean
Moisture, %	4.5	9.7	6.4
Protein, %	5.3	13.2	11.8
Lysine %	.32	1.12	.85
Calcium, %	.43	1.35	.71
Salt, %	2.2	3.9	2.8

3) Dried plasma protein, which are highly palatable and may have some role in the immune status of young pigs, can be an alternative to milk products?

C. Alternative grains (other than corn and milo):

1) Oats - Use ≤ 20% because of high-fiber/low-energy content.
2) Barley - Use ≤ 20-25% because of a palatability problem and also low in energy.
3) Wheat - Use ≤ 30-35% because of a palatability problem. Also, avoid fine grinding!

D. Fats/oils:

1) Palatable, excellent sources of energy, and reduce dustiness in feeds & buildings.
2) Fats are cheaper vs. oils, but have to be melted before incorporating into the diet.
3) Oils are easier to mix vs. fats, but still need extra time, and they are rather expensive.
4) In a high-milk diet, may or may not see beneficial effects of fats/oils.

5) Medium-chained fatty acids (MCT; contain 8-14 carbons, and, e.g., coconut oil contains ≈ 60% MCT):

   a) Research interest in recent years.
   b) Highly digestible vs. long-chained fatty acids because MCT may be absorbed without micelle formation.
   c) May improve the performance slightly, but very expensive and may not be justified economically?

E. Organic acids:

1) European producers have been trying to acidify starter diets for some time, and fumaric acid, citric acid & others may be effective in improving performance.
2) How do they work?

   a) Acidic diets can ↓ stomach pH (more acidic), which can ↑ activation of pepsin, ↓ rate of passage, and keep pathogenic bacteria in check.
   b) May prevent overeating because acids are slightly unpalatable, ∴ avoid overloading the digestive system, which can lead to less diarrhea.

3) Does it pay?

   a) Inclusion of 1½ to 3% fumaric or citric acid (60¢ to $1/lb) costs additional $30 to 60/ton. If pigs are healthy and growing well, may not see obvious responses!
   b) To offset $60/ton, need a sizable performance improvement, thus may not be beneficial unless problems exist!

F. Probiotics - A mixture(s) of bacteria, yeasts and(or) other microorganisms (MO), and may competitively inhibit undesirable MO, thus helping desirable MO. However, its effect on pig performance has been very inconsistent!

G. Flavors - Being used by the feed industry to enhance feed intake and(or) cover up odors (e.g., odor of fish meal), but adding flavors for pigs or producers? (Pigs have a different No. of taste buds.)

H Enzymes:

1) Included in the diet to assist digestive process . . . Remember that the young pig's digestive system is not fully competent, thus the idea is excellent!
2) The response has been very inconsistent:

   a) One of the reasons? - Heat processing! Baby pig diets are often pelleted or crumbled, thus the effectiveness may depend a method of incorporation!?
   b) Exception? The use of β-glucanase, which can breakdown β-glucan (e.g., 5-8% in barley), has been resulted a very consistent response!

I. Antimicrobial agents - Usually included in baby pig diets to improve pig performance. (Please see "Feed Additives" in Section 18!)

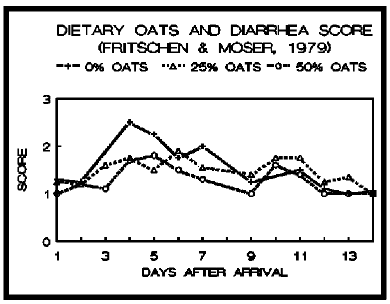
FEEDER PIGS

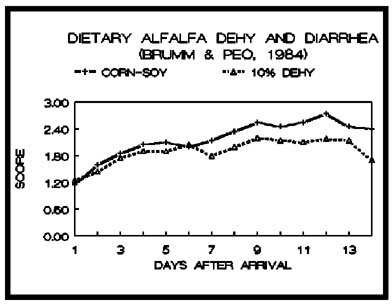
1. **Most Common Problem?**

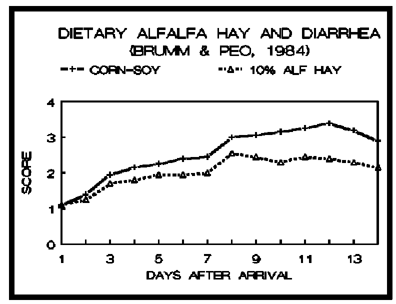
- Most common problem among newly arrived pigs is diarrhea - Can be caused by bacteria/virus infections, or non-disease factors such as nutrition or stress.

2. **To Prevent/Alleviate Diarrhea Through Nutritional Means**

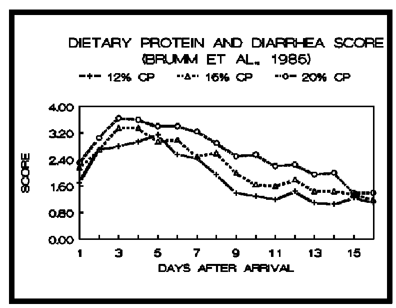
A. Use of fibrous ingredients - Inclusion of fibrous ingredients in receiving diets is one way to alleviate problems with diarrhea in newly arrived feeder pigs.







1) Oats [Figure (Fritschen & Moser, 1979. NE Swine Rep.)] - ↑ dietary oats (≈ 11% fiber) can delay and reduce incidence of diarrhea, but ↓ pig performance with 50% oats. Thus, 25% may be the optimum?!
2) Dehydrated alfalfa & alfalfa hay (Brumm & Peo, 1984. NE Swine Rep.) - No adverse effects on pig performance, and 10% alfalfa may ↓ severity of scours!



B. Dietary protein

1) It is a common practice among feeder pig finishing operators to reduce dietary CP content of receiving diets to alleviate diarrhea.
2) Effect of dietary CP content (Brumm et al., 1985. NE Swine Rep.):

a) Fairly common to feed a diet with 16% CP to pigs weighing 40 to 110 lb.
b) 12% dietary CP - May have a positive effect on diarrhea scores, but may not be sufficient to support the optimum gain or efficiency.

Numerical Goals (PIH-100)

Item	Excellent	Possible*
Weight gain, lb/day	> 1.40	1.58
Age at 230 lb, days	< 182	165
Efficiency (F:G)	< 3.40	3.00
Loin muscle, sq.in.	> 5.4	5.6
Avg. Backfat, in	< 1.1	1.0
Mortality, %	< 2.0	1.5

* Can get, 1.8-2.0 lb/day weight gain, > 6 sq. in. LMA, and < 1 in. BF via genetic & nutritional management though!

c) 20% dietary CP - Tendency for pigs to have higher diarrhea scores, but similar performance to those fed a 16% CP during the initial 16 days.

☛ The bottom line? - Not necessary to reduce the CP content of receiving diets!

GROWER-FINISHER PIGS

1. **General Goals During the Grower-Finisher Phase?**

A. Time - Produce the maximum amount of pork with the least time possible!
B. Inputs - Spend minimum dollars possible on feed to achieve the first goal! (Doesn't necessary mean the cheapest feed though!)
C. Quality - Maximize the quality of final products!

2. **Alternative Energy Sources**

A. Relative feeding values (corn = 100%): (NE Swine Diet Suggestion, 1992)

		Maximum recommended percent of complete diet[b]				
Ingredient	Feeding value[a]	Star-ter	G-F	Gest-ation	Lact-ation	Remarks
Alfalfa, dehy	75-85	0	5	25	10	Low energy, high in B vitamins
Alfalfa hay, early bloom	75-85	10	10	66	10	Low energy, high in B vitamins
Bakery waste, dehy	95-100	20	40	40	40	High energy, about 13% fat
Barley (48 lb/bu)	90-100	25	85	90	80	Low energy
Beet pulp	70-80	0	0	10	10	Bulky, high fiber, laxative
Corn & cob meal	80-90	0	0	70	10	Bulky, low energy
Corn distiller grains, dehy	115-130	5	15	40	10	B vitamin source, low lysine
Corn gluten feed	75-85	5	10	90	10	Dry pelleted source preferred
High lysine corn	100-105	60	90	90	90	Test lysine level
Corn silage (20-30% DM)	20-30	0	0	90	0	Bulky, low energy, for sows only
Fat (stabilized)	185-210	5	5	5	5	High energy, reduces dust
Hominy feed	100-105	0	60	60	60	Subject to rancidity
Millet, proso	90-95	40	75	90	40	Low lysine
Milo	95-97	60	85	90	80	Low lysine
Molasses (77% DM)	55-65	5	5	5	5	Energy source, used in pelleting
Oats (36 lb/bu)	85-95	15	20	70	10	May ↓ gut edema & nutritional scours
High protein oats	90-100	20	50	70	10	May ↓ gut edema & nutritional scours
Oat groats	110-115	20	85	90	90	Palatable, but expensive
Potatoes (22% DM)	20-25	0	25	80	0	Should be cooked, low protein
Rye	85-90	0	25	20	20	Watch for ergot toxicity
Triticale	90-95	20	75	90	40	Watch for ergot toxicity
Wheat bran	60-65	0	0	30	10	Bulky, High fiber, Laxative
Wheat, hard	100-105	35	85	40	40	Avoid fine grinding
Wheat middlings	110-125	5	15	30	10	Partial grain substitute

[a]Value apply when ingredients fed at no more than the maximum recommended % of diet; Ranges presented to compensate for quality variation. [b]Higher levels may be fed, but the performance may decrease.

☞ e.g., Milo - Feeding value is 95% of corn, thus, economically replace corn when the price of milo is less than 95% of corn.

B. How to use alternative sources?

1) Substitute on the pound-for-pound basis within the limit. Exceptions? Using ingredients low in the amino acids such as fat, corn silage, corn-corn cob meal, etc.
2) Reformulate the diet on the lysine basis - Can effectively utilize wheat, barley & others that are relatively high in Lys, thus can ↓ protein supplements.

3. **Alternative Amino Acid Sources**

A. Some by-products of oil extractions:

1) Peanut meal - Low in lysine (1.4-1.7%), and contains 5-7% fat, thus may cause rancidity problems?
2) Rapeseed meal - Low in lysine (2.1-2.3%), and the quality is influenced by glucosinolate content (goitrogenic).
3) Canola (**Can**ada **O**il-**L**ow **A**cid) meal is produced from rapeseed low in undesirable substances (erucic acid in the oil & glucosinolate in the meal), and its protein value is 75-85% of SBM (lb-for-lb basis).
4) Sunflower meal is high in the fiber content (≈ 12%) & low in lysine (≈ 1.7%), thus should not replace more than 20-30% of SBM, and also should be used only for pigs > 75-100 lb?

B. Suggested range of commonly protein sources: (KSU Swine Nutr. Guide, 1983)

	% of complete diet				
Source	Starter	G-F	Gest.	Lact.	% of suppl.
Alfalfa, dehy	0-5	0-20	0-75	0-10	0-20
Alfalfa hay	0-5	0-20	0-75	0-10	0-20
Cottonseed meal	0-2	0-5	0-5	0-5	0-20
Fish solubles, dr.	0-3	0-3	0-3	0-3	0-5
Meat & bone meal	0-5	0-5	0-5	0-5	0-30
Soybean meal	0-25	0-20	0-25	0-25	0-85
Tankage	0-5	0-5	0-5	0-5	0-30
Whey, dried	0-20	0-20	0-5	0-5	0-20
Yeast, brewers dr.	0-3	0-3	0-3	0-3	0-5

C. Alternative protein sources: (KSU Swine Nutr. Guide, 1983)

			Relative value as a lysine source	
Source	Protein, %	Lysine, %	%	Pounds[a]
Soybean meal	44	2.86	100	100
Soybean meal	47.5	3.18	111	90
Alfalfa meal	17	.73	26	385
Cottonseed meal	41	1.51	53	187
Wheat bran	15	.59	21	476
Wheat middlings	16	.69	24	417
Yeast, brewers dried	45	3.23	112	89
Fish meal	60	5.44	190	53
Fish soluble, dried	54	1.73	60	167

Meat & bone meal	50	2.60	91	110
Skim milk, dried	33	2.40	84	119
Tankage	60	3.00	105	95
Whey, dried	12	.97	34	294

[a]Pounds required to replace 100 lb of 44% SBM.

☞ e.g., The relative value of 47.5% CP SBM is 111% of 44% SBM. If 44% SBM is $200/ton, then the value of 47.5% SBM is $222/ton. Thus, if the price of 47.5% SBM is < $222, better to use 47.5% SBM!

4. **Other Feed Ingredients**

A. High lysine corn:

1) Higher in most indispensable amino acids vs normal corn (e.g., Lys content is ≈ 0.38% for high lysine corn vs. 0.25% for normal corn).
2) No differences in performance if diets are formulated based on lysine, thus can save protein supplements, however, when using high lysine corn:

a) Analysis is important because of the variation in the lysine content!
b) Should be ground coarsely because it become powdery easily during grinding!

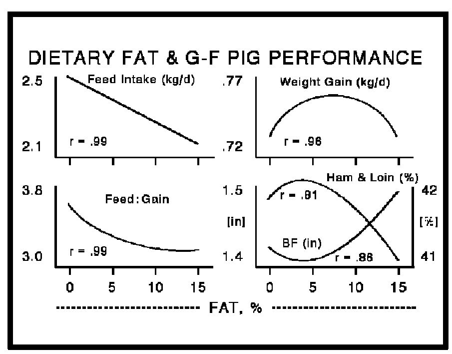
B. High moisture grains:

1) Can save drying costs and ↓ harvest-loss.
2) Similar feeding value to dry grain on the dry matter basis, but because of the moisture content, the quantity of grains in the diet must be increased accordingly:

Conversion factors (NE Swine Diet Suggestion, 1992):

15% no ∆	17% . . . . ↑ 2.4%	19% . . . . ↑ 4.9%
21% ↑ 7.6%	23% . . . . ↑ 10.4	25% . . . . ↑ 13.3%
27% ↑ 16.4%.		

3) Feeding to pigs less than 40 lb is not recommended.
4) Prepare diets frequently to prevent spoilage, i.e., every one or two days?



C. Fats or lipids:

1) Typical performance responses to dietary fats - See the summary [Moser, 1977. Feedstuffs 49(15):20].

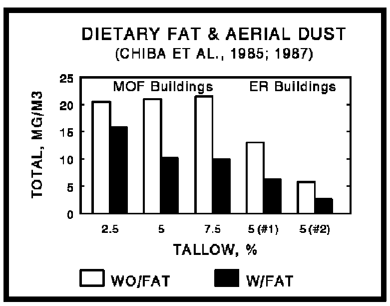
a) May or may not improve weight gain, but consistently improve feed efficiency.
b) Generally, can expect 2% improvement with 1% ↑ in dietary fat. (Lipids are utilized more efficiently during the summer vs winter!)

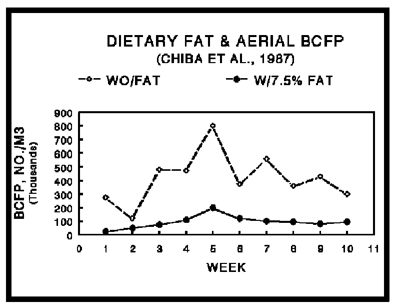
c) Generally, no adverse effects on the carcass quality, but may ↑ carcass fat with > 5% dietary fat.

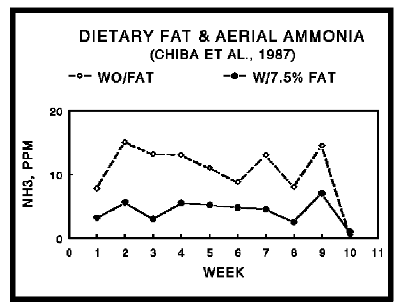
2) Effects of dietary fat on the environment:

a) Dust: (1) can be nuisance, (2) has adverse effects on buildings, ventilation ducts, motors, thermostats, timer, etc, (3) has adverse effects on humans (& pigs - e.g., eye irritation, headache, coughing, chest tightness, stuffy nose, shortness of breath, etc.), and (4) aerial particles can be a possible carrier of M.O. and harmful gases (particles > 5 μ are especially dangerous because can penetrate into a deeper portion of the respiratory tract!).

b) Effects of dietary fat on aerial dust, NH_3 & M.O. concentrations (Chiba et al., 1985. JAS 61:763 & Chiba et al., 1987. Trans. ASAE 30:464) - Simply adding lipids to diets can improve environment for both humans & pigs!







3) Additional benefits of dietary fat?

a) ↓ wear on mixing/handling machineries by its lubricating action.
b) Facilitate the pelleting process - ↓ power requirement.
c) ↑ palatability of feed.
d) ↓ feed wastage during handling/feeding process.
e) ↓ feed or particle separation, thus all pigs can receive a uniform diet.

4) Fats/oils should be stabilized with an antioxidant(s)!

D. Whole soybeans:

1) Depending on the price of soybean/oil and soybean meal, the use of whole soybeans can be economical from time to time.
2) Contain 32-37% protein and 18-19% fat, thus whole soybeans can be a good source of both amino acids and lipids!
3) The results of many studies indicate that the processed whole soybeans can be used as a replacement for SBM!

E. Crystalline amino acids:

1) At present, feed grade Lys, Thr & Trp (& Met has been available for a long time) are commercially available.
2) Economical? - Yes & No depending on the price of grains and supplemental protein sources. (Table.)

☞ Lys is often economical to use, but Trp and Thr are rather expensive at this time, and probably not!

Value of using synthetic lysine: (NHF, 1990)

	44% SBM, $/ton						
Corn, $/bu	160	165	170	175	180	185	190
2.00	1.51	1.60	1.68	1.76	1.85	1.93	2.01
2.10	1.45	1.54	1.62	1.70	1.79	1.87	1.95
2.20	1.40	**1.48**	1.56	1.65	1.73	1.81	1.90
2.30	1.34	1.42	1.51	1.59	1.67	1.76	1.84
2.40	1.28	1.36	1.45	1.53	1.61	1.69	1.78
2.50	1.23	1.31	1.39	1.48	1.56	1.64	1.73
2.60	1.17	1.25	1.33	1.42	1.50	1.58	1.67
2.70	1.11	1.19	1.27	1.36	1.44	1.52	1.61
2.80	1.05	1.13	1.21	1.30	1.38	1.46	1.55
2.90	.99	1.07	1.15	1.24	1.32	1.40	1.49
3.00	.93	1.01	1.09	1.18	1.26	1.34	1.43

* e.g., At $2.20/bu corn & $165/ton SBM, can ↓ the cost of diets if the price of Lys is ≤ $1.48/lb.

3) Commonly used methods:

a) For 44% SBM - 3 lb of L-Lys·HCl (78% Lys) plus 97 lb of corn to replace 100 lb of SBM.
b) For 48% SBM - 3.2 lb of Lys + 96.8 lb of corn to replace 100 lb of SBM.

4) Amino acids to replace protein supplements? (Lewis, 1989. NE Swine Rep.)

	Corn-SBM (+) control	Corn (-) control	Corn+ Lys & Trp	Corn+Lys, Trp & Thr
Initial wt, lb	133	132	132	132
Final wt, lb	247	213	239	237
Feed intake, lb/d	6.60	4.73	5.91	5.55
Weight gain, lb/d	1.75	.70	1.19	1.30
Feed:gain	3.77	6.79	4.98	4.28
Dressing %	75.5	74.0	74.7	74.9
Backfat, in	1.22	1.38	1.34	1.29
Lean, %	54.9	53.0	53.4	54.1

▸ May have the potential, but need more research on this area!

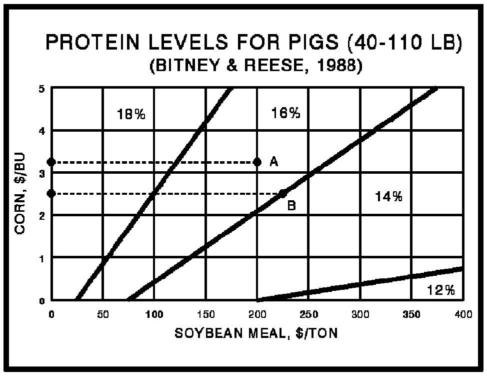
5. **Economical Dietary Protein?**

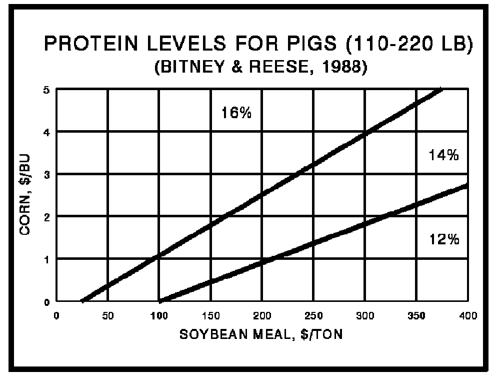
A. Both overfeeding or underfeeding protein can ↑ total production costs!

1) Underfeeding - ↓ growth performance & carcass quality.
2) Overfeeding - ↑ feed cost without affecting the performance.

B. The most economical level? (Bitney & Reese, 1988. NE Swine Rep.)

CP, %	ADG, lb	F:G	Feed, lb	Days	Costs/cwt gain, $ Feed	N-feed	Total
11	1.14	4.56	456	88	25.86	8.80	34.60
12	1.37	4.11	411	73	24.21	7.30	31.51
13	1.47	3.81	381	68	23.39	6.80	30.19
14	1.59	3.60	360	63	22.73	6.30	29.03
15	1.66	3.49	349	60	22.80	6.00	28.80
16	***1.66***	***3.49***	***349***	***60***	***23.56***	***6.00***	***29.56***
17	1.66	3.49	349	60	24.33	6.00	30.33
18	1.66	3.49	349	60	25.09	6.00	31.09
19	1.66	3.49	349	60	25.86	6.00	31.86
20	1.66	3.49	349	60	26.61	6.00	32.61





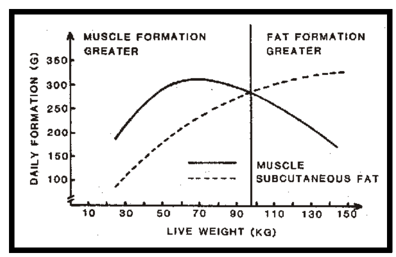
1) Point A - 16% CP diet is the most economical!
2) Point B, the boundary line, has alternatives: a) Feed higher protein - May reach market weights sooner with the same cost, b) Feed higher protein for a lower weight range & lower protein for a higher weight range, c) Feed an average of the two, and d) No problem with facility, feed lower protein.

Item	Avg Hog	High-Lean
Live wt, lb	244	245
Carcass wt, lb	181	185
Percent lean	46	58
Live price, $/cwt	44	44
Carcass price (75% yield), $/cwt	59	59
Base carcass value, $	106.79	109.15
Premium/discount for % lean, $	-1.36	+10.64
Price paid to producer, $	105.43	119.79
Slaughter cost, $	13.50	13.50
Total cost to packer, $	118.93	133.29
Pork cut value, $	117.52	139.70
Gain/loss to packer, $	-1.41	+6.41

6. Improving the Final Product, Pork?

A. General

1) Because of consumer demands for lean meats, need to improve leanness of pigs.
2) High-lean pigs can be beneficial for both producers (a higher base carcass value + premiums) and packers (a higher value for pork cuts). [Table - NHF 38(7):17 (1993)]
3) Excess consumption of energy? Finisher pigs have a propensity to consume energy in excess of their needs for "optimum" protein accretion, resulting in excess fat accretion! [Figure (Just, 1984. JAS 58:740)]



B. How to improve leanness?

1) A proper nutritional management - Mostly, amino acid and energy contents:

   a) Provide adequate protein or amino acids - According to some, in addition to satisfying the energy needs, pigs may eat to satisfy the Lys requirements. Thus, if the Lys content is too low, they may over-consume energy.
   b) Provide a proper balance of protein/amino acid & energy - e.g., Pigs eat less high-energy diet, thus may not consume enough amino acids for protein accretion if the amino acid-energy proportion is not appropriate.

2) Reducing energy intake of pigs:

a) Limit feeding:

(1) Extensively used in Europe, Australia & other countries to improve the efficiency of feed utilization and carcass leanness!

(2) Example - "Effect of restricted-feeding on pigs (20-110 kg; Haydon et al., 1989. JAS 67:1916).

Item	Ad lib	85%	70%
20 to 110 kg:			
ADG, kg	85	.75	.59
ADFI, kg	2.99	2.50	2.11
Feed:gain	3.53	3.26	3.60
At 110 kg:			
LMA, cm^2	34.3	34.7	40.3
Avg. BF, cm	4.00	3.22	2.78
Lean cut, %	58.3	60.7	61.5
Water, %	44.7	47.6	48.2
Protein, %	14.4	15.9	17.5
Eth. Ext., %	40.9	36.6	32.6

(3) Useful? (+) - Can ↑ leanness /↓ fat content of carcass, but (-) - ↓ weight gain, ∴ ↑ the feeding period, & (-) a practical feeding method (i.e., feeding *per se* and ensuring daily allowances for each pig) can be a problem.

b) Use of fibrous ingredients - The pig's ingestive capacity is limited, thus possible to reduce energy intake by increasing dietary bulk.

(1) Often improve leanness, but also reduce weight gain.

(2) Some concerns/questions - Adverse effects on digestibility of other nutrients & also, variations among various fibers as a source of energy.

3) Repartitioning agents:

1) Effective in improving growth performance and carcass characteristics! (Table)

2) Partitions nutrients away from fat deposition, thus more nutrients are used for lean muscle production.

3) Examples of repartitioning agents:

Responses to pST & β-agonists (% change vs control): (1988. HFM/Dec. pp 39-41)

Item	β-agonists	pST
ADG	+ 8	+ 22
F:G	- 10	- 28
Feed intake	- 5	- 13
Dressing %	+ 1.4	-
Loin muscle	+ 12	+ 14
Backfat	- 12	- 26
Lean	+ 8	+ 21
Protein depo.	-	+ 31
Ash depo.	-	+ 8
Heat prod.	-	+ 8
ME_m	-	+ 17

a) GH or pST (porcine somatotropin) - Increases muscle production & reduces fat deposition.

b) Beta adrenergic agonists - Similar to catecholamine (epinephrine, norepinephrine & dopamine) and examples include ractopamine, cimaterol, clenbuterol, and isoproterenol, which may or may not increase muscle production but reduce fat deposition.

4) Questions/problems:

a) Effectiveness may be depending on the type of pigs (genotypes & sex) & diets (especially, amino acids).

b) Cost-effectiveness?

c) pST - Must be injected or implanted (daily, weekly or whatever).

d) Consumer perception - Consumers have negative perceptions on the use of hormones or feed additives for animal production!

NUTRIENT REQUIREMENT TABLES
(Based on NRC, 1998)

1. Table 1. DIETARY Amino Acid Requirements of Growing Pigs (Ad Lib; 90% DM)[a]

	Body Weight (kg)					
	3-5	5-10	10-20	20-50	50-80	80-120
Average weight in range (kg)	4	7.5	15	35	65	100
DE content of diet (kcal/kg)	3,400	3,400	3,400	3,400	3,400	3,400
ME content of diet (kcal/kg)[b]	3,265	3,265	3,265	3,265	3,265	3,265
Estimated DE intake (kcal/day)	855	1,690	3,400	6,305	8,760	10,450
Estimated ME intake (kcal/day)[b]	820	1,620	3,265	6,050	8,410	10,030
Estimated feed intake (g/day)	250	500	1,000	1,855	2,575	3,075
Crude protein (%)[C]	26.0	23.7	20.9	18.0	15.5	13.2
Amino acid requirement[d]:						
True ileal digestible basis (%)						
Arginine	0.54	0.49	0.42	0.33	0.24	0.16
Histidine	0.43	0.38	0.32	0.26	0.21	0.16
Isoleucine	0.73	0.65	0.55	0.45	0.37	0.29
Leucine	1.35	1.20	1.02	0.83	0.67	0.51
Lysine	***1.34***	***1.19***	***1.01***	***0.83***	***0.66***	***0.52***
Methionine	0.36	0.32	0.27	0.22	0.18	0.14
Methionine + cystine	0.76	0.68	0.58	0.47	0.39	0.31
Phenylalanine	0.80	0.71	0.61	0.49	0.40	0.31
Phenylalanine + tyrosine	1.26	1.12	0.95	0.78	0.63	0.49
Threonine	0.84	0.74	0.63	0.52	0.43	0.34
Tryptophan	0.24	0.22	0.18	0.15	0.12	0.10
Valine	0.91	0.81	0.69	0.56	0.45	0.35
Apparent ileal digestible basis (%)						
Arginine	0.51	0.46	0.39	0.31	0.22	0.14
Histidine	0.40	0.36	0.31	0.25	0.20	0.16
Isoleucine	0.69	0.61	0.52	0.42	0.34	0.26
Leucine	1.29	1.15	0.98	0.80	0.64	0.50
Lysine	***1.26***	***1.11***	***0.94***	***0.77***	***0.61***	***0.47***
Methionine	0.34	0.30	0.26	0.21	0.17	0.13
Methionine + cystine	0.71	0.63	0.53	0.44	0.36	0.29
Phenylalanine	0.75	0.66	0.56	0.46	0.37	0.28
Phenylalanine + tyrosine	1.18	1.05	0.89	0.72	0.58	0.45
Threonine	0.75	0.66	0.56	0.46	0.37	0.30
Tryptophan	0.22	0.19	0.16	0.13	0.10	0.08
Valine	0.84	0.74	0.63	0.51	0.41	0.32
Total basis (%)[e]						
Arginine	0.59	0.54	0.46	0.37	0.27	0.19
Histidine	0.48	0.43	0.36	0.30	0.24	0.19
Isoleucine	0.83	0.73	0.63	0.51	0.42	0.33
Leucine	1.50	1.32	1.12	0.90	0.71	0.54
Lysine	***1.50***	***1.35***	***1.15***	***0.95***	***0.75***	***0.60***
Methionine	0.40	0.35	0.30	0.25	0.20	0.16
Methionine + cystine	0.86	0.76	0.65	0.54	0.44	0.35
Phenylalanine	0.90	0.80	0.68	0.55	0.44	0.34
Phenylalanine + tyrosine	1.41	1.25	1.06	0.87	0.70	0.55
Threonine	0.98	0.86	0.74	0.61	0.51	0.41
Tryptophan	0.27	0.24	0.21	0.17	0.14	0.11
Valine	1.04	0.92	0.79	0.64	0.52	0.40

[a]Mixed gender (1:1 ratio of barrows to gilts) of pigs with high-medium lean growth rate (325 g/day of carcass fat-free lean) from 20 to 120 kg body weight.

[b]Assumes that ME is 96% of DE. In corn-soybean meal diets of these crude protein levels, ME is 94-96% of DE.

[c]Crude protein levels apply to corn-soybean meal diets. In 3-10 kg pigs fed diets with dried plasma and/or dried milk products, protein levels will be 2-3% less than shown.

[d]Total amino acid requirements are based on the following types of diets: 3-5 kg pigs, corn-soybean meal diet that includes 5% dried plasma and 25-50% dried milk products; 5-10 kg pigs, corn-soybean meal diet that includes 5 to 25% dried milk products; 10-120 kg pigs, corn-soybean meal diet.

[e]The total lysine percentages for 3-20 kg pigs are estimated from empirical data. The other amino acids for 3-20 kg pigs are based on the ratios of amino acids to lysine (true digestible basis); however, there are very few empirical data to support these ratios. The requirements for 20-120 kg pigs are estimated from the growth model.

2. Table 2. DIETARY Amino Acid Requirements of Growing Pigs with Different Lean Growth Rates (Ad Lib; 90% DM)[a]

Body weight range:	50-80 kg Body Weight						80-120 kg Body Weight					
Lean gain (g/day):	300	300	325	325	350	350	300	300	325	325	350	350
Gender:	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt
Average weight in range (kg)	65	65	65	65	65	65	100	100	100	100	100	100
DE content of diet (kcal/kg)	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400
ME content of diet (kcal/kg)[b]	3,265	3,265	3,265	3,265	3,265	3,265	3,265	3,265	3,265	3,265	3,265	3,265
Estimated DE intake (kcal/day)	9,360	8,165	9,360	8,165	9,360	8,165	11,150	9,750	11,150	9,750	11,150	9,750
Estimated ME intake (kcaL/day)[b]	8,985	7,840	8,985	7,840	8,985	7,840	10,705	9,360	10,705	9,360	10,705	9,360
Estimated feed intake (g/day)	2,750	2,400	2,755	2,400	2,755	2,400	3,280	2,865	3,280	2,865	3,280	2,865
Crudeprotein (%)[C]	14.2	15.5	14.9	16.3	15.6	17.1	12.2	13.2	12.7	13.8	13.2	14.4
Amino acid requirements[d]:												
True ileal digestible basis (%)												
Arginine	0.20	0.23	0.22	0.26	0.25	0.28	0.13	0.15	0.15	0.17	0.16	0.19
Histidine	0.18	0.21	0.20	0.23	0.21	0.24	0.14	0.16	0.15	0.18	0.17	0.19
Isoleucine	0.32	0.36	0.34	0.39	0.37.	0.42	0.25	0.29	0.27	0.31	0.29	0.33
Leucine	0.58	0.66	0.62	0.72	0.67	0.77	0.45	0.51	0.48	0.55	0.52	0.59
Lysine	***0.58***	***0.66***	***0.62***	***0.71***	***0.67***	***0.76***	***0.45***	***0.51***	***0.48***	***0.55***	***0.52***	***0.59***
Methionine	0.16	0.18	0.17	0.19	0.18	0.21	0.12	0.14	0.13	0.15	0.14	0.16
Methionine + cystine	0.34	0.39	0.36	0.42	0.39	0.44	0.27	0.31	0.29	0.33	0.31	0.35
Phenylalanine	0.34	0.39	0.37	0.42	0.40	0.46	0.27	0.30	0.29	0.33	0.31	0.35
Phenylalanine + tyrosine	0.54	0.62	0.59	0.67	0.63	0.72	0.43	0.49	0.46	0.52	0.49	0.56
Threonine	0.37	0.43	0.40	0.46	0.43	0.49	0.30	0.34	0.32	0.37	0.34	0.39
Tryptophan	0.11	0.12	0.11	0.13	0.12	0.14	0.08	0.10	0.09	0.10	0.10	0.11
Valine	0.39	0.45	0.42	0.48	0.45	0.52	0.30	0.35	0.33	0.38	0.35	0.40
Apparent ileal digestible basis (%)												
Arginine	0.19	0.21	0.21	0.24	0.23	0.26	0.12	0.13	0.13	0.15	0.15	0.17
Histidine	0.17	0.20	0.19	0.21	0.20	0.23	0.14	0.15	0.15	0.17	0.16	0.18
Isoleucine	0.29	0.34	0.31	0.36	0.34	0.39	0.23	0.26	0.24	0.28	0.26	0.30
Leucine	0.56	0.64	0.60	0.69	0.65	0.74	0.43	0.50	0.47	0.53	0.50	0.57
Lysine	***0.53***	***0.61***	***0.57***	***0.66***	***0.61***	***0.71***	***0.41***	***0.47***	***0.44***	***0.51***	***0.47***	***0.54***
Methionine	0.15	0.17	0.16	0.18	0.17	0.20	0.12	0.13	0.13	0.14	0.13	0.15
Methionine + cystine	0.31	0.36	0.34	0.39	0.36	0.41	0.25	0.29	0.27	0.31	0.29	0.33
Phenylalanine	0.32	0.36	0.34	0.39	0.37	0.42	0.24	0.28	0.26	0.30	0.28	0.32
Phenylalanine + tyrosine	0.50	0.58	0.54	0.62	0.58	0.67	0.39	0.45	0.42	0.49	0.45	0.52
Threonine	0.32	0.37	0.35	0.40	0.37	0.43	0.26	0.30	0.28	0.32	0.30	0.34
Tryptophan	0.09	0.10	0.10	0.11	0.10	0.12	0.07	0.08	0.07	0.09	0.08	0.09
Valine	0.36	0.41	0.38	0.44	0.41	0.47	0.28	0.32	0.30	0.34	0.32	0.37
Total basis (%)[c]												
Arginine	0.24	0.27	0.26	0.29	0.28	0.32	0.16	0.18	0.18	0.20	0.19	0.22
Histidine	0.21	0.24	0.23	0.26	0.24	0.28	0.17	0.19	0.18	0.20	0.19	0.22
Isoleucine	0.36	0.41	0.39	0.45	0.42	0.48	0.29	0.33	0.31	0.35	0.33	0.37
Leucine	0.61	0.71	0.67	0.77	0.72	0.83	0.46	0.54	0.50	0.58	0.54	0.63
Lysine	***0.67***	***0.76***	***0.72***	***0.82***	***0.77***	***0.88***	***0.53***	***0.60***	***0.57***	***0.64***	***0.60***	***0.69***
Methionine	0.17	0.20	0.19	0.21	0.20	0.23	0.14	0.15	0.15	0.17	0.16	0.18
Methionine + cystine	0.38	0.44	0.41	0.47	0.44	0.50	0.31	0.35	0.33	0.38	0.35	0.40
Phenylalanine	0.38	0.44	0.41	0.47	0.44	0.51	0.29	0.34	0.32	0.36	0.34	0.39
Phenylalanine + tyrosine	0.61	0.70	0.65	0.75	0.70	0.80	0.48	0.54	0.51	0.59	0.55	0.63
Threonine	0.44	0.50	0.47	0.54	0.51	0.58	0.36	0.41	0.38	0.44	0.41	0.46
Tryptophan	0.12	0.14	0.13	0.15	0.14	0.16	0.10	0.11	0.10	0.12	0.11	0.13
Valine	0.45	0.51	0.48	0.55	0.52	0.59	0.35	0.40	0.38	0.43	0.40	0.46

[a]Average lean growth rates of 300, 325, and 350 g/day of carcass fat-free lean represent pigs with medium, high-medium, and high lean growth rates from 20 to 120 kg body weight.

[b]Assumes that ME is 96% of DE.

[c]Crude protein and total amino acid reqnirements are based on a corn-soybean meal diet.

dEstimated from the growth model.

3. Table 3. DIETARY Mineral, Vitamin, and Fatty Acid Requirements of Growing Pigs (Ad Lib; 90% DM)[a]

	Body Weight (kg)					
	3-5	5-10	10-20	20-50	50-80	80-120
Average weight in range (kg)	4	7.5	15	35	65	100
DE content of diet (kcal/kg)	3,400	3,400	3,400	3,400	3,400	3,400
ME content of diet (kcal/kg)[b]	3,265	3,265	3,265	3,265	3,265	3,265
Estimated DE intake (kcal/day)	855	1,690	3,400	6,305	8,760	10,450
Estimated ME intake (kcal/day)[b]	820	1,620	3,265	6,050	8,410	10,030
Estimated feed intake (g/day)	250	500	1,000	1,855	2,575	3,075
Requirements (% or amount/kg of diet):						
Mineral elements						
Calcium (%)[c]	0.90	0.80	0.70	0.60	0.50	0.45
Phosphorus, total (%)[c]	0.70	0.65	0.60	0.50	0.45	0.40
Phosphorus, available (%)[c]	0.55	0.40	0.32	0.23	0.19	0.15
Sodium (%)	0.25	0.20	0.15	0.10	0.10	0.10
Chlorine (%)	0.25	0.20	0.15	0.08	0.08	0.08
Magnesium (%)	0.04	0.04	0.04	0.04	0.04	0.04
PotasSium (%)	0.30	0.28	0.26	0.23	0.19	0.17
Copper (mg)	6.00	6.00	5.00	4.00	3.50	3.00
Iodine (mg)	0.14	0.14	0.14	0.14	0.14	0.14
Iron (mg)	100	100	80	60	50	40
Manganese (mg)	4.00	4.00	3.00	2.00	2.00	2.00
Selenium (mg)	0.30	0.30	0.25	0.15	0.15	0.15
Zinc (mg)	100	100	80	60	50	50
Vitamins						
Vitamin A (IU)[d]	2,200	2,200	1,750	1,300	1,300	1,300
Vitamin D3 (IU)[d]	220	220	200	150	150	150
Vitamin E (IU)[d]	16	16	11	11	11	11
Vitamin K (menadione) (mg)	0.50	0.50	0.50	0.50	0.50	0.50
Biotin (mg)	0.08	0.05	0.05	0.05	0.05	0.05
Choline (g)	0.60	0.50	0.40	0.30	0.30	0.30
Folacin (mg)	0.30	0.30	0.30	0.30	0.30	0.30
Niacin, available (mg)[e]	20.00	15.00	12.50	10.00	7.00	7.00
Pantothenic acid (mg)	12.00	10.00	9.00	8.00	7.00	7.00
Riboflavin (mg)	4.00	3.50	3.00	2.50	2.00	2.00
Thiamin (mg)	1.50	1.00	1.00	1.00	1.00	1.00
Vitamin B_6 (mg)	2.00	1.50	1.50	1.00	1.00	1.00
Vitamin B_{12} (µg)	20.00	17.50	15.00	10.00	5.00	5.00
Linoleic acid (%)	0.10	0.10	0.10	0.10	0.10	0.10

[a]Pigs of mixed gender (1:1 ratio of barrows to gilts). The requirements of certain minerals and vitamins may be slightly higher for pigs having high lean growth rates (> 325 g/day of carcass fat-free lean), but no distinction is made.

[b] Assumes that ME is 96% of DE. In corn-soybean meal diets, ME is 94-96% of DE, depending on crude protein level of the diet.

[c]The percentages of calcium., phosphorus, and available phosphorus should be increased by 0.05 to 0.1 percentage points for developing boars and replacement gilts from 50 to 120 kg body weight.

[d]Conversions: 1 IU vitamin A = 0.344 µg (g retinyl acetate; 1 IU vitamin D_3 = 0.025 µg cholecalciferol; 1 IU vitamin E = 0.67 mg of D-α-tocopherol or 1 mg of DL-α-tocopheryl acetate.

[e]The niacin in corn, grain sorghum, wheat, and barley is unavailable. Similarly, the niacin in by-products made from these cereal grains is poorly available unless the by-products have undergone a fermentation or wet-milling process.

4. Table 4. DAILY Amino Acid Requirements of Gestating Sows (90% DM)[a]

	Body Weight at Breeding (kg)					
	125	150	175	200	200	200
	Gestation Weight Gian (kg)[b]					
	55	45	40	35	30	35
	Anticipated Pigs in Litter					
	11	12	12	12	12	14
DE content of diet (kcal/kg)	3,400	3,400	3,400	3,400	3,400	3,400
ME content of diet (kcal/kg)[c]	3,265	3,265	3,265	3,265	3,265	3,265
Estimated DE intake (kcal/day)	6,660	6,265	6,405	6,535	6,115	6,275
Estimated ME intake (kcal/day)[c]	6,395	6,015	6,150	6,275	5,870	6,025
Estimated feed intake (kg/day)	1.96	1.84	1.88	1.92	1.80	1.85
Crude protein (%)[d]	12.9	12.8	12.4	12.0	12.1	12.4
Amino acid requirements:						
True ileal digestible basis (g/day)						
Arginine	0.8	0.1	0.0	0.0	0.0	0.0
Histidine	3.1	2.9	2.8	2.7	2.5	2.7
Isoleucine	5.6	5.2	5.1	5.0	4.7	5.0
Leucine	9.4	8.7	8.3	7.9	7.4	8.1
Lysine	***9.7***	***9.0***	***8.7***	***8.4***	***7.9***	***8.5***
Methionine	2.7	2.5	2.4	2.3	2.2	2.3
Methionine + cystine	6.4	6.1	6.1	6.0	5.7	6.1
Phenylalanine	5.7	5.2	5.0	4.8	4.6	4.9
Phenylalanine + tyrosine	9.5	8.9	8.6	8.4	7.9	8.5
Threonine	7.3	7.0	6.9	6.9	6.6	7.0
Tryptophan	1.9	1.8	1.7	1.7	1.6	1.7
Valine	6.6	6.1	5.9	5.7	5.4	5.8
Apparent ileal digestible basis (g/day)						
Arginine	0.6	0.0	0.0	0.0	0.0	0.0
Histidine	2.9	2.7	2.6	2.5	2.4	2.6
Isoleucine	5.1	4.8	4.7	4.5	4.3	4.6
Leucine	9.2	8.4	8.1	7.7	7.3	7.9
Lysine	***8.9***	***8.2***	***7.9***	***7.6***	***7.2***	***7.7***
Methionine	2.5	2.4	2.3	2.2	2.1	2.2
Methionine + cystine	6.0	5.7	5.7	5.6	5.3	5.7
Phenylalanine	5.2	4.8	4.6	4.4	4.2	4.5
Phenylalanine + tyrosine	8.8	8.2	8.0	7.7	7.3	7.9
Threonine	6.3	6.0	6.0	6.0	5.7	6.1
Tryptophan	1.6	1.5	1.4	1.4	1.3	1.4
Valine	6.0	5.6	5.4	5.2	4.9	5.3
Total basis (g/day)						
Arginine	1.3	0.5	0.0	0.0	0.0	0.0
Histidine	3.6	3.4	3.3	3.2	3.0	3.2
Isoleucine	6.4	6.0	5.9	5.7	5.4	5.8
Leucine	9.9	9.0	8.6	8.2	7.7	8.3
Lysine	***11.4***	***10.6***	***10.3***	***9.9***	***9.4***	***10.0***
Methionine	2.9	2.7	2.6	2.6	2.4	2.6
Methionine + cystine	7.3	7.0	6.9	6.8	6.5	6.9
Phenylalanine	6.3	5.8	5.6	5.4	5.0	5.4
Phenylalanine + tyrosine	10.6	9.9	9.6	9.4	8.9	9.5
Threonine	8.6	8.3	8.3	8.2	7.8	8.3
Tryptophan	2.2	2.0	2.0	1.9	1.8	2.0
Valine	7.6	7.0	6.8	6.6	6.2	6.7

[a]Daily intakes of DE and feed and the amino acid requirements are estimated by the gestation model.
[b]Weigbt gain includes maternal tissue and products of conception.
[c]Assumes that ME is 96% of DE.
[d]Crude protein and total amino acid requirements are based on a corn-soybean meal diet.

5. Table 5. DAILY Amino Acid Requirements of Lactating Sows (90% DM)[a]

	Sow Postfarrowing Weight (kg)					
	175	175	175	175	175	175
	Anticipated Lactational Weight Change (kg)[b]					
	0	0	0	-10	-10	-10
	Daily Weight Gain of Pigs (g)[b]					
	150	200	250	150	200	250
DE content of diet (kcal/kg)	3,400	3,400	3,400	3,400	3,400	3,400
ME content of diet (kcal/kg)[c]	3,265	3,265	3,265	3,265	3,265	3,265
Estimated DE intake (kcal/day)	14,645	18,205	21,765	12,120	15,680	19,240
Estimated ME intake (kcal/day)[c]	14,060	17,475	20,895	11,635	15,055	18,470
Estimated feed intake (kg/day)	4.31	5.35	6.40	3.56	4.61	5.66
Crude protein (%)[d]	16.3	17.5	18.4	17.2	18.5	19.2
Amino acid requirements:						
True ileal digestible basis (g/day)						
Arginine	15.6	23.4	31.1	12.5	20.3	28.0
Histidine	12.2	17.0	21.7	10.9	15.6	20.3
Isoleucine	17.2	23.6	30.1	15.6	22.1	28.5
Leucine	34.4	48.0	61.5	31.0	44.5	58.1
Lysine	***30.7***	***42.5***	***54.3***	***27.6***	***39.4***	***51.2***
Methionine	8.0	11.0	14.1	7.2	10.2	13.2
Methionine + cystine	15.3	20.6	26.0	13.9	19.2	24.5
Phenylalanine	16.8	23.3	29.7	14.9	21.4	27.9
Phenylalanine + tyrosine	34.6	47.9	61.1	31.4	44.6	57.8
Threonine	19.5	26.4	33.3	17.7	24.6	31.5
Tryptophan	5.5	7.6	9.7	5.2	7.3	9.4
Valine	25.8	35.8	45.8	23.6	33.6	43.6
Apparent ileal digestible basis (g/day)						
Arginine	14.6	22.0	29.3	11.7	19.1	26.4
Histidine	11.5	16.0	20.5	10.2	14.7	19.2
Isoleucine	15.9	21.9	27.9	14.5	20.5	26.5
Leucine	33.0	45.9	58.7	29.7	42.6	55.4
Lysine	***28.4***	***39.4***	***50.4***	***25.5***	***36.5***	***47.5***
Methionine	7.6	10.5	13.4	6.8	9.7	12.6
Methionine + cystine	14.2	19.2	24.1	12.9	17.8	22.8
Phenylalanine	15.5	21.6	27.6	13.8	19.9	25.9
Phenylalanine + tyrosine	32.3	44.7	57.1	29.3	41.7	54.1
Threonine	17.1	23.1	29.2	15.5	21.6	27.7
Tryptophan	4.7	6.6	8.4	4.5	6.3	8.1
Valine	23.6	32.8	42.0	21.6	30.8	40.0
Total basis (g/day)						
Arginine	17.4	25.8	34.3	14.0	22.4	30.8
Histidine	13.8	19.1	24.4	12.2	17.5	22.8
Isoleucine	19.5	26.8	34.1	17.7	25.0	32.3
Leucine	37.2	52.1	67.0	33.7	48.6	63.5
Lysine	***35.3***	***48.6***	***61.9***	***31.6***	***44.9***	***58.2***
Methionine	8.8	12.2	15.6	7.9	11.3	14.6
Methionine + cystine	17.3	23.4	29.4	15.7	21.7	27.8
Phenylalanine	18.7	25.9	33.2	16.6	23.9	31.1
Phenylalanine + tyrosine	38.7	53.4	68.2	35.1	49.8	64.6
Threonine	23.0	31.1	39.1	20.8	28.8	36.9
Tryptophan	6.3	8.6	11.0	5.9	8.2	10.6
Valine	29.5	40.9	52.3	26.9	38.4	49.8

[a]Daily intakes of DE and feed and the amino acid requirements are estimated by the lactation model.
[b]Assumes 10 pigs per litter and a 21-day lactation period.
[c]Assumes that ME is 96% of DE. In corn-soybean meal diets of these crude protein levels, ME is 95-96% of DE.
[d]Crude protein and total amino acid requirements are based on a corn-soybean meal diet.

6. Table 6. DIETARY Mineral, Vitamin, and Fatty Acid Requirements of Gestating and Lactating Sows (90% DM)[a]

	Gestation	Lactation
DE content of diet (kca1/kg)	3,400	3,400
ME content of diet (kca1/kg)[b]	3,265	3,265
DE intake (kcal/day)	6,290	17,850
ME intake (kcal/day)[b]	6,040	17,135
Feed intake (kg/day)	1.85	5.25
Requirements (% or amount/kg of diet):		
Mineral elements		
Calcium (%)	0.75	0.75
Phosphorus, total (%)	0.60	0.60
Phosphorus, available (%)	0.35	0.35
Sodium (%)	0.15	0.20
Chlorine (%)	0.12	0.16
Magnesium (%)	0.04	0.04
Potassium (%)	0.20	0.20
Copper (mg)	5.00	5.00
Iodine (mg)	0.14	0.14
Iron (mg)	80	80
Manganese (mg)	20	20
Selenium (mg)	0.15	0.15
Zinc (mg)	50	50
Vitamins		
Vitamin A (IU)[c]	4,000	2,000
Vitamin D3 (IU)[c]	200	200
Vitamin E (IU)[c]	44	44
Vitamin K (menadione) (mg)	0.50	0.50
Biotin (mg)	0.20	0.20
Choline (g)	1.25	1.00
Folacin (mg)	1.30	1.30
Niacin, available (mg)[d]	10	10
Pantothenic acid (mg)	12	12
Riboflavin (mg)	3.75	3.75
Thiamin (mg)	1.00	1.00
Vitamin B_6 (mg)	1.00	1.00
Vitamin B_{12} (μg)	15	15
Linoleic acid (%)	0.10	0.10

[a]The requirements are based on the daily consumption of 1.85 and 5.25 kg of feed, respectively. If lower amounts of feed are consumed, the dietary percentage may need to be increased.

[b]Assumes that ME is 96% of DE.

[c]Conversions: 1 IU vitamin A = 0.344 μg retinyl acetate; 1 IU vitamin D3 = 0.025 μg cholecalciferol; 1 IU vitamin E = 0.67 mg of D-α-tocopherol or 1 mg of DL-α-tocopheryl acetate.

[d]The niacin in corn, grain sorghum, wheat, and barley is unavailable. Similarly, the niacin in by-products made from these cereal grains is poorly available unless the by-products have undergone a fermentation or wet-milling process.

7. Table 7. DIETARY and DAILY Amino Acid, Mineral, Vitamin, and Fatty Acid Requirements of Sexually Active Boars (90% DM)[a]

	Dietary Requirement		Daily Requirement	
DE content of diet (kcal/kg)	3,400		3,400	
ME content of diet (kcal/kg)	3,265		3,265	
DE intake (kcal/day)	6,800		6,800	
ME intake (kcal/day)	6,530		6,530	
Feed intake (kg/day)	2.00		2.00	
Crude protein (%)	13.0		13.0	
	% or Amount/kg of Diet		Amount/day	
Amino acids (total basis)[b]				
Arginine	-		-	
Histidine	0.19	%	3.8	g
Isoleucine	0.35	%	7.0	g
Leucine	0.51	%	10.2	g
Lysine	***0.60***	***%***	***12.0***	***g***
Methionine	0.16	%	3.2	g
Methionine + cystine	0.42	%	8.4	g
Phenylalanine	0.33	%	6.6	g
Phenylalanine + tyrosine	0.57	%	11.4	g
Threonine	0.50	%	10.0	g
Tryptophan	0.12	%	2.4	g
Valine	0.40	%	8.0	g
Mineral elements				
Calcium	0.75	%	15.0	g
Phosphorus, total	0.60	%	12.0	g
Phosphorus, available	0.35	%	7.0	g
Sodium	0.15	%	3.0	g
Chlorine	0.12	%	2.4	g
Magnesium	0.04	%	0.8	g
Potassium	0.20	%	4.0	g
Copper	5	mg	10	mg
Iodine	0.14	mg	0.28	mg
Iron	80	mg	160	mg
Manganese	20	mg	40	mg
Selenium	0.15	mg	0.3	mg
Zinc	50	mg	100	mg
Vitamins				
Vitamin A[c]	4,000	IU	8,000	IU
Vitamin D3[c]	200	IU	400	IU
Vitamin E[c]	44	IU	88	IU
Vitamin K (menadione)	0.50	mg	1.0	mg
Biotin	0.20	mg	0.4	mg
Choline	1.25	g	2.5	g
Folacin	1.30	mg	2.6	mg
Niacin, available[d]	10	mg	20	mg
Pantothenic acid	12	mg	24	mg
Riboflavin	3.75	mg	7.5	mg
Thiamin	1.0	mg	2.0	mg
Vitamin B_6	1.0	mg	2.0	mg
Vitamin B_{12}	15	µg	30	µg
Linoleic acid	0.1	%	2.0	g

[a]The requirements are based on the daily consumption of 2.0 kg of feed. Feed intake may need to be adjusted, depending on the weight of the boar and the amount of weight gain desired.

[b] Assumes a corn-soybean meal diet. The lysine requirement was set as 0.60% (12.0 g/day). Other amino acids were calculated using ratios (total basis) similar to those for gestating sows.

[c]Couversions: 1 IU vitamin A = 0.344 µg retinyl acetate; 1 IU vitamin D_3 = 0.025 µg cholecalciferol; 1 IU vitamin E = 0.67 mg of D-α-tocopherol or 1 mg of DL-α-tocopheryl acetate.

[d]The niacin in corn, grain sorghum, wheat, and barley is unavailable. Similarly, the niacin in by-products made from these cereal grains is poorly available uuless the by-products have undergone a fermentation or wet-milling process.

POULTRY NUTRITION AND FEEDING

- *References: Jurgens (2002) & NRC (1994) as the main sources with Hooge (1998) in Kellems and Church (1998), Waldroup, P. W. [2001. Dietary nutrient allowances for chickens and turkeys. Feedstuffs 73(29):56-65], and Larbier and Leclercq [1992. Translation by J. Wiseman (1994)].*

INTRODUCTION

1. **Poultry Nutrition in General**

   A. Poultry - Any of the domesticated and commercialized types of birds used for production of eggs and(or) meat for human food (. . . also for other purposes though!).

      ◦ e.g., Chickens, turkeys, pigeons, peafowl, ducks, geese, upland game birds (quail, pheasant, partridges . . .) and ratites (ostriches, emu . . .).

   B. Chickens, turkeys and laying hens have been commercially produced in the confinement system for more than 70 years:

      1) For each species, the NRC includes suggested requirements for 14 amino acids, 12 minerals, 13 vitamins, and one fatty acid.
      2) Should be aware that those recommendations are based on limited and, sometimes, very old information (especially true with some vitamins & trace minerals).
      3) Thus, many gaps in the information pool for optimum production exist.

2. **Commercial Poultry Production/Industry**

   A. Has been an innovator and applicator of advancing technology and knowledge to keep meat and egg prices relatively constant for decades.
   B. Feed? Feed cost is the largest single item in poultry production & accounts for 60 to 75% of the total production cost . . . from hatching eggs to processing plant.

      1) Much emphasis has been placed on least-cost feed formulation and getting the lowest feed cost per unit of salable product.
      2) To do so, necessary to refine energy and nutrient requirements, disease control, genetic improvement, and housing & equipment.
      3) All those efforts led to steady improvements in growth rate, feed conversion, and livability under intensive commercial conditions.

POULTRY DIETS IN GENERAL

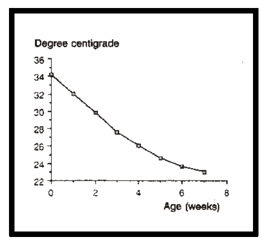
1. **Diet Formulation** - Steps involved poultry diet formulation are similar to formulating diets for pigs.

2. **Feed Ingredients and Additives**

   A. Corn and soybean meal - Usually the most plentiful and lowest-cost sources of energy and well-balanced protein, thus extensively used, especially in the US.
   B. Fish meals and meat meals - Good sources of protein and amino acids, and also contain bone, which is a source of highly available Ca and P. Add 2 to 5% of the diet depending on their prices.
   C. Ca & P - Major minerals. Only 30 to 40% of plant P is non-phytin P, which is available to poultry. Should either increase the availability somehow or supplement with inorganic sources.
   D. Salt - 0.2 to 0.5% is added to most poultry diets.
   E. Supplemental lipids (up to 5% of the diet) - May increase energy utilization through a reduced passage rate an others? Also, can reduce the heat increment.
   F. Yellow pigmentation - Use as much yellow corn as possible plus good sources of xanthophyll, such as alfalfa meal or corn gluten meal, for the yellow coloration of the shanks, feet, skin, and egg yolks?
   G. Non-nutritive additives are used for a variety of reasons - e.g., antibiotics (to stimulate growth & control diseases), arsenicals and nitrofurans (to improve performance), antiparasitic compounds, antioxidative, and antifungal compounds.

ENERGY AND NUTRIENTS FOR POULTRY

1. **Energy, Protein and Amino Acids**

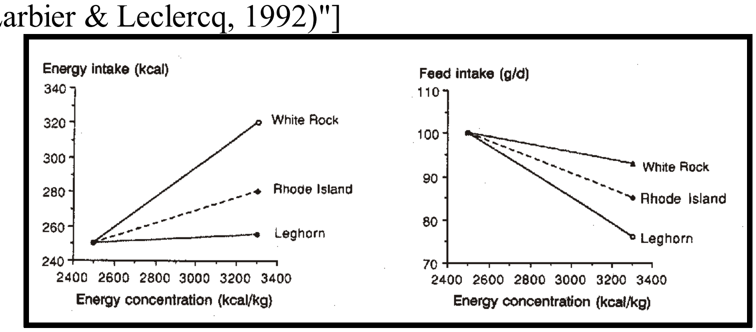


   A. Energy requirement:

      1) Comfort zone - ≈ 68 to 82°F (20 to 27.8°C):

         a) Can expect "optimum" metabolic activity, i.e., no panting, cold stress, etc.
         b) But, very young birds need a warmer temperature until they can maintain their body temperature at about 10 d of age. [Fgure - "Thermo-neutral temperature of the young bird (Larbier & Leclercq, 1992)"]

         ☞ Thus, younger birds can tolerate heat-stress better - Broilers over 4 wk & turkeys over 10 wk of age are most susceptible to heat stress!



      2) Impossible to set the energy requirement in terms of unit/kg diet because birds adjust their feed intake to achieve the daily energy intake? [Figure - Effect of the energy density on feed intake (Larbier & Leclercq, 1992)]

B. Protein requirement?

1) Dietary energy content must be specified to maintain the proper ratio of protein to energy so that birds can consume an adequate amount of protein.
2) The protein requirement or amino acid requirements can be defined accurately only in relation to the energy density. Also, the degree of fat deposition in meat producing birds can be affected by the relationship.
3) Ideal protein concept? - See Section 7 on "Protein."
4) Some variability in the optimal protein:energy concept?

a) Some combinations of fats and carbohydrates have a protein-sparing effect.
b) Perhaps, deliberately altered in some instances to influence fat deposition.

C. Methionine would be the first-limiting amino acid in grain & soybean meal diets, but Lys is likely to become the first-limiting amino acid if soybean meal is replaced by another plant protein supplement such as cottonseed meal.

D. Restricting protein/amino acids (& energy) to retard growth (e.g., pullets of modern broiler strains grow at a rapid rate and also mature sexually at an early age)?

1) Necessary to retard growth and delay the onset of sexual maturity to optimize the egg production and the production of viable chicks.
2) Feeding programs to retard growth?

a) From the beginning of the 7^{th} or 9^{th} wk, limit the total feed allowed per bird per day (to 70%?) - Continue until placing on the standard laying diet at the beginning of the 23^{rd} wk.
b) Feed the birds on the "skip-a-day program" from the 7^{th} or 9^{th} wk to the 23^{rd} wk - Allows the pullets all the feed they will consume on one day and only 2 lb of grain per 100 birds on the alternate day.
c) Use a diet containing only 10 to 10.5% protein - Feed from the beginning of the 7^{th} or 9^{th} wk until placing on the laying diet.
d) Use a diet that contains 0.40 to 0.45% Lys and 0.60 to 0.70% Arg after the 7^{th} or 9^{th} wk (12.5 to 13% CP) - Imbalance of amino acids would depresses "appetite!"

2. **Vitamins**

A. Vitamin & trace mineral supplementation? Contributions to the overall feed cost are not much ($2.50 to 7.50/ton), but vitamins & minerals play major roles in the metabolic functions of poultry.

B. Because of the variations in the content, availability, and stability, premixes are formulated to assure adequacy, rather than just satisfying the NRC recommendations - See "Recommended supplemental vitamins for various classes of poultry (per ton of complete feed (Waldrop, 2001)."

Vitamin	Units	Starting chickens (0-8 weeks)	Growing chickens (8-18 weeks)	Egg-type laying hens	Broiler and egg-type breeders	Starting turkeys (0-8 weeks)	Growing and finishing turkeys (8 weeks to market)	Turkey breeders
A	MIU*	7.0	7.0	6.0	8.0	9.0	7.0	9.0
D_3	MIU	2.0	2.0	2.0	2.0	3.0	2.5	3.0
E	TIU**	6.0	6.0	5.0	10.0	11.0	8.0	30.0
B_{12}	mg	10.0	10.0	6.0	10.0	6.0	6.0	8.0
Riboflavin	g	6.0	6.0	4.0	5.0	6.0	4.0	5.0
Niacin	g	30.0	30.0	15.0	20.0	65.0	45.0	30.0
d-Pantothenic acid	g	10.0	10.0	6.0	9.0	14.0	10.0	17.0
Choline	g	450.0	450.0	250.0	350.0	600.0	550.0	400.0
Menadione (K_3)	g	1.0	1.0	0.3	0.6	0.6	0.6	0.6
Folic acid	g	0.6	0.6	0.2	0.5	1.0	0.7	1.2
Thiamin	g	1.0	1.0	1.0	1.0	1.0	1.0	2.0
Pyridoxine	g	3.0	1.5	1.0	2.0	3.0	2.0	3.0
d-Biotin	mg	50.0[1]	30.0[1]	30.0[1]	100.0[1]	100.0[1]	50.0[1]	100.0[1]

*MIU = Million International Units
**TIU = Thousand International Units
[1]Add an additional 5 mg d-biotin per ton for each 10% of wheat, barley, oats or milo used to replace corn in the complete feed

C. Vitamin D - Expressed in ICU, which are based on the activity of D_3 because birds do not use D_2. (Turkeys are especially sensitive!)

D. Vitamin E - Requirements vary greatly depending on dietary lipids, Se, and antioxidant.

E. Some vitamins that were thought to be adequate in feeds and feed ingredients in the past, but may be questioned? - Perhaps, associated with the processing method (e.g., the use of expanders in mills for steam-conditioning feed to reduce/eliminate *Salmonella*)?

1) Folacin and biotin - Now added to some turkey diets to prevent the deficiency.
2) Niacin - May be required for laying and breeding hens. But, the requirement is so low that it will always be exceeded by natural feed ingredients?

F. Choline:

1) Growing chickens can use betaine interchangeably with choline for the methylation function, but it cannot replace choline to prevent perosis. Still, can spare choline!
2) Also, vitamin B_{12} can reduce the choline requirement.

3. **Minerals**

Mineral	Units	Starting chickens (0-8 weeks)	Growing chickens (8-18 weeks)	Egg-type laying hens	Broiler and egg-type breeders	Starting turkeys (0-8 weeks)	Growing and finishing turkeys (8 weeks to market)	Turkey breeders
Manganese	mg	25.0	25.0	50.0	75.0	50.0	50.0	75.0
Zinc	mg	25.0	25.0	50.0	75.0	50.0	50.0	75.0
Iron	mg	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Copper	mg	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Iodine	mg	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Selenium[1]	mg	0.05	0.05	0.05	0.05	0.1	0.1	0.1

[1]Selenium content of feed ingredients varies depending upon location. Values shown may need to be adjusted in areas where feed ingredients are reduced in selenium content. Maximum allowable amounts of this mineral are regulated by the Food & Drug Administration

A. See some comments for vitamins in general and the table containing the recommended supplemental trace minerals (per pound of mixed feed; Waldroup, 2001).

B. Ca - Perhaps, more difficult one to define the requirement, and the problem cannot be solved by simply adding a generous amount simply because excess Ca interferes with utilization of P, Mg, Mn, and Zn and it can reduce palatability of the diet.

C. Inorganic P - A greater availability vs. phytin P, but some variations in the availability.

D. The use of phytase in poultry diets has been increasing in recent years.

E. Trace minerals - Ones complexed with amino acids or protein have increased in commercial use in recent years because of higher availability, e.g., Zn-Met & Se-Met.

4. **Unidentified Nutrients?**

A. With the identification of vitamins & considering some findings on the essentiality or significance of some trace mineral elements, many are disregarding the importance of so called, "unidentified growth factors."

B. Still some responses? - Attributable to "truly" unidentified nutrient(s), or more likely to changes in feed palatability and(or) quality, mineral chelation, or simple improvement in the balance of available nutrients (NRC, 1994)?

5. **Some Additives** (Briefly mentioned some in the Introduction)

A. Antibiotics - Since 1950 or so, several antibiotics have become important additives in broiler and market turkey feeds to improve growth rate and feed efficiency. Also, egg production may be improved with dietary supplementation.

B. Antioxidants - Compounds used to prevent oxidative rancidity in fat, e.g., BHT, BHA & ethoxyquin.

Xanthophyll and Lutein content (mg/kg): (NRC, 1994)

Ingredients	Xanthophyll	Lutein
Alfalfa meal, 17% CP	220	143
Alfalfa meal, 22% CP	330	-
Alfalfa protein concetrate, 40% CP	800	-
Algae meal	2,000	-
Corn	17	0.12
Corn gluten meal, 60% CP	290	120
Marigold petal meal	7,000	-

C. Grits - Hard insoluble or soluble particles, which remain trapped in the thick-muscled gizzard to facilitate grinding of feed. e.g., oyster or clam shells, limestone, gravel, pebbles or granite products. When mash or finely ground feeds are used, the value of grits is diminished.

D Xanthophylls - Produce a deep yellow color in the beak, skin, shanks, feet, fat, and egg yolks of poultry. Many consumers believe that a deep yellow color of broiler skin/shanks and egg yolks is indicative of top quality. (See the table)

VARIOUS POULTRY DIETS

1. **Starter Diets** [e.g., See the table (Hooge, 1998)]

A. Usually fed first 2 to 3 wk to chickens and 2 to 4 wk to turkeys.

B. Higher energy and nutrient contents vs. others, especially protein/amino acids, but Leghorn-type pullets are fed diets with lower protein until 6 wk or so.

C. Include high doses of antibiotics to reduce mortality and initiate more rapid growth and also a suitable coccidiostat.

2. **Broiler Diets**

A. Fed as a complete feed to meat-type birds - May be fed in crumbles or pelleted form.

B. A higher vitamin supplementation to meet the added requirements for growth under the stressful conditions encountered in the average broiler operation.

C. May contain 3 to 5% added fat to increase the energy content and the protein content is adjusted to maintain an optimum protein:calorie ratio.

D. Fortified with antibiotics and should contain a coccidiostat.

E. Generally, two types: grower diets, fed from 3 wk to 6 wk of age, and finisher or withdrawal diets, fed from 6 wk to market age.

3. **Turkey Growing and Finishing Diets**

A. Similar to broiler diets and fed as a complete feed to meat-type birds.
B. Generally, use diets with a different CP content for 4- 8, 8-12, 12-16, 16-20 wk, and over 20 wk of age.

4. **Growing Diets and Developers for Leghorn-Type Chickens**

A. Designed to be fed to the replacement stock from 6 wk to sexual maturity.
B. Two types: 1) Complete feed, mash or pelleted - Generally lower in protein than starter diets, and 2) Mash concentrate - Fed with varying amounts of grain to meet the needs.

5. **Laying Diets for Leghorn-Type Chickens**

A. Diets fed to mature hens during egg production (e.g., see the table).
B. Two ways/types: 1) complete feed - mash or pelleted, and 2) mash concentrate to be fed with a specified amount of grain or mixed with grain & soybean meal.
C. The salt content may be decreased to reduce the incidence of wet droppings.
D. Cage fatigue? - Perhaps, the result of a Ca deficiency? If so, the Ca content should be increased, or provide a Ca source on a free choice basis.
E. Hens producing hatching eggs? - Should be fed a more highly fortified feed (especially, vitamins) than hens kept merely for commercial egg production.
F. Increase protein and vitamins during the period of stress or slumps in egg production. Also, use a higher dose of an antibiotic or a combination of antibiotics?

Examples of broiler starter, turkey starter, and caged layer peak egg production feeds[a] [Hooge (1998) in Kellems & Church (1998)]

Item	Broiler Starter (%)	Turkey Starter (%)	Layer Peak (%)
Ingredient			
Corn, yellow	56.45	47.75	60.50
Soybean meal (47.5% CP)	27.33	38.83	21.50
Meat and bone meal (50% CP)	7.00	-	5.09
Meat meal (56% CP)	-	9.50	-
Bakery by-product	6.00	-	-
Animal-vegetable fat	1.82	0.31	3.00
Limestone (or oyster shell)	0.49	0.81	8.66
Dicalcium phosphate	0.13	1.54	0.49
Salt	0.10	0.09	0.20
Sodium bicarbonate	0.20	0.20	0.20
Copper sulfate	0.05	0.05	-
Vitamin-mineral premix	0.25	0.25	0.25
DL-methionine (99%)	0.17	0.24	0.11
L-Iysine HCI (78.4% lysine)	-	0.23	-
Bacitracin-MD (50 g/lb)'	0.05	0.05	-
Coban (monensin) 30 g/lb	-	0.10	-
Nicarbazin (25%)	0.05	-	-
Liquid mold inhibitor	0.05	0.05	-
Calculated analysis			
Protein, % (N x 6.25)	22.50	28.00	18.00
ME, kcal/lb	1425	1280	1320
Lysine, %	1.21	1.80	0.94
Methionine + cystine, %	0.92	1.10	0.71
Ca, %	0.95	1.45	3.80
Available P, %	0.48	0.83	0.45
Na,%	0.20	0.19	0.18
K, %	0.83	0.94	0.68
Cl,%	0.25	0.24	0.19

[a]CP = crude protein; ME = metabolizable energy; N = nitrogen.

MAJOR INGREDIENTS FOR POULTRY DIETS

1. **Selecting Feedstuffs - Considerations?**

A. Nutrient availability? - Affected by the fiber content, fat content, and amino acid balance.

B. Palatability? - Affected by the moisture content, contaminants, feed preparation (whole vs. ground), and color or light reflections.
C. The content of growth inhibitors or undesirable chemicals or pigments.
D. The cost and market availability of feedstuffs.

2. **Energy Sources**

A. Grains - Corn is the most important & widely used. Also, milo, wheat, barley, and oats are being used, but, perhaps, inferior to corn in the relative value.
B. Grain by-products - Including various milling by-products (e.g., corn gluten & bran, and wheat processing by-products), brewery by-products, etc.
C. Molasses - Used as a source of energy but have an adverse laxative effect, thus should be limited to not more than 2% of the diet.
D. Vegetable & animal fats - Used as energy sources, but also reduce feed dustiness, increase palatability, and improve texture and appearance of the feed.

3. **Protein/Amino Acid Sources**

A. Plant sources

1) Soybean meal - Most widely used because of its ability to provide indispensable amino acids; high in digestibility and low in toxic or undesirable substances.
2) Cottonseed meal:

1) Generally not used for layer diets because of: a) gossypol, which can cause a mottling and greenish cast to egg yolks, and b) cyclopropenoic fatty acids, which can impart a pink color to egg whites.
2) May be used to replace up to 50% of the soybean meal in grower poultry diets.

3) Linseed meal - Can use a limited amount but may depress growth and cause diarrhea. Should not exceed 3 to 5% of the poultry diet.
4) Alfalfa meal and corn gluten meal - Used extensively, both for their high content of carotenoids. Both should be limited to not more than 10%.

B. Animal sources

1) Fish meals - Often used at 2 to 5% of the diet, but high in fat & tend to create a fishy flavor in meat and eggs when used in larger amounts.
2) Meat products (animal by-products, poultry meal, blood meal, hydrolyzed poultry feather) - Often economically priced, thus may replace an equal amount of soybean meal protein up to about 10% of the diet. Excellent sources of Ca & P.

4. **Mineral Sources**

A. Ca - Common supplements are ground limestone, crushed oyster shells or oyster shell flour, bone meal, and dicalcium phosphate.
B. P - Common supplements are bone meal, dicalcium phosphate, deflourinated rock phosphate, monosodium phosphate, and rock phosphate.
C. Salt - Common to add 0.2 to 0.5%. Too much salt will result in increased water consumption and wet droppings.

5. **Vitamin Sources**

A. Unlike in the past, a wide variety of feedstuffs are not included in poultry diets for their vitamin content.
B. Vitamin premixes are commonly used to satisfy the vitamin needs.

6. **Diet Preparation**

A. Most poultry feeds are: 1) mash - grind medium to fine, 2) pellets - composed of mash feeds that are pelleted, and 3) crumbles - produced by rolling pellets.
B. Pellets or crumbles - Cost slightly more, but can reduce feed wastage & sorting, adapted to automatic equipment, less feeder and storage space, and improve palatability.

FEEDING PROGRAMS

1. **Broilers**

A. Broiler chicks - Fed ad libitum for 42 to 56 d to an average weight of 4 to 5 lb.
B. Feed represent 60 to 75% of total production cost. Fed conversion - about 2.0?
C. Use a 3-stage feeding program (starter, grower and finisher) - The starter for the first 2 to 3 wk, the grower for about 2 wk, and the finisher for the remainder.

2. **Replacement Pullets**

A. Generally divided into three stages:

1) Starter with 18-20% CP & about 3,000 kcal ME/kg from 0 to 6 wk of age.
2) Grower with 14-16% CP & about 3,000 kcal ME/kg from 6 to 12 wk of age.
3) Developer with 12 to 14% CP & about 3,000 kcal ME/kg from 12 wk of age until lay (approximately 20 wks).

B. Leghorn-type pullets - Seldom fed restrictedly during the growing period because feed intake & sexual maturity can be controlled by varying lighting during 6 to 20 wk of age.
C. Heavy breeds - Tend to deposit excess body fat, thus common to restrict feed:

1) Most effective program? - Feed daily a controlled amount of a well-balanced diet. Requires adequate feeder space and a rapid even distribution of the diet.

2) Alternative? - A skip-a-day feeding program. With adequate feeder and water space, may produce a more uniform flock.

D. When pullets start producing eggs, their feed intake should increase. Sometimes, necessary to reduce the energy density at 18 to 19 wk of age to increase feed intake.
E. Laying about five eggs per 1000 birds, the birds should be placed on a pre-lay program, in which the diet contains about 2% or more Ca.
F. 5% egg production? - Should be placed on a regular layer feed program.

3. **Laying Hens**

A. Higher concentrations of vitamins (A, D, E, riboflavin, pantothenic acid, niacin, and B_{12}) and Mn & Zn would be required if eggs are to be used for hatching.
B. White Leghorn - Need about 18 g of protein/bird/d to support optimum egg production, thus with a 15% CP diet, must consume ≈ 25 to 26 lb of feed/100 birds/day.
C. Met - The first limiting amino acid and economical to use synthetic Met & its analogs.
D. Ca, P, and Vitamin D - Important for egg shell formation?

1) Ca requirement - Varies with the age, ambient temperature, rate of lay, and egg size, but a general recommendation is 3.4 g Ca/d & 3.8 g Ca/d after 40 wk of age.
2) P? - 0.3 to 0.4% available P, which is equivalent to about 0.5 to 0.6% total P.
3) Adequate vitamin D_3 is must.

E. Grits - Can improve feed efficiency slightly, but not when finely ground feeds are fed. Can be fed in special feeders every 3 wk, mixed in a complete feed at 0.25% of the diet, or sprinkled on top of the feed at a rate of 5 lb per 1,000 hens every week.
F. Phase feeding - To reduce the waste of nutrients caused by feeding more than necessary:

1) Pullets coming into egg production - 17 to 19% CP and reduce to 15 to 16% after 3 to 4 mo of lay, or when the pullet has attained the adult weight.
2) Feed intake decreases as the temperature increases above 85 to 90°F, thus may be necessary to increase CP to 18 or 20% when temperature exceeds 100°F for an extended period of time.

G. Challenge the flock to lay more eggs?

1) Young pullet flocks may respond to additional feed when their production seems to be reaching a plateau.
2) "Challenge" the flock with about 2 more pounds of feed per 100 birds. If the flock does not respond by the 4^{th} day, return to the amount fed prior to the challenge. Can be repeated as often as necessary depending on the flock response.

H. Peaked in egg production & begun a gradual decline in lay?

1) Sometimes, will produce more efficiently on less feed.

2) Passed peak & showing a normal decrease (4 to 6%)?

   a) Reducing the daily feed by ½ lb/100 birds for a period of 3-4 days. If results in an abnormal drop in egg production, return immediately to the prior feeding.
   b) As production continues to decline normally, this may be repeated as often as necessary depending on flock response.

I. The bottom line? The objective of feeding laying hens is to produce a dozen eggs of good quality at the lowest possible feed cost. For lightweight layers, a target should be a feed efficiency of 3.5 to 4.0 lb or less of feed/dozen eggs.

4. **Feeding Turkeys**

A. Marketing turkeys:

1) Change diets frequently to adjust to the specific needs and to minimize feed costs.
2) Grow faster than chickens, thus have relatively higher requirements:

   a) Protein requirements decrease by age, e.g., 28% with starting poults to 14% for mature birds.
   b) Energy requirements tend to increase during the growing stage; ranging from 2,900 to 3,300 kcal/kg.

3) Upon arrival, poults should be encouraged to consume feed and water as soon as possible. Using colored feed or placing brightly colored marbles in the feed and water may help.
4) Antibiotic & coccidiostat? - May be necessary for early starter diets but once past 8 to 12 wk of age, may be optional!
5) Young turkeys - Should be about 2.75 to 3.25 lb of feed/lb live turkey produced.
6) Marketing?

   a) Males/toms - 18 to 20 wk of age & 23 to 35 lb live weight. Younger toms for oven-ready dressed birds & older toms for further processing or restaurant trade.
   b) Females/hens - 14 to 16 wk of age and about 14 lb live weight.

B. Holding and breeding:

1) Feed a "holding diet" from ≈ 16 to 18 wk of age until the beginning of the lighting program (≈2 wk before egg production), which usually occurs about 30 wk of age.
2) "Holding diet?" - Contains less energy than the starter and grower diets & delays sexual maturity, which may result in desirable effects on later reproductive performance.
3) After 30 wk or so of age? Should feed the breeder diet.

NUTRIENT REQUIREMENT TABLES

(Based on NRC, 1994)

1. **Table 1. DIETARY Nutrient Requirements of Immature Leghorn-Type Chickens (% or Unit/kg; 90% DM?)**

		White-Egg-Laying Strains				Brown-Egg-Laying Strains			
Weeks:		0 to 6	6 to 12	12 to 18	18 to 1st Egg	0 to 6	6 to 12	12 to 18	18 to 1st Egg
Final Body Weight, g:		450	980	1,375	1,475	500	1,100	1,500	1,600
Typical dietary Energy, ME_n/kg:		2,850	2,850	2,900	2,900	2,800	2,800	2,850	2,850
Protein and amino acids:									
Crude protien[a]	%	18.00	16.00	15.00	17.00	17.00	15.00	14.00	16.00
Arginine	%	1.00	0.83	0.67	0.75	0.94	0.78	0.62	0.72
Glycine + serine	%	0.70	0.58	0.47	0.53	0.66	0.54	0.44	0.50
Histidine	%	0.26	0.22	0.17	0.20	0.25	0.21	0.16	0.18
Isoleucine	%	0.60	0.50	0.40	0.45	0.57	0.47	0.37	0.42
Leucine	%	1.10	0.85	0.70	0.80	1.00	0.80	0.65	0.75
Lysine	%	0.85	0.60	0.45	0.52	0.80	0.56	0.42	0.49
Methionine	%	0.30	0.25	0.20	0.22	0.28	0.23	0.19	0.21
Methionine + cystine	%	0.62	0.52	0.42	0.47	0.59	0.49	0.39	0.44
Phenylalanine	%	0.54	0.45	0.36	0.40	0.51	0.42	0.34	0.38
Phenylalanine + tyrosine	%	1.00	0.83	0.67	0.75	0.94	0.78	0.63	0.70
Threonine	%	0.68	0.57	0.37	0.47	0.64	0.53	0.35	0.44
Tryptophan	%	0.17	0.14	0.11	0.12	0.16	0.13	0.10	0.11
Valine	%	0.90	0.80	0.80	2.00	0.90	0.80	0.80	1.80
Linoleic acid:	%	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Macrominerals:									
Calcium[b]	%	0.90	0.80	0.80	2.00	0.90	0.80	0.80	1.80
Nonphytate phosphorus	%	0.40	0.35	0.30	0.32	0.40	0.35	0.30	0.35
Potassium	%	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Sodium	%	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Chlorine	%	0.15	0.12	0.12	0.15	0.12	0.11	0.11	0.11
Magnesium	mg	600.0	500.0	400.0	400.0	570.0	470.0	370.0	370.0
Trace minerals:									
Manganese	mg	60.0	30.0	30.0	30.0	56.0	28.0	28.0	28.0
Zinc	mg	40.0	35.0	35.0	35.0	38.0	33.0	33.0	33.0
Iron	mg	80.0	60.0	60.0	60.0	75.0	56.0	56.0	56.0
Copper	mg	5.0	4.0	4.0	4.0	5.0	4.0	4.0	4.0
Iodine	mg	0.35	0.35	0.35	0.35	0.33	0.33	0.33	0.33
Selenium	mg	0.15	0.10	0.10	0.10	0.14	0.10	0.10	0.10
Fat-soluble vitamins:									
Vitamin A	IU	1,500.0	1,500.0	1,500.0	1,500.0	1,420.0	1,420.0	1,420.0	1,420.0
Vitamin D_3	ICU	200.0	200.0	200.0	300.0	190.0	190.0	190.0	280.0
Vitamin E	IU	10.0	5.0	5.0	5.0	9.5	4.7	4.7	4.7
Vitamin K	mg	0.50	0.50	0.50	0.50	0.47	0.47	0.47	0.47
Water-soluble vitamins:									
Riboflavin	mg	3.6	1.8	1.8	2.2	3.4	1.7	1.7	1.7
Pantothenic acid	mg	10.0	10.0	10.0	10.0	9.4	9.4	9.4	9.4
Niacin	mg	27.0	11.0	11.0	11.0	26.0	10.3	10.3	10.3
Vitamin B_{12}	mg	0.009	0.003	0.003	0.003	0.009	0.003	0.003	0.003
Choline	mg	1,300.0	900.0	500.0	500.0	1,225.0	850.0	470.0	470.0
Biotin	mg	0.15	0.10	0.10	0.10	0.14	0.09	0.09	0.09
Folic acid	mg	0.55	0.25	0.25	0.25	0.52	0.23	0.23	0.23
Thiamin	mg	1.0	1.0	0.8	0.8	1.0	1.0	0.8	0.8
Pyridoxine	mg	3.0	3.0	3.0	3.0	2.8	2.8	2.8	2.8

☞ Some experimental data are lacking, thus some values represent an estimate based on values obtained for other ages or related species (NRC, 1994).

[a]Chickens do not have a requirement for crude protein per se. There, however, should be sufficient crude protein to ensure an adequate nitrogen supply for synthesis of nonessential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced somewhat when synthetic-amino acids are used.

[b]The calcium requirement may be increased when diets contain high levels of phytate phosphorus (Nelson, 1984).

2. Table 2. DIETARY Nutrient Requirements of Leghom-Type Laying Hens (% or Unit/kg; 90% DM)

		Dietary Concentrations			Amounts Required per Hen Daily (mg or IU)		
Type:		White-Egg Layers	White-Egg Layers	White-Egg Layers	White-Egg Breeders	White-Egg Layers	Brown-Egg Layers
Feed intake, g/hen/day[a]:		80	100	120	100	100	110
Protein and amino acids:							
Crude protein[b]	%	18.8	15.0	12.5	15,000	15,000	16,500
Arginine[c]	%	0.88	0.70	0.58	700	700	770
Histidine	%	0.21	0.17	0.14	170	170	190
Isoleucine	%	0.81	0.65	0.54	650	650	715
Leucine	%	1.03	0.82	0.68	820	820	900
Lysine	%	0.86	0.69	0.58	690	690	760
Methionine	%	0.38	0.30	0.25	300	300	330
Methionine + cystine	%	0.73	0.58	0.48	580	580	645
Phenylalanine	%	0.59	0.47	0.39	470	470	520
Phenylalanine + tyrosine	%	1.04	0.83	0.69	830	830	910
Threonine	%	0.59	0.47	0.39	470	470	520
Tryptophan	%	0.20	0.16	0.13	160	160	175
Valine	%	0.88	0.70	0.58	700	700	770
Linoleic acid:	%	1.25	1.00	0.83	1,00	1,00	1,00
Macrominerals:							
Calcium[d]	%	4.06	3.25	2.71	3,250	3,250	3,600
Chloride	%	0.16	0.13	0.11	130	130	145
Magnesium	mg	625	500	420	50	50	55
Nonphytate phosphorus[e]	%	0.31	0.25	0.21	250	250	275
Potassium	%	0.19	0.15	0.13	150	150	165
Sodium	%	0.19	0.15	0.13	150	150	165
Trace minerals:							
Copper	mg	?	?	?	?	?	?
Iodine	mg	0.044	0.035	0.029	0.010	0.004	0.004
Iron	mg	56	45	38	6.0	4.5	5.0
Manganese	mg	25	20	17	2.0	2.0	2.2
Selenium	mg	0.08	0.06	0.05	0.006	0.006	0.006
Zinc	mg	44.0	35.0	29.0	4.5	3.5	3.9
Fat-soluble vitamins:							
Vitamin A	IU	3,750	3,000	2,500	300	300	330
Vitamin D_3	ICU	375	300	250	30	30	33
Vitamin E	IU	6.00	5.00	4.00	1.00	0.50	0.55
Vitamin K	mg	0.60	0.50	0.40	0.10	0.05	0.055
Water-soluble vitamins:							
Vitamin B_{12}	mg	0.004	0.004	0.004	0.008	0.0004	0.00004
Biotin	mg	0.13	0.10	0.08	0.01	0.01	0.011
Choline	mg	1,310	1,050	875	105	105	115
Folic acid	mg	0.31	0.25	0.21	0.035	0.025	0.028
Niacin	mg	12.50	10.00	8.30	1.00	1.00	1.10
Pantothenic acid	mg	2.50	2.00	1.70	0.70	0.20	0.22
Pyridoxine	mg	3.10	2.50	2.10	0.45	0.25	0.28
Riboflavin	mg	3.10	2.50	2.10	0.36	0.25	0.28
Thiamin	mg	0.88	0.70	0.60	0.07	0.07	0.08

☞ Some experimental data are lacking, thus some values represent an estimate based on values obtained for other ages or related species (NRC, 1994).

[a]Based on dietary MEn concentrations of approximately 2,900 kcal/kg and an assumed rate of egg production of 90 percent (90 eggs per 100 hens daily).

[b]Laying hens do not have a requirement for crude protein per se. However, there should be sufficient crude protein to ensure an adequate supply of nonessential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced somewhat when synthetic amino acids are used.

[c]Italicized amino acid values for white-egg-Iaying chickens were estimated by using Model B (Hurwitz and Bomstein, 1973), assuming a body weight of 1,800 g and 47 g of egg mass per day.

[d]The requirement may be higher for maximum eggshell thickness.

[e]The requirement may be higher in very hot temperatures.

3. Table 3. DIETARY Nutrient Requirements of Broilers (% or Unit/kg; 90% DM)

Week[a]:		0 to 3	3 to 6	6 to 8
Typical dietary energy, ME_n/kg		3,200	3,200	3,200
Protein and amino acids:				
Crude protein[b]	%	23.00	20.00	18.00
Arginine	%	1.25	1.10	1.00
Glycine + Serine	%	1.25	1.14	0.97
Histidine	%	0.35	0.32	0.27
Isoleucine	%	0.80	0.73	0.62
Leucine	%	1.20	1.09	0.93
Lysine	%	1.10	1.00	0.85
Methionine	%	0.50	0.38	0.32
Methionine + cystine	%	0.90	0.72	0.60
Phenylalanine	%	0.72	0.65	0.56
Phenylalanine + tyrosine	%	1.34	1.22	1.04
Threonine	%	0.80	0.74	0.68
Tryptophan	%	0.20	0.18	0.16
Valine	%	0.90	0.82	0.70
Linoleic acid:	%	1.00	1.00	1.00
Macrominerals:				
Calcium[c]	%	1.00	0.90	0.80
Chloride	%	0.20	0.15	0.12
Magnesium	mg	600	600	600
Nonphytate phosphorus[c]	%	0.45	0.35	0.30
Potassium	%	0.30	0.30	0.30
Sodium	%	0.20	0.15	0.12
Trace minerals:				
Copper	mg	8	8	8
Iodine	mg	0.35	0.35	0.35
Iron	mg	80	80	80
Manganese	mg	60	60	60
Selenium	mg	0.15	0.15	0.15
Zinc	mg	40	40	40
Fat-soluble vitamins:				
Vitamin A	IU	1,500	1,500	1,500
Vitamin D_3	ICU	200	200	200
Vitamin E	IU	10	10	10
Vitamin K	mg	0.50	0.50	0.50
Water-soluble vitamins:				
Vitamin B_{12}	mg	0.01	0.01	0.007
Biotin	mg	0.15	0.15	0.12
Choline	mg	1,300	1,000	750
Folic acid	mg	0.55	0.55	0.50
Niacin	mg	35	30	25
Pantothenic acid	mg	10	10	10
Pyridoxine	mg	3.5	3.5	3.0
Riboflavin	mg	3.6	3.6	3.0
Thiamin	mg	1.80	1.80	1.80

☞ Some experimental data are lacking, thus some values represent an estimate based on values obtained for other ages or related species (NRC, 1994).

[a]0 to 3, 3 to 6, and 6 to 8 week intervals for nutrient requirements are based on chronology for which data were available; hoever, these nutrient requirements are often implemented at younger age intervals or on a weight-of-feed consumed basis.

[b]Broiler chickens do not have a requirement for crude protein per se. However, there should be sufficient crude protein to ensure an adequate supply of nonessential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced somewhat when synthetic amino acids are used.

[c]The calcium requirement may be increased when diets contain high levels of phytate phosphorus (Nelson,1984).

4. Table 4. Body Weight and Feed Consumption of Immature Leghorn-Type Chickens[a]

Age (wk)	White-Egg-Laying Strains Body Weight (g)	White-Egg-Laying Strains Feed intake (g/wk)	Brown-Egg-Laying Strains Body Weight (g)	Brown-Egg-Laying Strains Feed Intake (g/wk)
0	35	50	37	70
2	100	140	120	160
4	260	260	325	280
6	450	340	500	350
8	660	360	750	380
10	750	380	900	400
12	980	400	1,100	420
14	1,100	420	1,240	450
16	1,220	430	1,380	470
18	1,375	450	1,500	500
20	1,475	500	1,600	550

[a]Average genetic potential when feed is consumed on an ad libitum basis. Different commercial strains may show different growth rates and different final mature body weights.

5. Table 5. Estimates of Metabolizable Energy Required per Hen per Day by Chickens in Relation to Body Weight and Egg Production (kcal)

Body Weight (kg)	Rate of Egg Production (%) 0	50	60	70	80	90
1.0	130	192	205	217	229	242
1.5	177	239	251	264	276	289
2.0	218	280	292	305	317	330
2.5	259	321	333	346	358	371
3.0	296	358	370	383	395	408

☞ A number of formulas have been suggested for prediction of the daily energy requirements of chickens. The formula used here was derived from that in *Effect of Environment on Nutrient Requirements of Domestic Animals* (Nrc, 1981): ME per hen daily = $W^{0.75}$ (173 -1.95T) + 5.5 $\triangle W$ + 2.07 EE where W = body weight (kg), T = ambient temperature (°C), $\triangle W$ = change in body weight (g/day), and EE = daily egg mass (g). Temperature of 22°C, egg weight of 60 g, and no change in body weight were used in calculations.

6. Table 6. Typical Body Weights, Feed Intake, and Energy Intake of Broilers

Age (wk)	Body Weight (g) Male	Body Weight (g) Female	Feed Intake (g) Weekly Male	Feed Intake (g) Weekly Female	Feed Intake (g) Cumulative Male	Feed Intake (g) Cumulative Female	Energy Intake (kcal ME/bird) Weekly Male	Energy Intake (kcal ME/bird) Weekly Female	Energy Intake (kcal ME/bird) Cumulative Male	Energy Intake (kcal ME/bird) Cumulative Female
1	152	144	135	131	135	131	432	419	432	419
2	376	344	290	273	425	404	928	874	1,360	1,293
3	686	617	487	444	912	848	1,558	1,422	2,918	2,715
4	1,085	965	704	642	1,616	1,490	2,256	2,056	5,174	4,771
5	1,576	1,344	960	738	2,576	2,228	3,075	2,519	8,249	7,290
6	2,088	1,741	1,141	1,001	3,717	3,229	3,651	3,045	11,900	10,335
7	2,590	2,134	1,281	1,081	4,998	4,310	4,102	3,459	16,002	13,794
8	3,077	2,506	1,432	1,165	6,430	5,475	4,585	3,728	20,587	17,522
9	3,551	2,842	1,577	1,246	8,007	6,721	5,049	3,986	25,636	21,508

☞ Values are typical broilers fed well-balanced diets providing 3,200 kcal ME/kg.

7. Table 7. DIETARY Nutrient Requirements of Turkeys (% or Unit/kg; 90% DM)

		Growing Turkeys						Breeders	
Males - Age (wk):		0 to 4	4 to 8	8 to 12	12 to 16	16 to 20	20 to 24		
Females - Age (wk):		0 to 4	4 to 8	8 to 11	11 to 14	14 to 17	17 to 20		
Status: Holding Laying								Holding	Laying
Dietary energy, ME_n/kg[a]:		2,800	2,900	3,000	3,100	3,200	3,300	2,900	2,900
Protein and amino acids:									
Protein[b]	%	28.0	26.0	22.0	19.0	16.5	14.0	12.0	14
Arginine	%	1.60	1.40	1.10	0.90	0.75	0.60	0.50	0.60
Glycine + serine	%	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.50
Histidine	%	0.58	0.50	0.40	0.30	0.25	0.20	0.20	0.30
Isoleucine	%	1.10	1.00	0.80	0.60	0.50	0.45	0.40	0.50
Leucine	%	1.90	1.75	1.50	1.25	1.00	0.80	0.50	0.50
Lysine	%	1.60	1.50	1.30	1.00	0.80	0.65	0.50	0.60
Methionine	%	0.55	0.45	0.40	0.35	0.25	0.25	0.20	0.20
Methionine + cystine	%	1.05	0.95	0.80	0.65	0.55	0.45	0.40	0.40
Phenylalanine	%	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.55
Phenylalanine + tyrosine	%	1.80	1.60	1.20	1.00	0.90	0.90	0.80	1.00
Threonine	%	1.00	0.95	0.80	0.75	0.60	0.50	0.40	0.45
Tryptophan	%	0.26	0.24	0.20	0.18	0.15	0.13	0.10	0.13
Valine	%	1.20	1.10	0.90	0.80	0.70	0.60	0.50	0.58
Linoleic acd:	%	1.00	1.00	0.80	0.80	0.8	0.8	0.8	1.1
Macrominerals:									
Calcium[c]	%	1.20	1.00	0.85	0.75	0.65	0.55	0.5	2.25
Nonphytate phosphorus[d]	%	0.60	0.50	0.42	0.38	0.32	0.28	0.25	0.35
Potassium	%	0.70	0.60	0.50	0.50	0.40	0.40	0.40	0.60
Sodium	%	0.17	0.15	0.12	0.12	0.12	0.12	0.12	0.12
Chlorine	%	0.15	0.14	0.14	0.12	0.12	0.12	0.12	0.12
Magnesium	mg	500	500	500	500	500	500	500	500
Trace minerals:									
Manganese	mg	60	60	60	60	60	60	60	60
Zinc	mg	70	65	50	40	40	40	40	65
Iron	mg	80	60	60	60	50	50	50	60
Copper	mg	8	8	6	6	6	6	6	8
Iodine	mg	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Selenium	mg	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Fat-soluble vitamins:									
Vitamin A	IU	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Vitamin D_3[e]	ICU	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
Vitamin E	IU	12	12	10	10	10	10	10	25
Vitamin K	mg	1.75	1.50	1.00	0.75	0.75	0.50	0.50	1.00
Water-soluble vitamins:									
Vitamin B_{12}	mg	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Biotin[f]	mg	0.250	0.200	0.125	0.125	0.100	0.100	0.100	0.200
Choline	mg	1,600	1,400	1,100	1,000	950	800	800	1,000
Folacin	mg	1.00	1.00	0.80	0.80	0.70	0.70	0.70	1.00
Niacin	mg	60.0	60.0	50.0	50.0	40.0	40.0	40.0	40.0
Pantothenic acid	mg	10.00	9.00	9.00	9.00	9.00	9.00	9.00	16.00
Pyridoxine	mg	4.50	4.50	3.50	3.50	3.00	3.00	3.00	4.00
Riboflavin	mg	4.00	3.60	3.00	3.00	2.50	2.50	2.50	4.00
Thiamin	mg	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

☞NOTE Where experimental data are lacking, values typeset in bold italics represent estimates based on valued obtained from other ages or relate species or from modeling experiments. Also, genetic improvements in body weight gain have led to an "earlier implementation" of those requirements (e.g., males - 0-3, 3-6, 6-9, 9-12, 12-15, and 15-18 wk & females - 0-3, 3-6, 6-9, 9-12, 12-14, and 14-16 wk) by the industry at large.

[a]These are approximate metabolizable energy (ME) values provided with typical corn-soybean-meal-based feeds, expressed in kcal MEn/kg diet. Such energy, when accompanied by the nutrient levels suggested, is expected to provide near-maximum growth, particularly with pelleted feed.

[b]Turkeys do not have a requirement for crude protein per se. There, however, should be sufficient crude protein to ensure an adequate nitrogen supply for synthesis of noness ential amino acids. Suggested requirements for crude protein are typical of those derived with corn-soybean meal diets, and levels can be reduced when synthetic amino acids are used. .

[c]The calcium requirement may be increased when diets contain high levels of phytate phosphorus (Nelson, 1984).

[d]Organic phosphorus is generally considered to be associated with phytin and of limited availability.

[e]These concentrations of vitamin Dare considered satisfactory when the associated calcium and phoxphorus levels are used.

[f]Requirement may increase with wheat-based diets.

8. Table 8. Growth Rate, Feed Intake, and Energy Intake in Large-Type Turkeys

	Body Weight (kg)		Feed Intake, per week (kg)		Feed Intake, Cumulative (kg)		ME Intake, Cumulative (Mcal)	
Age (wk)	Male	Female	Male	Female	Male	Female	Male	Female
1	0.12	0.12	0.10	0.10	0.10	0.10	0.28	0.28
2	0.25	0.24	0.19	0.18	0.29	0.28	0.53	0.5
3	0.50	0.46	0.37	0.34	0.66	0.62	1.0	1.0
4	1.00	0.90	0.70	0.59	1.36	1.21	2.0	1.7
5	1.60	1.40	0.85	0.64	2.21	1.85	2.5	1.9
6	2.20	1.80	1.10	0.80	3.31	2.65	3.2	2.3
7	3.10	2.30	1.40	0.98	4.71	3.63	4.1	2.8
8	4.00	3.00	1.73	1.21	6.44	4.84	5.0	3.5
9	5.00	3.70	2.00	1.42	8.44	6.26	6.0	4.3
10	6.00	4.40	2.34	1.70	10.78	7.96	7.0	5.1
11	7.10	5.20	2.67	1.98	13.45	9.94	8.0	5.9
12	8.20	6.00	2.99	2.18	16.44	12.12	9.0	6.8
13	9.30	6.80	3.20	2.44	19.64	14.56	9.9	7.6
14	10.50	7.50	3.47	2.69	23.11	17.25	10.8	8.4
15	11.50	8.30	3.73	2.81	26.84	20.06	11.6	9.0
16	12.60	8.90	3.97	3.00	10.81	23.06	12.3	9.6
17	13.50	9.60	4.08	3.14	34.89	26.20	13.1	10.1
18	14.40	10.20	4.30	3.18	39.19	29.38	13.8	10.5
19	15.20	10.90	4.52	3.31	43.71	32.69	14.5	10.9
20	16.10	11.50	4.74	3.40	48.45	36.09	15.2	11.2
21	17.00	-	4.81	-	53.26	-	15.9	-
22	17.90	-	5.00	-	58.26	-	16.5	-
23	18.60	-	5.15	-	63.41	-	17.1	-
24	19.40	-	5.28	-	68.69	-	17.4	-

(-) No data given because females are usually not marketed after 20 weeks of age.

HORSE NUTRITION AND FEEDING

- *References: NRC (1989, 2007), Lawrence (1998) in Kellems and Church (1998), Pagan (1998), Kline [2001. Horse feeds and feeding. Feedstuffs 73(29): 66-69], and Jurgens (2002).*

INTRODUCTION

1. **Horse Industry**

A. The horse industry has become a very important part of the agricultural scene in many areas of the States - An increase in horse research in recent years because of the popularity and the economic impact of the horse industry.
B. After several years of declining horse populations, which began in the mid 1980s, the status of the horse industry has improved in recent years:

1) High feed sales by most major horse feed manufacturers - A reflection of not only the number of horses, but also the demand for high-quality feeds to keep horses "fully content" rather than merely satisfying the needs or maintaining the health.
2) High sale prices at a public auction [e.g., the avg. for selected yearlings at one sale (2000) in Kentucky was more than $620,000, the highest since the mid 1980s].

2. **Feeding Horses?**

A. Some examples of "myths and wives' tales?" [Jackson (1998) in Pagan (1998)]

1) "*Beet pulp must be soaked prior to feeding!*"”
2) "*When I feed my horse high protein feed, it goes DITZO!*"
3) "*Molasses causes colic!*"
4) "*Pellets cause horses to choke!*"”
5) "*If horses are getting pot bellies, reduce their grain intake!*"”
6) "*I feed corn oil to prevent impaction!*"
7) "*High protein causes development of orthopedic disease!*"
8) "*New hay must go through a sweat before being fed!*"
9) "*Alfalfa causes kidney damage in horses!*"

B. Feeding horses for show or performance purposes? - Perhaps, more complicated than feeding other farm animals!?
C. Limited experimental information on the nutritional need of horses: 1) large gaps on the published information on many issues, 2) "unresolved" and conflicting reports on many issues, and 3) some difficulty in actual application of information obtained under diverse conditions.
D. Some considerations?

1) Digestive and metabolic differences among horses - Should make appropriate adjustments to compensate the possible differences!?
2) Variations in the production/performance capability and the expectation of the owner?
3) Others? Health status of the animal, variations in the nutrient availability in feed ingredients, interrelationships among nutrients, previous nutritional status, and weather/environmental conditions.

NUTRIENT REQUIREMENTS

1. **Water**

Expected daily water consumption (Gal; Lawrence, 1998)	
Maintenance, 500 kg (Thermoneutral)	6-8
Maintenance, 500 kg (Warm environ)	8-15
Lactating mare, 500 kg	10-15
Working (moderate), 500 kg	10-12
Working (moderate), 500 kg (Warm environ)	12-18
Weanling, 300 kg (Thermoneutral)	6-8

A. Like other species, an adequate supply of clean water is important for horses - Should have water available all the time via buckets, troughs, ponds, or streams (Table).
B. The water content of the body is relatively constant (68 to 72% of the total weight on a fat-free basis) and cannot change appreciably . . . without severe consequences.
C. A minimum requirement? Sum of the water lost from the body (via urine, feces, sweat, and secretions) plus a component of growth in young animals.
D. Some factors influencing the water consumption/needs:

1) Dry matter intake - Horses may need 2 to 3 L of water/kg of dry matter intake.
2) High salt or excess protein contents - Increase water intake.
3) Environmental temperatures - e.g., need 2 L of water/kg dry feed at -18°C, but need 8 L of water/kg dry feed at 38°C.
4) Work/exercising - May increase water needs by 20 to 300%.
5) Lactation.

E. Dehydration and electrolyte balance

1) Dehydration through sweating can result in the loss of water and electrolytes (mostly, Na & Cl with some K).
2) Preventive electrolyte therapy by oral or i.v. administration of 1-3 L of electrolyte solution - Beneficial? No conclusive evidence, but, oral supplementation may be helpful for a heavily sweating endurance horse in a hot or humid environment!
3) An adequate water supply, a balanced diet, and a trace mineralized salt on a free-choice should be sufficient in most racing situations!

2. **Energy**

A. The energy requirements are expressed in megacalories (Mcal) of DE.
B. Differences among individuals:

1) "Easy keeper" - Often used to describe a horse that can maintain body weight on less than the average dietary energy supply.
2) "Hard keeper" - One requires more than the average dietary energy to maintain body weight.

C. Energy status? Can be determined by weighing regularly! If not, can use subjective condition scoring system to monitor body condition - See the table:

Body Condition Scoring System (1 - 9)

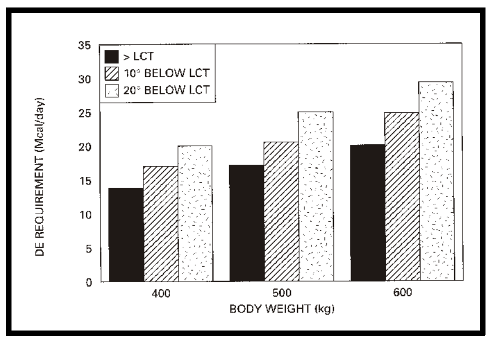
	Description
1	No fat covering on ribs, spine, pelvis, etc. All boney structures in trunk extremely apparent. Bones in neck may be visible.
2	Ribs, shoulder, spine, and pelvis structures are prominent. Neck is very thin.
3	Ribs, shoulder, spine, and pelvis are clearly discernable but some fat cover can be felt. Neck is thin.
4	Ribs are slightly visible. Some fat cover can be felt on ribs, spine, tailhead. Neck is not thin.
5	Some fat covering over ribs, spine, shoulder, and pelvis. Ribs not visible; back (loin) may be flat. Body parts are distinct but blend together smoothly.
6	More fat accumulation on ribs and at tailhead. Back (loin) may be flat or have a slight crease. Neck starting to fill out.
7	Fat accumulating on ribs and tailhead feels soft. Definition between body parts (neck to shoulder; shoulder to ribs) is decreased. Neck is filled in over crest.
8	Ribs are difficult to feel. Back (loin) has noticable crease. Neck is thick. Tailhead is very fat and soft.
9	Soft, thick fat accumulated on ribs, shoulder, and tailhead. Neck is very thick and withers have lost definition. Fat accumulated between thighs, in flank area, and behind shoulder.

Henneke et al. (1983). Modified by Lawrence (1998).

1) Based on body fatness using 1 (very thin) to 9 (very fat).
2) Most horses should be maintained at a score of at least 4 and not exceeding 7.

D. Environmental temperatures:

1) Have a large impact on energy requirements for maintenance, especially if they don't have a shelter.
2) See "Effect of cold stress on DE requirements of mature horses (LCT = lower critical temperature; Lawrence, 1998)."



E. The maintenance requirement has been estimated to be: DE (Mcal/d) = 1.4 + 0.03BW, where BW = body weight of the horse (kg).

F. Energy requirements for growth? - Can be estimated by:

1) Weanlings 1.4 + 0.03 BW + 9 ADG (kg)
2) Yearlings 1.4 + 0.03 BW + 16 ADG (kg)
3) Long yearlings 1.4 + 0.03 BW + 18 ADG (kg)
4) 2-yr-olds 1.4 + 0.03 BW + 20 ADG (kg)

☞ NRC (1989): 9.1, 11.0, 15.5, 18.4, and 19.6 Mcal DE/kg gain for 4-mo. weanling, 6-mo. weanling, yearling, long yearling, and 2-yr-old horses, respectively.

G. Energy requirements for work?

1) Depend not only on the type of work but the speed and the terrain over which the work is done.

2) The NRC's DE need above the maintenance? - From 4 Mcal to as high as 16 Mcal DE/hour of work (Jurgens, 2002).

H. Sources of energy:

1) At maintenance? - May derive most of the energy need from the digestion of fiber in the large intestine.
2) Fiber digestion alone is, usually, not sufficient to satisfy the energy need for lactation, growth, and exercise - May need some supplemental grains or lipids.
3) Can satisfy the energy need by using only grains, but should never be done! Diets with a large amount of starch and a low amount of fiber are associated with an increased incidence of colic and laminitis. Should provide, at least, "12 to 15% fiber?!"

3. **Protein**

A. Protein requirements? - Usually expressed as grams of CP required per day.
B. Mature horses at maintenance:

1) Have relatively low protein needs and deficiency is rare with an adequate energy.
2) A mature 500-kg horse needs ≈ 660 g/CP/d, which can be supplied by 8 kg of a hay containing 8.25% CP.

C. Young horses, lactating mares, and mares in late gestation - Need a diet with higher protein quantity and quality.
D. Protein quality - An important consideration in growing horses, and Lys seems to be the first limiting amino acid in diets for growing horses, with Thr being suggested as the second limiting.
E. Microbial protein/amino acid synthesis:

1) Unclear on the rate of amino acid synthesis and absorption at the cecum, thus, should provide an adequate amount of dietary indispensable amino acids, especially for growing horses until more information is available?
2) Possible that horses can absorb some N (as ammonia?) from the cecum and(or) large intestine, which can be used for the synthesis of dispensable amino acids.
3) Similarly, microbes can synthesize some indispensable amino acids, but their absorption by the hindgut might be limited!?

F. Broodmares - Need protein for the deposition of fetal tissues and milk production.

1) If the mare's milk contains about 2.0% protein and a 500-kg mare produces 15 kg of milk/day, about 300 g of protein will be secreted in the milk.
2) Conversion is not very efficient, so, perhaps, ≈ 1,430 g of dietary CP is needed?

4. **Minerals**

A. Ca & P - Special importance in horses:

1) The development of quality bone is more important in horses than other livestock species simply because some athleticactivity may put more stress on bones.
2) The horse's bone? - About 35% Ca and 16% P, and deficiencies or imbalances in dietary Ca and P can result in various bone disorders.
3) High-P can impair the absorption of Ca, thus, the concentration of P should not exceed the concentration of Ca. Also, must consider availability of Ca and P!
4) Obviously, a sufficient amount of vitamin D must be available!

B. Sodium, K, and Cl - Function as electrolytes and essential for all classes of horses.

1) Most non-working horses obtain enough Na and Cl to meet their needs with their access to a salt block or a "loose" salt mix.
2) Potassium? - Usually met by K found in hay and pasture.
3) The needs are greater for working horses, lactating mares, and horses that are exposed to high environmental temperatures.
4) Deficiency? - Can reduce a water/feed intake, plus show some unusual oral behavior such as licking of stall surfaces.

C. Others minerals?

1) Iodine - Both I deficiency and I toxicity have been reported in horses. The I content of common horse feeds can vary considerably!
2) Iron - Usually met by the typical feed ingredients, even though the availability of Fe in grains and forages may be low. Fe deficiency signs are rarely reported.
3) Copper - The level and availability of Cu is very low in many forages, and it is a common practice to formulate grain mixes to contain 20 to 30 mg Cu/kg DM.
4) Zinc - Forages may also be low in Zn. Zinc deficiency can reduce growth of young horses.
5) Selenium - Low in soils of many regions of North America, thus, feeds are also low in Se. Selenium supplementation is often necessary but should be done carefully because of its toxicity.

5. **Vitamins**

A. Fat-soluble vitamins:

1) Vitamin A and E are of the most practical importance in horse diets:

a) One of the richest sources of β-carotene (precursor of vitamin A) is "green" pasture.
b) Vitamin E activity? - High in forages with an early stage of maturity, but once a plant is harvested for hay, the vitamin E activity can decrease.

2) Vitamin D - Usually, supplementation of horses kept outside is not necessary.
3) Vitamin K - The requirement has not been established. Microbes can synthesize compounds with vitamin K activity, and also can get substances with vitamin K activity from hay and pasture.

B. Water-soluble vitamins - Little information is available on the horse's dietary need!

1) A dietary requirement for vitamin C has not been determined.
2) Microbes in the hind gut seem to be capable of synthesizing several B vitamins.

FEED INGREDIENTS AND FEEDS

1. **Forages**

A. Forages are the basis for any horse feeding program - Should receive 1.0 to 2.5 kg of good quality hay (or "pasture equivalent")/100 kg of body weight/day:

Daily hay consumption of horses (500 kg) [Lawrence, 1998]

Type of Horse	Hay, kg/d*	Comments
Maintenance, early gestation, very light work	9.5-12	More hay may be needed in cold temperatures; if alfalfa hay is fed, concentrate is usually not necessary
Late gestation, light work	7.5-11	Most horses require a small amount of concentrate (1.5 to 3 kg) in addition to hay
Lactation	9.5-13	Most lactating mares require at least 3 to 4 kg of concentrate grain in addition to hay
Yearling	7-11.5	Amount of concentrate varies (2 to 6 kg) depending on age, type of hay, and situation (sale preparation, breaking, etc.)
Weanling	3.5-7	Amount of concentrate varies (2 to 4 kg) depending on age of horse and type of hay
Performance horse	7-12	Amount of hay and grain varies depending on level of work; most will receive 3 to 6 kg of grain per day

*Assumes that horses have no access to pasture. When pasture is available, the amount of hay needed will be reduced.

1) Forages can provide many of the essential nutrients required by the horse.
2) The fiber in forages assists the horse in maintaining gastrointestinal health.

B. Pasture should be utilized whenever possible:

1) Can reduce labor costs and provide a high-quality source of nutrients.
2) During most part of the growing season, about 2.5 to 3.0 kg of fresh pasture is equivalent to about 1 kg of good hay.
3) Most grasses can be grazed by the horse, and legume-grass mixtures make excellent high quality pastures.
4) Rotational grazing and(or) clipping are important management practices because horses are selective and tend to graze the youngest and most tender grasses.
5) With plenty of high-quality pasture or hay, only rapidly developing weanling and yearling horses, mares that are lactating and to be bred back, and show and performance horses may need supplemental grains.

C. Hay for horses

1) Undoubtedly, obtaining good hay, storing, and feeding can be a major management problem.
2) Some factors associated with feeding hay:

    a) Moldy or dusty hay may cause colic and heaves in horses.
    b) Large amounts of very poor quality hay cane be poorly digested and may not pass the digestive tract, and can cause "impaction and colic?"
    c) Very high quality clover or small grain hay can be readily digested, and when fed with a high-grain feed, may result in a "loose" feces or colic.
    d) When a very high-quality hay is fed with grain, perhaps, necessary to feed a poorer quality grass hay?

3) Bromegrass, orchardgrass, timothy, and Bermudagrass make excellent hay for horses:

    a) Palatable and usually less dusty and less likely to become moldy than legume hays.
    b) Legumes:

        (1) Higher in the nutrient content than grasses and may be fed by themselves or in combination with grass hays.
        (2) Heavier and more difficult to cure properly, and are, thus, more prone to mold and become dusty. Alfalfa hay is more laxative than grass hays and may cause "loose" feces.

2. **Concentrates**

A. When a horse cannot meet its energy and protein needs through forage alone, must provide additional nutrients via concentrated feedstuffs.
B. Grains

1) Oats:

    a) Still the most widely used and the most popular grain for horses - Some believe that oats can cause fewer digestive problems than corn, possibly because of its fiber content?
    b) Heavy (> 32 lb/bu.), bright, or clean oats, which contain a small percentage of hull, are preferred - Best to roll or crush oats for horses with poor teeth or young foals.
    c) Lower in the energy content than other grains but will cause less trouble with stomach compaction. Dusty oats should be avoided because they may cause colic.

2) Corn:

a) Like oats, widely used for horses - Should be cracked, coarsely ground, or preferably rolled.
b) Higher in energy vs. oats - Usually mix it with oats, and include less corn than oats in the mixture.

3) Barley - Used some in the States (west), but popular in some other countries. Should be coarsely ground or preferably rolled, and usually mix it with oats in about equal parts.
4) Wheat, rye, and milo - Not used much because they become rather doughy and tend to ball up with moisture when ground. If used, should be rolled and mixed at a low level with bulky feed such as oats or wheat bran. (Milo has a very hard seed coat!)
5) Grain by-products:

a) Wheat bran - Very valuable for its mild laxative effect and for its bulky nature. Generally used at 5 to 15% of the diet.
b) Wheat middlings - Used in pelleted feeds and an economical source of energy.

C. Protein supplements

1) Linseed meal:

a) A popular protein supplement for horse feeding - May contain something that produces bloom and luster in the hair coat?
b) Often, pelleted meal is used because of its dustiness - Perhaps, too low in fat after extraction?
c) Usually more costly and inferior amino acid composition vs. soybean meal.

2) Soybean meal - Also, used quite extensively for horses and may be substituted on an equal protein basis for linseed meal. Contains high-quality protein and is generally more economical.
3) Cottonseed meal - Lower in protein quantity and quality vs. soybean meal. May contain gossypol, which may not be toxic to horses, but a maximum of 0,03% for young horses.
4) Milk protein - Dried whey or commercial supplements with milk products are often used in a starter diet for foals. Rarely used for mature horses because of the cost.

D. Other miscellaneous feed ingredients

1) Beet pulp - High in fiber, but the fiber is well-digested and has fairly high energy value. Often, used to replace hay in the diet for horses with heaves (or broken wind, an asthmatic disease of horses).
2) Molasses - Including 5 to 10% sweetens the feed and makes it more palatable. Also, tends to condition feeds, prevent separation, and reduce dustiness.

3) Dehydrated alfalfa meal - Include 5 to 10%. A good source of vitamins, minerals, protein, and "unidentified factors."
4) Also, rice bran, rice hulls, citrus pulp, or soybean hulls are being used depending on the cost and availability.

3. **Other Ingredients**

A. Minerals:

1) Sodium, Cl, and K - Na and Cl needs can be met easily by the addition of salt to a horse diet via plain, iodized, or trace mineralized salt. Forages are a good source of K.
2) Calcium and P - When diets are low, may be supplemented with limestone, dicalcium phosphate, steamed bone meal, or defluorinated rock phosphate.
3) Trace minerals - Usually via commercial trace mineral premixes or trace mineralized salt.

B. Fats and oils - Animal fats and vegetable oils (5 to 10%) can be used as a highly concentrated energy source for horses.

1) Vegetable oils are generally more palatable than animal fats.
2) Can be used as a source of linoleic acid, to reduce feed dustiness, and to put a bloom on the animal hair coat.

4. **Antibiotics**

A. No information available on the value of antibiotics for horses, but addition of an antibiotic may be helpful for young foals? - Infections, digestive troubles, lack of milk, poor weather, or other stress factors.
B. Presently, the Food and Drug Administration allows the use of 85 mg chlortetracycline per head daily for horses up to one year of age for stimulating growth and improving feed efficiency (Jurgen, 2002).

5. **Pelleting Feeds?**

A. Pellets may be especially useful in creep feeds and diets for weanlings where there is a tendency for horses to separate out the fine particles.
B. Pelleted diets containing hay, as well as grain, should contain 60 to 70% coarsely ground hay to decrease problems with colic.
C. May be necessary to feed a small amount of unprocessed hay to prevent wood chewing and mane and tail chewing when groups of animals are penned together?

6. **Manufactured Feeds**

A. Fortified grain mixes - Used widely in the horse industry:

1) Include a combination of grain or grain by-products, protein supplement, Ca and P, trace minerals, vitamins, and salt, and others. Formulated/designed to meet the nutrient needs when fed with forage alone.
2) Most manufactures offer at least three separate formulations:

    a) For maintenance or light work horses - Contains about 10 to 12% CP.
    b) For performance horses, broodmares, and yearlings - Contains about 13 to 14% CP.
    c) For lactating mares, weanlings, and yearlings - Contains 15 to 16% CP.

3) Also available in several physical forms, i.e., a corse mix (aka, sweet feed or textured feed?), pelleted, or extruded.

B. Supplements - Designed to satisfy the need for protein, vitamins, and minerals by feeding a small amount every day to horses on lush pastures to satisfy their energy needs.

C. Complete feeds:

1) Useful? - a) When good quality hay or pasture is not available, and b) in older horses with poor teeth or ones with respiratory allergies to hay.
2) Contain a roughage source (alfalfa dehy and beet pulp are common) and designed to be fed without any forage - Ones with alfalfa are often pelleted.
3) Fiber - Usually at least 12 to 15%, and may be > 20%.

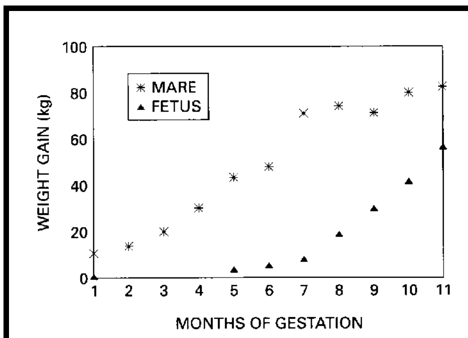
FEEDING HORSES

1. Breeding, Gestation & Lactation

A. Breeding? Most mares are not bred until 3 to 4 yr of age, whereas successful performance horses may not be bred until 8 yr of age.

B. Desirable for mares to have a foal every year, and most mares can be rebred within a few weeks of foaling (no lactational anestrus?) - Thus often, gestation & lactation overlap in horses.

C. Just like other species, mares will use body reserves to meet the nutrient needs for fetal growth and milk production if they do not consume a sufficient amount of nutrients during gestation and lactation.



D. Breeding/gestation:

1) The recommended maintenance needs for energy and protein should be sufficient during the breeding and early gestation periods, but need additional nutrients during the last 90 d because about 60% of the

weight of the fetus develops during that time. See the figure on "Fetal and mare weight gains during gestation (Lawrence, 1998)."

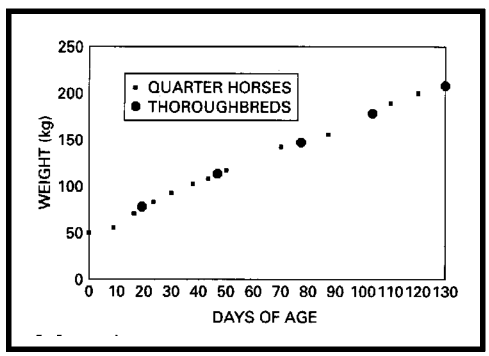
2) But, if mares are lactating, they obviously need more nutrients.
3) Loss of weight or body condition - Obviously, a clear indication of the inadequate nutritional status.
4) Ca - An inadequate Ca intake during lactation may lead to mobilization of Ca from the bone to meet the demands, thus, could have a significant impact on the long-term soundness if continued over several cycles.
5) Increase a nutrient intake by 10 to 20% above the maintenance if mares lost the weight during lactation and enters the second trimester of gestation in sub-optimal body condition.
6) During a 340-d gestation, a 500-kg mare may gain 50 to 70 kg (foal weighs about 40 to 55 kg at birth) - Regular weighing/assessing body condition scores would be helpful.
7) Can meet the mare's requirements for late gestation by increasing feed, but they may eat less feed in late gestation, thus necessary to change the composition of the diet, i.e., to increase concentrate?

E. Lactation

1) A mare has just foaled, lactating, and being prepared for breeding? - Obviously a period of critical nutritional stress and they must be well nourished!
2) Mares should be in a good condition prior to foaling so that they can use their "build-up" reserves in the time of need.
3) A few days before foaling, provide a bulky diet to reduce potential constipation problems, and allow 7 to 10 d after foaling to bring mares to full feed.
4) Mares peak lactation at 3 mo. post-foaling, and a 500-kg mare may produce over 35 lb of milk/d?

2. **Growing Horses**

A. Foals:



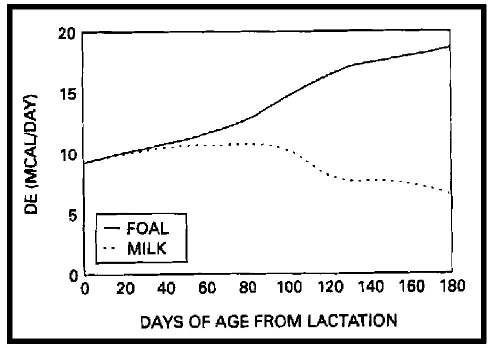
1) Nutrients from the mare (assuming well-fed) would be adequate during the first 3 to 4 mo.
2) But, they begin to eat solid food within a few days and will consume significant amounts of hay, pasture, or grain by 2 mo. of age.

B. Weight gain and creep feed:

1) Weight gain - 1.2 to 1.6 kg/day in the first mo. and gradually declines to about 1.0 kg/d at 4 mo. of age. See the figure on "Representative growth curves for foals (Lawrence, 1998)."

2) May want to provide an appropriate creep feed (e.g., 16% CP, 0.9% Ca, and 0.6% P) at about 2 mo. of age, and can be fed about 0.5 kg/mo. of age/day?

    ☛ Foals should not be given unlimited access to a creep feed!



C. Weaning:

1) Most foals are weaned at 4 to 6 mo. of age
2) By 4 mo. of age, the contribution of milk to the total nutrient needs starts to decline, and additional feed is necessary even if the foal is not weaned.
3) By 6 mo. of age, milk provides less than 50% of the daily nutrient intake. See the figure on "DE needs of a growing horse & DE contributed by mare's milk (Lawrence, 1998)."
4) The foals should be consuming 6 to 8 lb (2.7 to 3.6 kg) of feed at weaning time or 5 to 6 mo. of age - Weaning can be stressful for many foals, and the reduction in weight gain may be as brief as a week if foals are accustomed to eating substantial amounts of pasture, hay, or grain prior to weaning.

D. Yearling and 2-yr-old:

1) Weight gain during the first 2 yr of life will not affect the final mature size, but may affect the age at which the animal reaches maturity.
2) Very rapid rates of growth - Associated with an increased incidence of bone and joint problems (osteochondrosis, physitis, cervical vertebral malformation, and angular limb deformities):

    a) Feed diets that have an adequate amount of all required nutrients, not just energy.
    b) Some additional nutritional factors? Low dietary Ca, low or high dietary P, an unbalanced Ca:P ratio, low dietary Cu, and very high dietary Zn.

3) At 1 yr of age or about 800 lb, change to a yearling diet. Possible to start relying on hay and pasture more extensively, but still very important to assure adequate protein, vitamin, and mineral intakes.
4) Feed based on the requirements for maintenance and growth that is desired, and feeding practice should be based on maintaining the desired condition and development and growth of the horse as the horse goes into training.

3. **Working/Performance Horses**

A. Include horses being trained for various performance events or horses used for roping, cutting, jumping, etc.

B. Generally, ridden every day, and thus have a relatively high energy expenditure, but perhaps, no greater demands for protein, Ca, P, most trace minerals, and most fat-soluble vitamins?

C. Nutrient requirements - Vary with the type and degree of activity, e.g., racing Quarter Horse running at maximal speed for 400 yd or less vs. Arabian endurance horse competing over distances of 50 to 100 miles.

Some Racing Diets for Thoroughbreds in Full Work

	Trainer					
Ingredient (kg)	A	B	C	D	E	F
Oats	5.4	1.3	6.0	5.2	5.9	4.2
R Oats	-	1.8	-	-	-	-
R Barley	-	0.6	-	-	-	-
Cr Maize	1.55	0.6	2.1	-	0.8	0.9
Lupins	0.3	-	0.33	1.8	-	-
Peas	-	-	0.33	--	0.4	-
Tick Beans	-	0.4	-	-	0.4	0.875
Bran	0.3	0.53	0.2	0.3	-	0.3
Sunflowers	0.25	0.2	0.1	0.1	0.4	0.075
Pellets	-	0.7	-	-	-	-
Oil	-	-	0.2	-	-	0.12
Cereal Chaff	0.4	1.8	0.45	0.8	0.65	1.8
Lucerne Chaff	0.3	0.75	0.7	0.8	0.9	1.2
Lucerne Hay	1.7	-	1.5	2	0.75	1.0
Oaten Hay	1.35	-	1.4	-	-	-
Supplements	5.0	2.0	3.0	1.0	5.0	4.0
Pasture		+			+	+

[See the table on "Examples of racing horse diets used in Australia & New Zealand," Huntingdon & Jenkinson (1998) in Pagan (1998).]

D. Energy required by performance horses:

1) Affected by two primary factors - The intensity of the daily exercise and the duration of the daily exercise.
2) Some recommendations for the DE intake are based on general categories of work effort - Increase DE by 25, 50, and 100% above maintenance for horses involved in light, moderate, and intense exercise, respectively (. . . e.g., light work can be pleasure riding, whereas intense work can include training for races and polo?).
3) Horses performing moderate or intense work? - Cannot consume enough forage to meet their energy needs, thus must increase a concentrate.
4) Addition of fat to a concentrate feed can increase energy density without increasing feed/starch intake, and commercially manufactured feeds nowadays contain 4 to 8% added fat. Also, can be added directly by top dressing.
5) Feeding more than 7 lb (3.2 kg) or more of concentrate/day - Should be fed in two to three meals depending on the amount. No single meal should exceed 3 kg of concentrate!?
6) Feeding programs for Thoroughbred and Standardbred racehorses - Often, restrict forage intake the night or morning before a race to decrease bulk in the gastrointestinal tract.

E. Protein - Working horses need more dietary protein than sedentary horses?

1) Reasons? - a) Protein is lost in sweat, b) a small amount of protein may be broken down during exercise, and c) horses in training may retain slightly more nitrogen than horses at maintenance.

2) The magnitude of the needed increase may be small, and if feed intake is increased to satisfy the energy demand, perhaps, the protein requirement would be almost always satisfied!?

F. Electrolytes & other minerals:

1) Horse sweat is very high in Na, K, and CI, and exercise can result in losses of these minerals.
2) Electrolytes cannot be stored in the body, thus the needs must be satisfied on a daily basis. Should give a small amount of a balanced supplement at regular intervals during a long ride.
3) Little is known about the effect of exercise on the requirement for other minerals, even though it is known that Ca and P intakes are most critical for young horses.
4) A reasonable guideline for mineral requirements in exercising horses? - Perhaps, increase the mineral intake (in grams per day) in proportion to the increase in the energy intake?

G. Vitamins:

1) Performance horses may require a higher dietary concentration of some vitamins than sedentary horses.
2) Many B vitamins are synthesized by microbes, but it may be better to ensure that by providing, at least, 50% of the need by the diet.
3) Important ones? - Thiamin, niacin, riboflavin, pantothenic acid, choline, biotin, folic acid, and B_{12}, and also vitamin E?

H. Following a heavy exercise, small quantities (a few swallows) of water should be provided at 5- to 10 min intervals until thirst is quenched. By doing that, can prevent digestive disturbances and possibly founder from excessive water intake.

NUTRITION RELATED PROBLEMS AND FEEDING MANAGEMENT

1. **Nutritional Related Problems**

A. Colic

1) Many factors can contribute to colic, but some may be caused by dietary factors.
2) Colic?

a) Severe abdominal pain.
b) Horses with colic may kick at their abdomens, roll, or repeatedly attempt to urinate.
c) Sweating and signs of anxiety and discomfort are also common.
d) Some cases are mild and resolve quickly, but other cases require surgery. Can result in death.

3) Dietary factors?

   a) Lower incidence in horses with 24-hr access to pasture, but high in horses consuming a high-concentrate diet.
   b) Also, sudden changes in the diet and lack of water availability can cause the problem.
   c) To minimize the potential problem, should provide adequate water and forage, and any diet changes should be made slowly.

B. Laminitis or founder

1) May be caused by overconsumption of concentrate or lush-growing pasture.
2) Ones with acute laminitis exhibit pain and heat in the hooves and reluctant to move.
3) Often results in permanent lameness and may cause death in some cases.
4) To reduce a potential problem?

   a) Should be adjusted to lush pastures gradually, and, whenever possible, the energy need should be met with roughage instead of concentrate.
   b) If a horse needs a large amount of concentrate, should be adjusted to the diet gradually and should not be given more than 3 kg of concentrate at any meal.
   c) Once a horse has foundered, she/he may become more susceptible.

C. Plant poisoning

1) Thistles, nettles, and burrs - Mechanically injurious to horses and may cause damage to the nose and mouth.
2) St. John's wort and buckwheat - May produce photosensitization, most often observed in unpigmented areas, and dermatitis.
3) Mountain laurel, azalea, jimson weed, oak, field blind weed, buttercups, and a number of other plants - May cause colic or diarrhea and some of these plants may be fatal with consumption of a sufficient quantity.
4) Other plants that may be fatal include serviceberry, elderberry, foxglove, oleander, and yew.

2. **Feeding Management**

A. Housing:

1) Grazing:

   a) Eating and non-eating periods are interspersed and eating periods are rarely separated by more than 2 or 3 hr, i.e., gazing horses often spend about 50 to 60% of their time or 12 to 14 hr eating.
   b) Mature horses on good-quality pasture should have access to a salt block and a source of clean fresh water.

c) Supplementation is not necessary unless the pasture is not sufficient to meet the nutrient needs
d) If supplementation is needed:

(1) Better to bring the horse into stalls for individual feeding once or twice a day.
(2) If not possible to feed individually, can avoid over- or underfeeding by grouping horses by their needs.

2) Many pleasure and performance horses are housed in box stalls and have little access to pasture:

a) Easy to provide each horse with a diet that is specific to its needs, but usually fed only two or three times per day, which is, perhaps, too long between meals?
b) Horses on a typical hay and concentrate diet may spend less than 6 hr a day "eating."
d) To allow stabled horses to have a more natural feeding environment:

(1) Hay availability should be maximized - Hay should be offered at least 1 hr before a concentrate to encourage the horse to consume hay first.
(2) No more than 3 kg of concentrate should be fed at one time to a mature horse (500 kg).
(3) Feeding more than 6 kg of concentrate/day? Then, the concentrate should be divided into at least three meals.

NUTRIENT REQUIREMENT TABLES

[Tables 1 to 5 - NRC (2007); Tables 6 to 8 - NRC (1989); Abbreviations: **Wt** = weight; **ADG** = average daily gain; **DE** = digestible energy; **CP** = crude protein]

1. Table 1. Daily Nutrient Requirements of Horses (Mature Body Wt, 200 kg)[a]

Type	Wt, kg	ADG/ Milk, kg/d	DE, Mcal	CP, g	Lys, g	Ca, g	P, g	Mg, g	K, g	Na, g	Cl, g	S, g
Adult - no work[b]												
Minimum	200		6.1	216	9.3	8.0	5.6	3.0	10.0	4.0	16.0	6.0
Average	200		6.7	252	10.8	8.0	5.6	3.0	10.0	4.0	16.0	6.0
Elevated	200		7.3	288	12.4	8.0	5.6	3.0	10.0	4.0	16.0	6.0
Working[C]												
Light exercise	200		8.0	280	12.0	12.0	7.2	3.8	11.4	5.6	18.7	6.0
Moderate exercise	200		9.3	307	13.2	14.0	8.4	4.6	12.8	7.1	21.3	6.8
Heavy exercise	200		10.7	345	14.8	16.0	11.6	6.0	15.6	10.2	26.6	7.5
Very heavy exercise	200		13.8	402	17.3	16.0	11.6	6.0	21.2	16.4	37.2	7.5
Stallions												
Nonbreeding	200		7.3	288	12.4	8.0	5.6	3.0	10.0	4.0	16.0	6.0
Breeding	200		8.7	316	13.6	12.0	7.2	3.8	11.4	5.6	18.7	6.0
Pregnant mares												
Early (< 5 months)	200		6.7	252	10.8	8.0	5.6	3.0	10.0	4.0	16.0	6.0
5 months	201	0.05	6.8	274	11.8	8.0	5.6	3.0	10.0	4.0	16.0	6.0
6 months	203	0.07	7.0	282	12.1	8.0	5.6	3.0	10.0	4.0	16.0	6.0
7 months	206	0.10	7.2	291	12.5	11.2	8.0	3.0	10.0	4.0	16.0	6.0
8 months	209	0.13	7.4	304	13.1	11.2	8.0	3.0	10.0	4.0	16.0	6.0
9 months	214	0.16	7.7	319	13.7	14.4	10.5	3.1	10.3	4.4	16.4	6.0
10 months	219	0.21	8.1	336	14.5	14.4	10.5	3.1	10.3	4.4	16.4	6.0
11 months	226	0.26	8.6	357	15.4	14.4	10.5	3.1	10.3	4.4	16.4	6.0
Lactating mares												
1 months	200	6.52	12.7	614	33.9	23.6	15.3	4.5	19.1	5.1	18.2	7.5
2 months	200	6.48	12.7	612	33.8	23.6	15.2	4.5	19.1	5.1	18.2	7.5
3 months	200	5.98	12.2	587	32.1	22.4	14.4	4.3	18.4	5.0	18.2	7.5
4 months	200	5.42	11.8	559	30.3	16.7	10.5	4.2	14.3	4.8	18.2	7.5
5 months	200	4.88	11.3	532	28.5	15.8	9.9	4.1	13.9	4.7	18.2	7.5
6 months	200	4.36	10.9	506	26.8	15.0	9.3	3.5	13.5	4.6	18.2	7.5
Growing animals												
4 months	67	0.34	5.3	268	11.5	15.6	8.7	1.4	4.4	1.7	6.3	2.5
6 months	86	0.29	6.2	270	11.6	15.5	8.6	1.7	5.2	2.0	8.0	3.2
12 months	128	0.18	7.5	338	14.5	15.1	8.4	2.2	7.0	2.8	10.6	4.8
18 months	155	0.11	7.7	320	13.7	14.8	8.2	2.5	8.1	3.2	12.8	5.8
18 light exercise	155	0.11	8.8	341	14.7	14.8	8.2	4.6	9.2	4.4	14.8	5.8
18 moderate exercise	155	0.11	10.0	362	15.6	14.8	8.2	4.6	10.3	5.6	16.9	5.8
24 months	172	0.07	7.5	308	13.2	14.7	8.1	2.7	8.8	3.5	14.2	6.4
24 light exercise	172	0.07	8.7	332	14.3	14.7	8.1	5.2	10.0	4.8	16.4	6.4
24 moderate exercise	172	0.07	9.9	355	15.3	14.7	8.1	5.2	11.2	6.2	18.7	6.4
24 heavy exercise	172	0.07	11.2	387	16.7	14.7	8.1	5.2	13.6	8.8	23.3	6.4
24 very heavy exercise	172	0.07	13.0	436	18.8	14.7	8.1	5.2	18.4	14.1	32.4	6.4

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[c]Examples of the type of regular exercise performed by horses in each category are described in Chapter 1. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

- Cont. - Table 1. Daily Nutrient Requirements of Horses (Mature Body Wt, 200 kg)[a]

Type	Co, mg	Cu, mg	I, mg	Fe, mg	Mn, mg	Se, mg	Zn, mg	A, kIU	D, IU	E, IU	Thiamin, mg	Riboflavin, mg
Adult - no work[b]												
Minimum	0.2	40.0	1.4	160.0	160.0	0.40	160.0	6.0	1320	200	12.0	8.0
Average	0.2	40.0	1.4	160.0	160.0	0.40	160.0	6.0	1320	200	12.0	8.0
Elevated	0.2	40.0	1.4	160.0	160.0	0.40	160.0	6.0	1320	200	12.0	8.0
Working[C]												
Light exercise	0.2	40.0	1.4	160.0	160.0	0.40	160.0	9.0	1320	320	12.0	8.0
Moderate exercise	0.2	45.0	1.6	180.0	180.0	0.45	180.0	9.0	1320	360	22.6	9.0
Heavy exercise	0.3	50.0	1.8	200.0	200.0	0.50	200.0	9.0	1320	400	25.0	10.0
Very heavy exercise	0.3	50.0	1.8	200.0	200.0	0.50	200.0	9.0	1320	400	25.0	10.0
Stallions												
Nonbreeding	0.2	40.0	1.4	160.0	160.0	0.40	160.0	6.0	1320	200	12.0	8.0
Breeding	0.2	40.0	1.4	160.0	160.0	0.40	160.0	9.0	1320	320	12.0	8.0
Pregnant mares												
Early (< 5 months)	0.2	40.0	1.4	160.0	160.0	0.40	160.0	12.0	1320	320	12.0	8.0
5 months	0.2	40.0	1.4	160.0	160.0	0.40	160.0	12.0	1320	320	12.0	8.0
6 months	0.2	40.0	1.4	160.0	160.0	0.40	160.0	12.0	1320	320	12.0	8.0
7 months	0.2	40.0	1.4	160.0	160.0	0.40	160.0	12.0	1320	320	12.0	8.0
8 months	0.2	40.0	1.4	160.0	160.0	0.40	160.0	12.0	1320	320	12.0	8.0
9 months	0.2	50.0	1.6	200.0	160.0	0.40	160.0	12.0	1320	320	12.0	8.0
10 months	0.2	50.0	1.6	200.0	160.0	0.40	160.0	12.0	1320	320	12.0	8.0
11 months	0.2	50.0	1.6	200.0	160.0	0.40	160.0	12.0	1320	320	12.0	8.0
Lactating mares												
1 months	0.3	50.0	1.8	250.0	200.0	0.50	200.0	12.0	1320	400	15.0	10.0
2 months	0.3	50.0	1.8	250.0	200.0	0.50	200.0	12.0	1320	400	15.0	10.0
3 months	0.3	50.0	1.8	250.0	200.0	0.50	200.0	12.0	1320	400	15.0	10.0
4 months	0.3	50.0	1.8	250.0	200.0	0.50	200.0	12.0	1320	400	15.0	10.0
5 months	0.3	50.0	1.8	250.0	200.0	0.50	200.0	12.0	1320	400	15.0	10.0
6 months	0.3	50.0	1.8	250.0	200.0	0.50	200.0	12.0	1320	400	15.0	10.0
Growing animals												
4 months	0.1	16.8	0.6	84.2	67.4	0.17	67.4	3.0	1496	135	5.1	3.4
6 months	0.1	21.6	0.8	107.9	86.4	0.22	86.4	3.9	1917	173	6.5	4.3
12 months	0.2	32.1	1.1	160.6	128.5	0.32	128.5	5.8	2236	257	9.6	6.4
18 months	0.2	38.7	1.4	193.7	155.0	0.39	155.0	7.0	2464	310	11.6	7.7
18 light exercise	0.2	38.7	1.4	193.7	155.0	0.39	155.0	7.0	2464	310	11.6	7.7
18 moderate exercise	0.2	38.7	1.4	193.7	155.0	0.39	155.0	7.0	2464	310	11.6	7.7
24 months	0.2	42.9	1.5	214.6	171.7	0.43	171.7	7.7	2352	343	12.9	8.6
24 light exercise	0.2	42.9	1.5	214.6	171.7	0.43	171.7	7.7	2352	343	12.9	8.6
24 moderate exercise	0.2	42.9	1.5	214.6	171.7	0.43	171.7	7.7	2352	343	12.9	8.6
24 heavy exercise	0.2	42.9	1.5	214.6	171.7	0.43	171.7	7.7	2352	343	12.9	8.6
24 very heavy exercise	0.2	42.9	1.5	214.6	171.7	0.43	171.7	7.7	2352	343	12.9	8.6

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[c]Examples of the type of regular exercise performed by horses in each category are described in Chapter 1. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

2. Table 2. Daily Nutrient Requirements of Horses (Mature Body Wt, 400 kg)[a]

Type	Wt, kg	ADG/ Milk, kg/d	DE, Mcal	CP, g	Lys, g	Ca, g	P, g	Mg, g	K, g	Na, g	Cl, g	S, g
Adult-no work[b]												
Minimum	400		12.1	432	18.6	16.0	11.2	6.0	20.0	8.0	32.0	12.0
Average	400		13.3	504	21.7	16.0	11.2	6.0	20.0	8.0	32.0	12.0
Elevated	400		14.5	576	24.8	16.0	11.2	6.0	20.0	8.0	32.0	12.0
Working[c]												
Light exercise	400		16.0	559	24.1	24.0	14.4	7.6	22.8	11.1	37.3	12.0
Moderate exercise	400		18.6	614	26.4	28.0	16.8	9.2	25.6	14.2	42.6	13.5
Heavy exercise	400		21.3	689	29.6	32.0	23.2	12.0	31.2	20.4	53.2	15.0
Very heavy exercise	400		27.6	804	34.6	32.0	23.2	12.0	42.4	32.8	74.4	15.0
Stallions												
Nonbreeding	400		14.5	576	24.8	16.0	11.2	6.0	20.0	8.0	32.0	12.0
Breeding	400		17.4	631	27.1	24.0	14.4	7.6	22.8	11.1	37.3	12.0
Pregnant mares												
Early (< 5 months)	400		13.3	504	21.7	16.0	11.2	6.0	20.0	8.0	32.0	12.0
5 months	403	0.11	13.7	548	23.6	16.0	11.2	6.0	20.0	8.0	32.0	12.0
6 months	407	0.15	13.9	563	24.2	16.0	11.2	6.0	20.0	8.0	32.0	12.0
7 months	412	0.19	14.3	583	25.1	22.4	16.0	6.1	20.0	8.0	32.0	12.0
8 months	419	0.26	14.8	607	26.1	22.4	16.0	6.1	20.0	8.0	32.0	12.0
9 months	427	0.33	15.4	637	27.4	28.8	21.0	6.1	20.7	8.8	32.8	12.0
10 months	439	0.42	16.2	673	28.9	28.8	21.0	6.1	20.7	8.8	32.8	12.0
11 months	453	0.52	17.1	714	30.7	28.8	21.0	6.1	20.7	8.8	32.8	12.0
Lactating mares												
1 months	400	13.04	25.4	1228	67.8	47.3	30.6	8.9	38.3	10.2	36.4	15.0
2 months	400	12.96	25.3	1224	67.5	47.1	30.5	8.9	38.1	10.2	36.4	15.0
3 months	400	11.96	24.5	1174	64.2	44.7	28.8	8.7	36.7	10.0	36.4	15.0
4 months	400	10.84	23.6	1118	60.5	33.3	20.9	8.4	28.7	9.5	36.4	15.0
5 months	400	9.76	22.7	1064	57.0	31.6	19.7	8.2	27.8	9.4	36.4	15.0
6 months	400	8.72	21.8	1012	53.5	30.0	18.6	7.0	27.0	9.2	36.4	15.0
Growing animals												
4 months	135	0.67	10.6	535	23.0	31.3	17.4	2.9	8.8	3.4	12.5	5.1
6 months	173	0.58	12.4	541	23.3	30.9	17.2	3.3	10.4	4.0	16.1	6.5
12 months	257	0.36	15.0	677	29.1	30.1	16.7	4.3	13.9	5.5	21.2	9.6
18 months	310	0.23	15.4	639	27.5	29.6	16.5	4.9	16.2	6.4	25.6	11.6
18 light exercise	310	0.23	17.7	682	29.3	29.6	16.5	9.3	18.4	8.8	29.7	11.6
18 moderate exercise	310	0.23	20.0	725	31.2	29.6	16.5	9.3	20.5	11.2	33.8	11.6
24 months	343	0.14	15.0	616	26.5	29.3	16.3	5.3	17.6	7.0	28.3	12.9
24 light exercise	343	0.14	17.4	663	28.5	29.3	16.3	10.3	20.0	9.7	32.9	12.9
24 moderate exercise	343	0.14	19.9	710	30.6	29.3	16.3	10.3	22.4	12.3	37.4	12.9
24 heavy exercise	343	0.14	22.3	775	33.3	29.3	16.3	10.3	27.2	17.7	46.5	12.9
24 very heavy exercise	343	0.14	26.0	873	37.5	29.3	16.3	10.3	36.8	28.3	64.7	12.9

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[c]Examples of the type of regular exercise performed by horses in each category are described in Chapter I. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

- Cont. - Table 2. Daily Nutrient Requirements of Horses (Mature Body Wt, 400 kg)[a]

Type	Co, mg	Cu, mg	I, mg	Fe, mg	Mn, mg	Se, mg	Zn, mg	A, kIU	D, IU	E, IU	Thiamin, mg	Riboflavin, mg
Adult - no work[b]												
Minimum	0.4	80.0	2.8	320.0	320.0	0.80	320.0	12.0	2640	400	24.0	16.0
Average	0.4	80.0	2.8	320.0	320.0	0.80	320.0	12.0	2640	400	24.0	16.0
Elevated	0.4	80.0	2.8	320.0	320.0	0.80	320.0	12.0	2640	400	24.0	16.0
Working[C]												
Light exercise	0.4	80.0	2.8	320.0	320.0	0.80	320.0	18.0	2640	640	24.0	16.0
Moderate exercise	0.5	90.0	3.2	360.0	360.0	0.90	360.0	18.0	2640	720	45.2	18.0
Heavy exercise	0.5	100.0	3.5	400.0	400.0	1.00	400.0	18.0	2640	800	50.0	20.0
Very heavy exercise	0.5	100.0	3.5	400.0	400.0	1.00	400.0	18.0	2640	800	50.0	20.0
Stallions												
Nonbreeding	0.4	80.0	2.8	320.0	320.0	0.80	320.0	12.0	2640	400	24.0	16.0
Breeding	0.4	80.0	2.8	320.0	320.0	0.80	320.0	18.0	2640	640	24.0	16.0
Pregnant mares												
Early (< 5 months)	0.4	80.0	2.8	320.0	320.0	0.80	320.0	24.0	2640	640	24.0	16.0
5 months	0.4	80.0	2.8	320.0	320.0	0.80	320.0	24.0	2640	640	24.0	16.0
6 months	0.4	80.0	2.8	320.0	320.0	0.80	320.0	24.0	2640	640	24.0	16.0
7 months	0.4	80.0	2.8	320.0	320.0	0.80	320.0	24.0	2640	640	24.0	16.0
8 months	0.4	80.0	2.8	320.0	320.0	0.80	320.0	24.0	2640	640	24.0	16.0
9 months	0.4	100.0	3.2	400.0	320.0	0.80	320.0	24.0	2640	640	24.0	16.0
10 months	0.4	100.0	3.2	400.0	320.0	0.80	320.0	24.0	2640	640	24.0	16.0
11 months	0.4	100.0	3.2	400.0	320.0	0.80	320.0	24.0	2640	640	24.0	16.0
Lactating mares												
1 months	0.5	100.0	3.5	500.0	400.0	1.00	400.0	24.0	2640	800	30.0	20.0
2 months	0.5	100.0	3.5	500.0	400.0	1.00	400.0	24.0	2640	800	30.0	20.0
3 months	0.5	100.0	3.5	500.0	400.0	1.00	400.0	24.0	2640	800	30.0	20.0
4 months	0.5	100.0	3.5	500.0	400.0	1.00	400.0	24.0	2640	800	30.0	20.0
5 months	0.5	100.0	3.5	500.0	400.0	1.00	400.0	24.0	2640	800	30.0	20.0
6 months	0.5	100.0	3.5	500.0	400.0	1.00	400.0	24.0	2640	800	30.0	20.0
Growing animals												
4 months	0.2	33.7	1.2	168.5	134.8	0.34	134.8	6.1	2992	270	10.1	6.7
6 months	0.2	43.2	1.5	215.9	172.7	0.43	172.7	7.8	3834	345	13.0	8.6
12 months	0.3	64.2	2.3	321.2	257.0	0.64	257.0	11.6	4471	514	19.3	12.8
18 months	0.4	77.5	2.7	387.5	310.0	0.77	310.0	13.9	4929	620	23.2	15.5
18 light exercise	0.4	77.5	2.7	387.5	310.0	0.77	310.0	13.9	4929	620	23.2	15.5
18 moderate exercise	0.4	77.5	2.7	387.5	310.0	0.77	310.0	13.9	4929	620	23.2	15.5
24 months	0.4	85.8	3.0	429.2	343.4	0.86	343.4	15.5	4704	687	25.8	17.2
24 light exercise	0.4	85.8	3.0	429.2	343.4	0.86	343.4	15.5	4704	687	25.8	17.2
24 moderate exercise	0.4	85.8	3.0	429.2	343.4	0.86	343.4	15.5	4704	687	25.8	17.2
24 heavy exercise	0.4	85.8	3.0	429.2	343.4	0.86	343.4	15.5	4704	687	25.8	17.2
24 very heavy exercise	0.4	85.8	3.0	429.2	343.4	0.86	343.4	15.5	4704	687	25.8	17.2

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[c]Examples of the type of regular exercise performed by horses in each category are described in Chapter I. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

3. Table 3. Daily Nutrient Requirements of Horses (Mature Body Wt, 500 kg)[a]

Type	Wt, kg	ADG/ Milk, kg/d	DE, Mcal	CP, g	Lys, g	Ca, g	P, g	Mg, g	K, g	Na, g	Cl, g	S, g
Adult - no work[b]												
Minimum	500		15.2	540	23.2	20.0	14.0	7.5	25.0	10.0	40.0	15.0
Average	500		16.7	630	27.1	20.0	14.0	7.5	25.0	10.0	40.0	15.0
Elevated	500		18.2	720	31.0	20.0	14.0	7.5	25.0	10.0	40.0	15.0
Working[C]												
Light exercise	500		20.0	699	30.1	30.0	18.0	9.5	28.5	13.9	46.6	15.0
Moderate exercise	500		23.3	768	33.0	35.0	21.0	11.5	32.0	17.8	53.3	16.9
Heavy exercise	500		26.6	862	37.1	40.0	29.0	15.0	39.0	25.5	66.5	18.8
Very heavy exercise	500		34.5	1004	43.2	40.0	29.0	15.0	53.0	41.0	93.0	18.8
Stallions												
Nonbreeding	500		18.2	720	31.0	20.0	14.0	7.5	25.0	10.0	40.0	15.0
Breeding	500		21.8	789	33.9	30.0	18.0	9.5	28.5	13.9	46.6	15.0
Pregnant mares												
Early (< 5 months)	500		16.7	630	27.1	20.0	14.0	7.5	25.0	10.0	40.0	15.0
5 months	504	0.14	17.1	685	29.5	20.0	14.0	7.5	25.0	10.0	40.0	15.0
6 months	508	0.18	17.4	704	30.3	20.0	14.0	7.5	25.0	10.0	40.0	15.0
7 months	515	0.24	17.9	729	31.3	28.0	20.0	7.6	25.0	10.0	40.0	15.0
8 months	523	0.32	18.5	759	32.7	28.0	20.0	7.6	25.0	10.0	40.0	15.0
9 months	534	0.41	19.2	797	34.3	36.0	26.3	7.7	25.9	11.0	41.0	15.0
10 months	548	0.52	20.2	841	36.2	36.0	26.3	7.7	25.9	11.0	41.0	15.0
11 months	566	0.65	21.4	893	38.4	36.0	26.3	7.7	25.9	11.0	41.0	15.0
Lactating mares												
1 months	500	16.30	31.7	1535	84.8	59.1	38.3	11.2	47.8	12.8	45.5	18.8
2 months	500	16.20	31.7	1530	84.4	58.9	38.1	11.1	47.7	12.8	45.5	18.8
3 months	500	14.95	30.6	1468	80.3	55.9	36.0	10.9	45.9	12.5	45.5	18.8
4 months	500	13.55	29.4	1398	75.7	41.7	26.2	10.5	35.8	11.9	45.5	18.8
5 months	500	12.20	28.3	1330	71.2	39.5	24.7	10.2	34.8	11.7	45.5	18.8
6 months	500	10.90	27.2	1265	66.9	37.4	23.2	8.7	33.7	11.5	45.5	18.8
Growing animals												
4 months	168	0.84	13.3	669	28.8	39.1	21.7	3.6	10.9	4.2	15.7	6.3
6 months	216	0.72	15.5	676	29.1	38.6	21.5	4.1	13.0	5.0	20.1	8.1
12 months	321	0.45	18.8	846	36.4	37.7	20.9	5.4	17.4	6.9	26.5	12.0
18 months	387	0.29	19.2	799	34.4	37.0	20.6	6.2	20.2	8.0	32.0	14.5
18 light exercise	387	0.29	22.1	853	36.7	37.0	20.6	11.6	22.9	11.0	37.1	14.5
18 moderate exercise	387	0.29	25.0	906	39.0	37.0	20.6	11.6	25.7	14.0	42.2	14.5
24 months	429	0.18	18.7	770	33.1	36.7	20.4	6.7	22.0	8.8	35.4	16.1
24 light exercise	429	0.18	21.8	829	35.7	36.7	20.4	12.9	25.0	12.1	41.1	16.1
24 moderate exercise	429	0.18	24.8	888	38.2	36.7	20.4	12.9	28.0	15.4	46.8	16.1
24 heavy exercise	429	0.18	27.9	969	41.7	36.7	20.4	12.9	34.0	22.1	58.2	16.1
24 very heavy exercise	429	0.18	32.5	1091	46.9	36.7	20.4	12.9	46.0	35.4	80.9	16.1

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[c]Examples of the type of regular exercise performed by horses in each category are described in Chapter 1. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

- Cont. - Table 3. Daily Nutrient Requirements of Horses (Mature Body Wt, 500 kg)[a]

Type	Co mg	Cu mg	I mg	Fe mg	Mn mg	Se mg	Zn mg	A kIU	D IU	E IU	Thiamin mg	Riboflavin mg
Adult - no work[b]												
Minimum	0.5	100.0	3.5	400.0	400.0	1.00	400.0	15.0	3300	500	30.0	20.0
Average	0.5	100.0	3.5	400.0	400.0	1.00	400.0	15.0	3300	500	30.0	20.0
Elevated	0.5	100.0	3.5	400.0	400.0	1.00	400.0	15.0	3300	500	30.0	20.0
Working[C]												
Light exercise	0.5	100.0	3.5	400.0	400.0	1.00	400.0	22.5	3300	800	30.0	20.0
Moderate exercise	0.6	112.5	4.0	450.0	450.0	1.13	450.0	22.5	3300	900	56.5	22.5
Heavy exercise	0.6	125.0	4.4	500.0	500.0	1.25	500.0	22.5	3300	1000	62.5	25.0
Very heavy exercise	0.6	125.0	4.4	500.0	500.0	1.25	500.0	22.5	3300	1000	62.5	25.0
Stallions												
Nonbreeding	0.5	100.0	3.5	400.0	400.0	1.00	400.0	15.0	3300	500	30.0	20.0
Breeding	0.5	100.0	3.5	400.0	400.0	1.00	400.0	22.5	3300	800	30.0	20.0
Pregnant mares												
Early (< 5 months)	0.5	100.0	3.5	400.0	400.0	1.00	400.0	30.0	3300	800	30.0	20.0
5 months	0.5	100.0	3.5	400.0	400.0	1.00	400.0	30.0	3300	800	30.0	20.0
6 months	0.5	100.0	3.5	400.0	400.0	1.00	400.0	30.0	3300	800	30.0	20.0
7 months	0.5	100.0	3.5	400.0	400.0	1.00	400.0	30.0	3300	800	30.0	20.0
8 months	0.5	100.0	3.5	400.0	400.0	1.00	400.0	30.0	3300	800	30.0	20.0
9 months	0.5	125.0	4.0	500.0	400.0	1.00	400.0	30.0	3300	800	30.0	20.0
10 months	0.5	125.0	4.0	500.0	400.0	1.00	400.0	30.0	3300	800	30.0	20.0
11 months	0.5	125.0	4.0	500.0	400.0	1.00	400.0	30.0	3300	800	30.0	20.0
Lactating mares												
1 months	0.6	125.0	4.4	625.0	500.0	1.25	500.0	30.0	3300	1000	37.5	25.0
2 months	0.6	125.0	4.4	625.0	500.0	1.25	500.0	30.0	3300	1000	37.5	25.0
3 months	0.6	125.0	4.4	625.0	500.0	1.25	500.0	30.0	3300	1000	37.5	25.0
4 months	0.6	125.0	4.4	625.0	500.0	1.25	500.0	30.0	3300	1000	37.5	25.0
5 months	0.6	125.0	4.4	625.0	500.0	1.25	500.0	30.0	3300	1000	37.5	25.0
6 months	0.6	125.0	4.4	625.0	500.0	1.25	500.0	30.0	3300	1000	37.5	25.0
Growing animals												
4 months	0.2	42.1	1.5	210.6	168.5	0.42	168.5	7.6	3740	337	12.6	8.4
6 months	0.3	54.0	1.9	269.9	215.9	0.54	215.9	9.7	4793	432	16.2	10.8
12 months	0.4	80.3	2.8	401.5	321.2	0.80	321.2	14.5	5589	642	24.1	16.1
18 months	0.5	96.9	3.4	484.4	387.5	0.97	387.5	17.4	6161	775	29.1	19.4
18 light exercise	0.5	96.9	3.4	484.4	387.5	0.97	387.5	17.4	6161	775	29.1	19.4
18 moderate exercise	0.5	96.9	3.4	484.4	387.5	0.97	387.5	17.4	6161	775	29.1	19.4
24 months	0.5	107.3	3.8	536.5	429.2	1.07	429.2	19.3	5880	858	32.2	21.5
24 light exercise	0.5	107.3	3.8	536.5	429.2	1.07	429.2	19.3	5880	858	32.2	21.5
24 moderate exercise	0.5	107.3	3.8	536.5	429.2	1.07	429.2	19.3	5880	858	32.2	21.5
24 heavy exercise	0.5	107.3	3.8	536.5	429.2	1.07	429.2	19.3	5880	858	32.2	21.5
24 very heavy exercise	0.5	107.3	3.8	536.5	429.2	1.07	429.2	19.3	5880	858	32.2	21.5

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[c]Examples of the type of regular exercise performed by horses in each category are described in Chapter 1. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

4. Table 4. Daily Nutrient Requirements of Horses (Mature Body Wt, 600 kg)[a]

Type	Wt , kg	ADG/ Milk, kg/d	DE, Meal	CP, g	Lys, g	Ca, g	P, g	Mg , g	K, g	Na, g	Cl, g	S, g
Adult - no work[b]												
Minimum	600		18.2	648	27.9	24.0	16.8	9.0	30.0	12.0	48.0	18.0
Average	600		20.0	756	32.5	24.0	16.8	9.0	30.0	12.0	48.0	18.0
Elevated	600		21.8	864	37.2	24.0	16.8	9.0	30.0	12.0	48.0	18.0
Working[C]												
Light exercise	600		24.0	839	36.1	36.0	21.6	11.4	34.2	16.7	56.0	18.0
Moderate exercise	600		28.0	921	39.6	42.0	25.2	13.8	38.4	21.3	63.9	20.3
Heavy exercise	600		32.0	1034	44.5	48.0	34.8	18.0	46.8	30.6	79.8	22.5
Very heavy exercise	600		41.4	1205	51.8	48.0	34.8	18.0	63.6	49.2	111.6	22.5
Stallions												
Nonbreeding	600		21.8	864	37.2	24.0	16.8	9.0	30.0	12.0	48.0	18.0
Breeding	600		26.1	947	40.7	36.0	21.6	11.4	34.2	16.7	56.0	18.0
Pregnant mares												
Early (< 5 months)	600		20.0	756	32.5	24.0	16.8	9.0	30.0	12.0	48.0	18.0
5 months	604	0.16	20.5	822	35.3	24.0	16.8	9.0	30.0	12.0	48.0	18.0
6 months	610	0.22	20.9	845	36.3	24.0	16.8	9.0	30.0	12.0	48.0	18.0
7 months	618	0.29	21.5	874	37.6	33.6	24.0	9.1	30.0	12.0	48.0	18.0
8 months	628	0.38	22.2	911	39.2	33.6	24.0	9.1	30.0	12.0	48.0	18.0
9 months	641	0.49	23.1	956	41.1	43.2	31.5	9.2	31.0	13.2	49.2	18.0
10 months	658	0.63	24.2	1009	43.4	43.2	31.5	9.2	31.0	13.2	49.2	18.0
11months	679	0.78	25.7	1072	46.1	43.2	31.5	9.2	31.0	13.2	49.2	18.0
Lactating mares												
1 months	600	19.56	38.1	1842	101.7	70.9	45.9	13.4	57.4	15.3	54.6	22.5
2 months	600	19.44	38.0	1836	101.3	70.7	45.7	13.4	57.2	15.3	54.6	22.5
3 months	600	17.94	36.7	1761	96.4	67.1	43.2	13.0	55.1	15.0	54.6	22.5
4 months	600	16.26	35.3	1677	90.8	50.0	31.4	12.7	43.0	14.3	54.6	22.5
5 months	600	14.64	34.0	1596	85.5	47.4	29.6	12.3	41.7	14.0	54.6	22.5
6 months	600	13.08	32.7	1518	80.3	44.9	27.9	10.5	40.5	13.8	54.6	22.5
Growing animals												
4 months	202	1.01	15.9	803	34.5	46.9	26.1	4.3	13.1	5.1	18.8	7.6
6 months	259	0.87	18.6	811	34.9	46.4	25.8	5.0	15.6	6.0	24.1	9.7
12 months	385	0.54	22.5	1015	43.6	45.2	25.1	6.5	20.9	8.3	31.8	14.5
18 months	465	0.34	23.1	959	41.2	44.5	24.7	7.4	24.3	9.6	38.4	17.4
18 light exercise	465	0.34	26.5	1023	44.0	44.5	24.7	13.9	27.5	13.2	44.5	17.4
18 moderate exercise	465	0.34	30.0	1087	46.7	44.5	24.7	13.9	30.8	16.9	50.7	17.4
24 months	515	0.22	22.4	924	39.7	44.0	24.4	8.0	26.4	10.5	42.5	19.3
24 light exercise	515	0.22	26.1	995	42.8	44.0	24.4	15.5	30.0	14.5	49.3	19.3
24 moderate exercise	515	0.22	29.8	1066	45.8	44.0	24.4	15.5	33.6	18.5	56.1	19.3
24 heavy exercise	515	0.22	33.5	1162	50.0	44.0	24.4	15.5	40.8	26.5	69.8	19.3
24 very heavy exercise	515	0.22	39.0	1309	56.3	44.0	24.4	15.5	55.2	42.4	97.1	19.3

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[b]Examples of the type of regular exercise performed by horses in each category are described in Chapter 1. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

- Cont. - Table 4. Daily Nutrient Requirements of Horses (Mature Body Wt, 600 kg)[a]

Type	Co, mg	Cu, mg	I, mg	Fe, mg	Mn, mg	Se, mg	Zn, mg	A, kIU	D, IU	E, IU	Thiamin, mg	Riboflavin, mg
Adult - no work[b]												
Minimum	0.6	120.0	4.2	480.0	480.0	1.20	480.0	18.0	3960	600	36.0	24.0
Average	0.6	120.0	4.2	480.0	480.0	1.20	480.0	18.0	3960	600	36.0	24.0
Elevated	0.6	120.0	4.2	480.0	480.0	1.20	480.0	18.0	3960	600	36.0	24.0
Working[C]												
Light exercise	0.6	120.0	4.2	480.0	480.0	1.20	480.0	27.0	3960	960	36.0	24.0
Moderate exercise	0.7	135.0	4.7	540.0	540.0	1.35	540.0	27.0	3960	1080	67.8	27.0
Heavy exercise	0.8	150.0	5.3	600.0	600.0	1.50	600.0	27.0	3960	1200	75.0	30.0
Very heavy exercise	0.8	150.0	5.3	600.0	600.0	1.50	600.0	27.0	3960	1200	75.0	30.0
Stallions												
Nonbreeding	0.6	120.0	4.2	480.0	480.0	1.20	480.0	18.0	3960	600	36.0	24.0
Breeding	0.6	120.0	4.2	480.0	480.0	1.20	480.0	27.0	3960	960	36.0	24.0
Pregnant mares												
Early (< 5 months)	0.6	120.0	4.2	480.0	480.0	1.20	480.0	36.0	3960	960	36.0	24.0
5 months	0.6	120.0	4.2	480.0	480.0	1.20	480.0	36.0	3960	960	36.0	24.0
6 months	0.6	120.0	4.2	480.0	480.0	1.20	480.0	36.0	3960	960	36.0	24.0
7 months	0.6	120.0	4.2	480.0	480.0	1.20	480.0	36.0	3960	960	36.0	24.0
8 months	0.6	120.0	4.2	480.0	480.0	1.20	480.0	36.0	3960	960	36.0	24.0
9 months	0.6	150.0	4.8	600.0	480.0	1.20	480.0	36.0	3960	960	36.0	24.0
10 months	0.6	150.0	4.8	600.0	480.0	1.20	480.0	36.0	3960	960	36.0	24.0
11 months	0.6	150.0	4.8	600.0	480.0	1.20	480.0	36.0	3960	960	36.0	24.0
Lactating mares												
1 months	0.8	150.0	5.3	750.0	600.0	1.50	600.0	36.0	3960	1200	45.0	30.0
2 months	0.8	150.0	5.3	750.0	600.0	1.50	600.0	36.0	3960	1200	45.0	30.0
3 months	0.8	150.0	5.3	750.0	600.0	1.50	600.0	36.0	3960	1200	45.0	30.0
4 months	0.8	150.0	5.3	750.0	600.0	1.50	600.0	36.0	3960	1200	45.0	30.0
5 months	0.8	150.0	5.3	750.0	600.0	1.50	600.0	36.0	3960	1200	45.0	30.0
6 months	0.8	150.0	5.3	750.0	600.0	1.50	600.0	36.0	3960	1200	45.0	30.0
Growing animals												
4 months	0.3	50.5	1.8	252.7	202.1	0.51	202.1	9.1	4488	404	15.2	10.1
6 months	0.3	64.8	2.3	323.8	259.1	0.65	259.1	11.7	5751	518	19.4	13.0
12 months	0.5	96.4	3.4	481.8	385.5	0.96	385.5	17.3	6707	771	28.9	19.3
18 months	0.6	116.2	4.1	581.2	465.0	1.16	465.0	20.9	7393	930	34.9	23.2
18 light exercise	0.6	116.2	4.1	581.2	465.0	1.16	465.0	20.9	7393	930	34.9	23.2
18 moderate exercise	0.6	116.2	4.1	581.2	465.0	1.16	465.0	20.9	7393	930	34.9	23.2
24 months	0.6	128.8	4.5	643.8	515.0	1.29	515.0	23.2	7056	1030	38.6	25.8
24 light exercise	0.6	128.8	4.5	643.8	515.0	1.29	515.0	23.2	7056	1030	38.6	25.8
24 moderate exercise	0.6	128.8	4.5	643.8	515.0	1.29	515.0	23.2	7056	1030	38.6	25.8
24 heavy exercise	0.6	128.8	4.5	643.8	515.0	1.29	515.0	23.2	7056	1030	38.6	25.8
24 very heavy exercise	0.6	128.8	4.5	643.8	515.0	1.29	515.0	23.2	7056	1030	38.6	25.8

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[b]Examples of the type of regular exercise performed by horses in each category are described in Chapter 1. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

5. Table 5. Daily Nutrient Requirements of Horses (Mature Body Wt, 900 kg)[a]

Type	Wt, kg	ADG/ Milk, kg/d	DE, Mcal	CP, g	Lys, g	Ca, g	P, g	Mg, g	K, g	Na, g	Cl, g	S, g
Adult - no work[b]												
Minimum	900		27.3	972	41.8	36.0	25.2	13.5	45.0	18.0	72.0	27.0
Average	900		30.0	1134	48.8	36.0	25.2	13.5	45.0	18.0	72.0	27.0
Elevated	900		32.7	1296	55.7	36.0	25.2	13.5	45.0	18.0	72.0	27.0
Working[C]												
Light exercise	900		36.0	1259	54.1	54.0	32.4	17.1	51.3	25.0	83.9	27.0
Moderate exercise	900		42.0	1382	59.4	63.0	37.8	20.7	57.6	32.0	95.9	30.4
Heavy exercise	900		48.0	1551	66.7	72.0	52.2	27.0	70.2	45.9	119.7	33.8
Very heavy exercise	900		62.1	1808	77.7	72.0	52.2	27.0	95.4	73.8	167.4	33.8
Stallions												
Nonbreeding	900		32.7	1296	55.7	36.0	25.2	13.5	45.0	18.0	72.0	27.0
Breeding	900		39.2	1421	6Ll	54.0	32.4	17.1	51.3	25.0	83.9	27.0
Pregnant mares												
Early (< 5 months)	900		30.0	1134	48.8	36.0	25.2	13.5	45.0	18.0	72.0	27.0
5 months	906	0.24	30.8	1233	53.0	36.0	25.2	13.5	45.0	18.0	72.0	27.0
6 months	915	0.33	31.4	1267	54.5	36.0	25.2	13.5	45.0	18.0	72.0	27.0
7 months	927	0.44	32.2	1311	56.4	50.4	36.0	13.7	45.0	18.0	72.0	27.0
8 months	942	0.57	33.3	1367	58.8	50.4	36.0	13.7	45.0	18.0	72.0	27.0
9 months	962	0.74	34.6	1434	61.7	64.8	47.3	13.8	46.5	19.8	73.8	27.0
10 months	987	0.94	36.4	1514	65.1	64.8	47.3	13.8	46.5	19.8	73.8	27.0
11 months	1019	1.17	38.5	1607	69.1	64.8	47.3	13.8	46.5	19.8	73.8	27.0
Lactating mares												
1 months	900	29.34	54.4	2763	152.6	106.4	68.9	20.1	86.1	23.0	81.9	33.8
2 months	900	29.16	54.3	2754	152.0	106.0	68.6	20.1	85.8	23.0	81.9	33.8
3 months	900	26.91	52.4	2642	144.5	100.6	64.9	19.6	82.7	22.6	81.9	33.8
4 months	900	24.39	50.3	2516	136.2	75.0	47.1	19.0	64.5	21.4	81.9	33.8
5 months	900	21.96	48.3	2394	128.2	71.1	44.4	18.4	62.6	21.1	81.9	33.8
6 months	900	19.62	46.3	2277	120.5	67.4	41.8	15.7	60.7	20.7	81.9	33.8
Growing animals												
4 months	303	1.52	23.9	1204	51.8	70.3	39.1	6.4	19.7	7.6	28.2	11.4
6 months	389	1.30	28.0	1217	52.3	69.5	38.7	7.5	23.3	9.1	36.1	14.6
12 months	578	0.82	33.8	1522	65.5	67.8	37.7	9.7	31.4	12.4	47.7	21.7
18 months	697	0.51	34.6	1438	61.8	66.7	37.1	11.1	36.4	14.5	57.5	26.2
18 light exercise	697	0.51	39.8	1535	66.0	66.7	37.1	20.9	41.3	19.9	66.8	26.2
18 moderate exercise	697	0.51	45.0	1631	70.1	66.7	37.1	20.9	46.2	25.3	76.0	26.2
24 months	773	0.32	33.7	1386	59.6	66.0	36.7	12.0	39.6	15.8	63.7	29.0
24 light exercise	773	0.32	39.2	1492	64.2	66.0	36.7	23.2	45.0	21.8	74.0	29.0
24 moderate exercise	773	0.32	44.7	1599	68.7	66.0	36.7	23.2	50.4	27.7	84.2	29.0
24 heavy exercise	773	0.32	50.2	1744	75.0	66.0	36.7	23.2	61.2	39.7	104.7	29.0
24 very heavy exercise	773	0.32	58.4	1964	84.5	66.0	36.7	23.2	82.9	63.7	145.6	29.0

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[c]Examples of the type of regular exercise performed by horses in each category are described in Chapter 1. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

- Cont. - Table 5. Daily Nutrient Requirements of Horses (Mature Body Wt, 900 kg)[a]

Type	Co, mg	Cu, mg	I, mg	Fe, mg	Mn, mg	Se, mg	Zn, mg	A, kIU	D, IU	E, IU	Thiamin, mg	Riboflavin, mg
Adult - no work[b]												
Minimum	0.9	180.0	6.3	720.0	720.0	1.80	720.0	27.0	5940	900	54.0	36.0
Average	0.9	180.0	6.3	720.0	720.0	1.80	720.0	27.0	5940	900	54.0	36.0
Elevated	0.9	180.0	6.3	720.0	720.0	1.80	720.0	27.0	5940	900	54.0	36.0
Working[C]												
Light exercise	0.9	180.0	6.3	720.0	720.0	1.80	720.0	40.5	5940	1440	54.0	36.0
Moderate exercise	1.0	202.5	7.1	810.0	810.0	2.03	810.0	40.5	5940	1620	101.7	40.5
Heavy exercise	1.1	225.0	7.9	900.0	900.0	2.25	900.0	40.5	5940	1800	112.5	45.0
Very heavy exercise	1.1	225.0	7.9	900.0	900.0	2.25	900.0	40.5	5940	1800	112.5	45.0
Stallions												
Nonbreeding	0.9	180.0	6.3	720.0	720.0	1.80	720.0	27.0	5940	900	54.0	36.0
Breeding	0.9	180.0	6.3	720.0	720.0	1.80	720.0	40.5	5940	1440	54.0	36.0
Pregnant Mares												
Early (< 5 months)	0.9	180.0	6.3	720.0	720.0	1.80	720.0	54.0	5940	1440	54.0	36.0
5 months	0.9	180.0	6.3	720.0	720.0	1.80	720.0	54.0	5940	1440	54.0	36.0
6 months	0.9	180.0	6.3	720.0	720.0	1.80	720.0	54.0	5940	1440	54.0	36.0
7 months	0.9	180.0	6.3	720.0	720.0	1.80	720.0	54.0	5940	1440	54.0	36.0
8 months	0.9	180.0	6.3	720.0	720.0	1.80	720.0	54.0	5940	1440	54.0	36.0
9 months	0.9	225.0	7.2	900.0	720.0	1.80	720.0	54.0	5940	1440	54.0	36.0
10 months	0.9	225.0	7.2	900.0	720.0	1.80	720.0	54.0	5940	1440	54.0	36.0
11 months	0.9	225.0	7.2	900.0	720.0	1.80	720.0	54.0	5940	1440	54.0	36.0
Lactating mares												
1 months	1.1	225.0	7.9	1125.0	900.0	2.25	900.0	54.0	5940	1800	67.5	45.0
2 months	1.1	225.0	7.9	1125.0	900.0	2.25	900.0	54.0	5940	1800	67.5	45.0
3 months	1.1	225.0	7.9	1125.0	900.0	2.25	900.0	54.0	5940	1800	67.5	45.0
4 months	1.1	225.0	7.9	1125.0	900.0	2.25	900.0	54.0	5940	1800	67.5	45.0
5 months	1.1	225.0	7.9	1125.0	900.0	2.25	900.0	54.0	5940	1800	67.5	45.0
6 months	1.1	225.0	7.9	1125.0	900.0	2.25	900.0	54.0	5940	1800	67.5	45.0
Growing animals												
4 months	0.4	75.8	2.7	379.0	303.2	0.76	303.2	13.6	6731	606	22.7	15.2
6 months	0.5	97.1	3.4	485.7	388.6	0.97	388.6	17.5	8627	777	29.1	19.4
12 months	0.7	144.5	5.1	722.7	578.2	1.45	578.2	26.0	10061	1156	43.4	28.9
18 months	0.9	174.4	6.1	871.9	697.5	1.74	697.5	31.4	11090	1395	52.3	34.9
18 light exercise	0.9	174.4	6.1	871.9	697.5	1.74	697.5	31.4	11090	1395	52.3	34.9
18 moderate exercise	0.9	174.4	6.1	871.9	697.5	1.74	697.5	31.4	11090	1395	52.3	34.9
24 months	1.0	193.1	6.8	965.7	772.6	1.93	772.6	34.8	10584	1545	57.9	38.6
24 light exercise	1.0	193.1	6.8	965.7	772.6	1.93	772.6	34.8	10584	1545	57.9	38.6
24 moderate exercise	1.0	193.1	6.8	965.7	772.6	1.93	772.6	34.8	10584	1545	57.9	38.6
24 heavy exercise	1.0	193.1	6.8	965.7	772.6	1.93	772.6	34.8	10584	1545	57.9	38.6
24 very heavy exercise	1.0	193.1	6.8	965.7	772.6	1.93	772.6	34.8	10584	1545	57.9	38.6

[a]The daily requirements listed in this table for S, Co, I, Fe, Mn, Se, and Zn are calculated using assumed feed intakes of 2.5% of BW for heavy and very heavy exercise, lactating mares, and growing horses; 2.25% of BW for moderate exercise; and 2% of BW for all other classes. Daily requirements for Cu are also calculated from assumed feed intakes for adult horses (no work) and exercising horses.

[b]Minimum maintenance applies to adult horses with a sedentary lifestyle, due either to confinement or to a docile temperament. Average maintenance applies to adult horses with alert temperaments and moderate voluntary activity. Elevated maintenance applies to adult horses with nervous temperaments or high levels of voluntary activity.

[c]Examples of the type of regular exercise performed by horses in each category are described in Chapter 1. These categories are based on average weekly exercise. Four categories are given but users should recognize that the nutrient requirements are more accurately described by a continuous function than by discrete groups.

6. Table 6. Nutrient Concentrations in Total Diets for Horses and Ponies (100% DM or 90% DM Basis)[a,b] [NRC, 1989]

		Diet Proportions								
	DE, Mcal/kg	Concent-rate, %	Hay, %	CP, %	Lys, %	Ca, %	P, %	Mg, %	K, %	Vitamin A, IU/kg
DM or 100% DM Basis										
Mature horses										
Maintenance	2.00	0	100	8.0	0.28	0.24	0.17	0.09	0.30	1830
Stallions	2.40	30	70	9.6	0.34	0.29	0.21	0.11	0.36	2640
Pregnant mares										
9 months	2.25	20	80	10.0	0.35	0.43	0.32	0.10	0.35	3710
10 months	2.25	20	80	10.0	0.35	0.43	0.32	0.10	0.36	3650
11 months	2.40	30	70	10.6	0.37	0.45	0.34	0.11	0.38	3650
Lactating mares										
Foaling to 3 months	2.60	50	50	13.2	0.46	0.52	0.34	0.10	0.42	2750
3 months to weaning	2.45	35	65	11.0	0.37	0.36	0.22	0.09	0.33	3020
Working horses										
Light work	2.45	35	65	9.8	0.35	0.30	0.22	0.11	0.37	2690
Moderate work	2.65	50	50	10.4	0.37	0.31	0.23	0.12	0.39	2420
Intensework	2.85	65	35	11.4	0.40	0.35	0.25	0.13	0.43	1950
Growing horses										
Weanling, 4 months	2.90	70	30	14.5	0.60	0.68	0.38	0.08	0.30	1580
Weanling, 6 months										
Moderate growth	2.90	70	30	14.5	0.61	0.56	0.31	0.08	0.30	1870
Rapid growth	2.90	70	30	14.5	0.61	0.61	0.34	0.08	0.30	1630
Yearling, 12 months										
Moderate growth	2.80	60	40	12.6	0.53	0.43	0.24	0.08	0.30	2160
Rapid growth	2.80	60	40	12.6	0.53	0.45	0.25	0.08	0.30	1920
Long yearling, 18 months										
Not in training	2.50	45	55	11.3	0.48	0.34	0.19	0.08	0.30	2270
In training	2.65	50	50	12.0	0.50	0.36	0.20	0.09	0.30	1800
Two year old, 24 months										
Not in training	2.45	35	65	10.4	0.42	0.31	0.17	0.09	0.30	2640
In training	2.65	50	50	11.3	0.45	0.34	0.20	0.10	0.32	2040
90% DM Basis										
Mature horses										
Maintenance	1.80	0	100	7.2	0.25	0.21	0.15	0.08	0.27	1650
Stallions	2.15	30	70	8.6	0.30	0.26	0.19	0.10	0.33	2370
Pregnant mares										
9 months	2.00	20	80	8.9	0.31	0.39	0.29	0.10	0.32	3330
10 months	2.00	20	80	9.0	0.32	0.39	0.30	0.10	0.33	3280
11 months	2.15	30	70	9.5	0.33	0.41	0.31	0.10	0.35	3280
Lactating mares										
Foaling to 3 months	2.35	50	50	12.0	0.41	0.47	0.30	0.09	0.38	2480
3 months to weaning	2.20	35	65	10.0	0.34	0.33	0.20	0.08	0.30	2720
Working horses										
Light work	2.20	35	65	8.8	0.32	0.27	0.19	0.10	0.34	2420
Moderate work	2.40	50	50	9.4	0.35	0.28	0.22	0.11	0.36	2140
Intense work	2.55	65	35	10.3	0.36	0.31	0.23	0.12	0.39	1760
Growing horses										
Weanling, 4 months	2.60	70	30	13.1	0.54	0.62	0.34	0.07	0.27	1420
Weanling, 6 months										
Moderate growth	2.60	70	30	13.0	0.55	0.50	0.28	0.07	0.27	1680
Rapid growth	2.60	70	30	13.1	0.55	0.55	0.30	0.07	0.27	1470
Yearling, 12 months										
Moderate growth	2.50	60	40	11.3	0.48	0.39	0.21	0.07	0.27	1950
Rapid growth	2.50	60	40	11.3	0.48	0.40	0.22	0.07	0.27	1730
Long yearling, 18 months										
Not in training	2.30	45	55	10.1	0.43	0.31	0.17	0.07	0.27	2050
In training	2.40	50	50	10.8	0.45	0.32	0.18	0.08	0.27	1620
Two year old, 24 months										
Not in training	2.20	35	65	9.4	0.38	0.28	0.15	0.08	0.27	2380
In training	2.40	50	50	10.1	0.41	0.31	0.17	0.09	0.29	1840

[a]DE values assume a concentrate feed containing 3.3 Mcal!kg and hay containing 2.00 Mcal/kg of dry matter.
[b]Light work: Examples are horses used in Western and English pleasure, bridle path work, equitation, etc.; Moderate work: Examples are horses used in ranch work, roping, cutting, barrel racing, jumping, etc.; Intense work: Examples are horses in race training, polo, etc.

7. Table 7. Other Minerals and Vitamins for Horses and Ponies (DM Basis)[a] [NRC, 1989]

	Adequate Concentrations in Total Diets				
	Maintenance	Pregnant & Lactaing Mares	Growing Horses	Working Horses	Maximum Tolerance
Minerals					
Na, %	0.10	0.10	0.10	0.30	3[b]
S, %	0.15	0.15	0.15	0.15	1.25
Fe, mg/kg	40	50	50	40	1,000
Mn, mg/kg	40	40	40	40	1,000
Cu, mg/kg	10	10	10	10	800
Zn, mg/kg	40	40	40	40	500
Se, mg/kg	0.1	0.1	0.1	0.1	2.0
I, mg/kg	0.1 - 0.6	0.1 - 0.6	0.1 - 0.6	0.1 - 0.6	5.0
Co, mg/kg	0.1	0.1	0.1	0.1	10
Vitamins					
Vitamin A, IU/kg	2,000	3,000	2,000	2,000	16,000
Vitamin D, IU/kg[c]	300	600	800	300	2,200
Vitamin E, IU/kg	50	80	80	80	1,000
Vitamin K, mg/kg	-	-	-	-	-
Thiamin, mg/kg	3	3	3	5	3,000
Riboflavin, mg/kg	2	2	2	2	-
Niacin, mg/kg	-	-	-	-	-
Pantothenic acid, mg/kg	-	-	-	-	-
pyridoxine, mg/kg	-	-	-	-	-
Biotin, mg/kg	-	-	-	-	-
Folacin, mg/kg	-	-	-	-	-
Vitamin B_{12}, µg/kg	-	-	-	-	-
Ascorbic acid, mg/kg	-	-	-	-	-
Choline, mg/kg	-	-	-	-	-

[a]Dash (" -") indicates that data are insufficient to determine a requirement or maximum tolerable concentration.
[b]As sodium chloride.
[c]Recommendations for horses not exposed to sunlight or to artificial light with an emission spectrum of 280-315 nm.

8. Table 8. Expected Feed Consumption by Horses (% Body Wt; Air-Dry Feed or About 90% DM) [NRC, 1989]

	Forage	Concentrate	Total
Mature horses			
Maintenance	1.5 - 2.0	0 - 0.5	1.5 - 2.0
Mares, late gestation	1.0 - 1.5	0.5 - 1.0	1.5 - 2.0
Mares, early lactation	1.0 - 2.0	1.0 - 2.0	2.0 - 3.0
Mares, late lactation	1.0 - 2.0	0.5 - 1.5	2.0 - 2.5
Working horses			
Light work	1.0 - 2.0	0.5 - 1.0	1.5 - 2.5
Moderate work	1.0 - 2.0	0.75 - 1.5	1.75 - 2.5
Intense work	0.75 - 1.5	1.0 - 2.0	2.0 - 3.0
Young horses			
Nursing foal, 3 months	0	1.0 - 2.0	2.5 - 3.5
Weanling foal, 6 months	0.5 - 1.0	1.5 - 3.0	2.0 - 3.5
Yearling foal, 12 months	1.0 - 1.5	1.0 - 2.0	2.0 - 3.0
Long yearling, 18 months	1.0 - 1.5	1.0 - 1.5	2.0 - 2.5
Two year old (24 months)	1.0 - 1.5	1.0 - 1.5	1.75 - 2.5

BEEF CATTLE NUTRITION AND FEEDING

- *References: Bowman & Sowell (1998) & Galyean & Duff (1998) in Kellems & Church (19980), NRC (2000. Update), and Jurgens (2002).*

BEEF BREEDING HERD

1. **General**

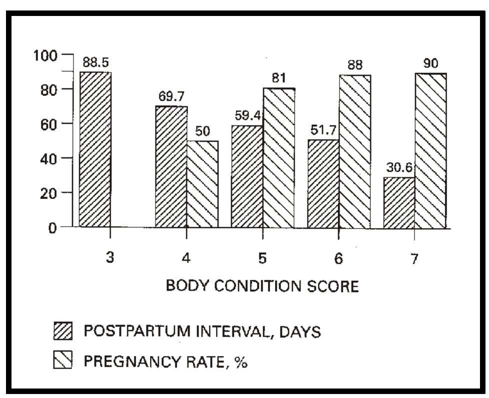
A. The one most important consideration? - A high percentage of calf crop, i.e., a live calf from each cow each year!
B. Cow-calf operation relies heavily on grazed forages:

1) Much of the requirements for protein & energy can be met with low- to medium-quality forages. Can use native rangelands & introduced pastures.
2) Feed hay when weather conditions limit grazing or forage availability.
3) May need supplemental feeding during late gestation & lactation with limited forage quantity or quality.

C. Biological cycle? - Can be divided into four period:

1) First trimester - Needs nutrients for maintenance & lactation (if the cow has a calf) - Body weight & breed effects on the maintenance needs, and the rate of milk production & fat content affects the nutrient needs in those lactating.
2) Second trimester - Calf is weaned & lactation needs end, thus the time of lowest nutrient needs for the beef cow.
3) Third trimester - Nutrient needs are increasing rapidly because of the fetal growth, thus need to watch body condition carefully.
4) Postpartum interval - Critical period for the cow because lactation needs are high & also the cow's reproductive system is recovering from parturition. Feed intake is 35 to 50% higher vs. non-lactating.

2. **Cow Herd**



A. Cows gaining just before and during the breeding season will show a shorter period between calving & the first estrus, and tend to have high conception rates. [Effect body conditioning score at calving (Bowman & Sowell, 1998)].
B. The most important period in terms of nutrition? - 30 days before calving until 70 days after calving (. . . until after rebreeding).
C. Usually, either a spring (March through April) or fall (September through October) calving:

1) Can avoid severely cold weather & extreme heat of summer.
2) In general, producers favor the spring calving because of minimum housing needs and use of less harvested feed.

D. Energy and nutrient needs vary depending on the frame size and condition of the cow, stage of production and environmental conditions, but generally cows require the followings - See the table (Jurgens, 2002).

Ration	Pregnant Cows	Lactating Cows
Protein, %	7-9	9.5-12.5
Protein, lb/d	1.1-1.7	1.8-2.9
TDN, %	49-64	55-68
TDN, lb/d	8-13	10.5-16
ME, Mcal/lb	0.8-1.1	0.9-1.3
ME, Mcal/d	14-21	18-28
Ca & P, %	0.2-0.3	0.25-0.5
Ca & P, g/d	15-25	25-40

1) Energy:

   a) Considered first in diet formulation - Energy intake can determine the ability of the cow to utilize other nutrients to a large extent.
   b) Affected by mature body size (higher maintenance needs for larger cows), physical activity (30 to 50% more free-grazing vs. confined cows), and environmental temperatures.

2) Protein:

   a) Microbial protein supplies about 50% of the protein & amino acid needs.
   b) Protein deficiency - The most common deficiency in cows grazing mature forages or low-quality hays, or straw.
   c) With < 7% CP, not enough ruminal N/ammonia for the microbes, thus resulting in reduced digestion of forages & forage intake.

3) Minerals:

   a) Pregnancy and high milk production can increase the needs for Ca & P - If not consuming adequate amounts, various deficiency disorders can develop, e.g., rickets in young animals & osteomalacia in adults, milk fever, etc.
   b) Co - Needed by microbes to synthesize vitamin B_{12}.
   c) I - Deficiencies in the Northwest & Great Lakes regions because of low I in the soil. The use of iodized salt would be the most convenient way to provide I.
   d) Others? - Forages are relatively high in many minerals (e.g., Cu, Fe, Mg, Mn, etc.), but grains are usually very low in many minerals.

4) Vitamins:

   a) Rumen microbes can synthesize vitamin K and B vitamins - Meeting most of the needs.
   b) Sun-cured forages contain large amounts of vitamin D, vitamin E, and β-carotene.
   c) Vitamin A - Can be stored enough for 2 to 4 mo., but would be depleted quickly without dietary Vitamin A.

5) Water:

   a) Nonlactating cows consume about 3 parts water for 1 part dry matter intake.
   b) Lactating cows need additional 0.1 gal/d for each 1 lb of milk produced.
   c) Affected by environmental temperatures - 8, 8-9, 10, 11-12, 13-14, and 15-19 gal/d expected water intake by a 1,200-lb cow as the temperature increases to < 40, 50, 60, 70, 80, and 90°F, respectively. (& + 0.1 gal/1 lb milk produced.)

E. Summer

1) Spring calving cows - Should calve early enough so that calves will be 1 to 2 mo. old by turnout to pasture.
2) Milk production - Average about 10 to 25 lb/day over a 175- to 200-day lactation, but the maximum during the first 2 mo. after calving & then declines.
3) Pasture will supply most of the nutrients needed.
4) Hay feeding on lush legume pasture may help control bloat.
5) Need minerals (free-choice) - e.g., A mixture of 1 part bone meal or 1 part dical with 1 part plain salt. Can include both, but either of these Ca and P sources mixed with salt are satisfactory. Salt may also be fed free-choice, block, or granular salt.
6) If pasture is short or inadequate, supplemental energy will be needed - Use silage, hay or both, e.g.:

   a) 15 lb of corn silage/head/d will substitute for about ⅓ of the pasture acreage normally needed; 30 lb/day will make up for ⅔ of the usual pasture acreage.
   b) 5 to 10 lb of a good quality hay/head/d will give the same results.

F. Winter

1) When grazing forage is not available, can feed hay, crop residues, or silage:

   a) Average quality forages (7 to 8 + % CP) are adequate as the main or sole feed.
   b) Poor quality forages may need supplementation with energy or protein sources.
   c) Provide daily roughage in one or two feedings & supplement at a single feeding - At least half of the ration should be fed in the evening during cold weather.

2) Spring calving cows? - No more than about 15% of fall weight should be lost through calving & until grass is ample in the spring. Cows normally lose about 100 to 130 lb at calving.
3) Dry cows wintered on dry grass pastures? - Should be fed 1½ to 2 lb of 40 to 44% CP protein supplement, and if additional energy is needed, provide 1 to 2 lb of grain along with a protein supplement.
4) Fall calving cows on dry grass pasture? - Protein supplement and energy higher than those mentioned may be needed.

5) Use legume hay as a protein supplement? - About 3 lb = 1 lb of 40 to 44% CP supplement.
6) Dry cows on harvested feeds?

    a) Total dry feed allowance: 1.50, 1.75, and 2.0-2.5 lb/100 lb Body Weight for cows in "fleshy, average, and thin conditions," respectively.
    b) Supplement? - Depend on the forage used, but 1½ to 2 lb of 40 to 44% CP supplement will usually be adequate even with low-quality forages.

Body Condition Scoring in Beef Cattle

BCS	Description
1 Emaciated	Extremely emaciated, bone structure of shoulder, ribs, backbone, hips and pelvic bones is easily visible and sharp to the touch, tailhead and ribs are very prominent, no detectable fat deposits, little muscling
2 Poor	Somewhat emaciated, tailhead and ribs less prominent, backbone still sharp to the touch, some evidence of muscling in the hindquarters
3 Thin	Ribs are individually identifiable but not quite as sharp to the touch, some palpable fat along spine and over tailhead, some tissue cover over rear portion of ribs
4 Borderline	Individual ribs are no longer visually obvious, backbone can be identified individually by touch but feels rounded rather than sharp, some fat covers ribs and hip bones
5 Moderate	Good overall appearance, fat cover over ribs feels spongy, and areas on either side of tailhead have some fat cover
6 High moderate	Firm pressure now needs to be applied to feel backbone, fat deposits in brisket, over ribs and around tailhead, back appears rounded
7 Good	Fleshy appearance, thick and spongy fat cover over ribs and around tailhead, some fat around vulva and in pelvis
8 Fat	Very fleshy and overconditioned, backbone difficult to palpate, large fat deposits over ribs, around tailhead, and below vulva
9 Extremely fat	Smooth, blocklike appearance, tailhead and hips buried in fatty tissue, bone structure no longer visible and barely palpable

Source: Richards et al., 1986. J. Anim. Sci. 62:300. (Cited by Bowman & Sowell, 1998)

7) Adjustments to typical daily intakes? - Should be adjusted based on:

    a) The body condition scores of cows (Table).
    b) Environmental temperature:

        (1) The lower critical temperature (LCT) for beef cows with an average dry winter hair-coat thickness is about 20°F.
        (2) See the table on "Additional energy needs by 1,000-lb pregnant cow (Bowman & Sowell, 1998)."

°F below LCT	Additional Mcal needed/d
0	0
5	0.9
10	2.0
15	3.2
20	3.6
25	4.5
30	5.4
35	6.4
40	7.3

8) The use of urea?

    a) Can be used as the only source of supplemental protein source when cows are wintered on corn silage.
    b) To supplement low-protein roughage? - Better to use with a 20 to 25% CP supplement that contains some grain & molasses as readily digestible carbohydrate to aid in the utilization of urea.

MANAGEMENT OF CALVES

1. General

- Just like some other species, need proper nutrition for calves before the animal is born - Data from the Western US [Cited by Bowman & Sowell (1998)]:

    1) Low dietary protein intake in the dam? - Caused weak calf syndrome & resulted in the deaths of young calves.
    2) Cow herds that consumed an avg. of 2 lb CP/d and herds consuming hay with at least 10% CP during the prepartum had no problem, whereas those fed the hay with less than 10% CP had serious weak calf problems.

2. Creep feeding

A. Creep feeding:

1) Definition? Some means of providing additional nutrients to calves, which can be hay, grain, or mixed rations - e.g., 30% cracked corn, 30% cracked oats, 30% cracked barley, 5% molasses, and 5% soybean meal.
2) Generally, milk production is enough during the first 100 days or so of postpartum to support growth of the calf.
3) Milk production starts to decline after that, and the calf obviously needs additional nutrients. Thus, may need creep feed or would be a beneficial effect of creep feed!?

B. Advantages?

1) Heavier wt calves at weaning (. . . can add 25 to 50 lb?).
2) Improves the condition & uniformity of calves at weaning.
3) Less wt loss by cows.

C. Disadvantages?

1) Requires extra labor, equipment, feed, and management.
2) Higher feed costs - Perhaps, needs 7 to 10 lb feed/lb of gain.
3) Replacement heifer? May become too fat, which may reduce milk production later because of the impairment of milk-secreting tissue development, and also may increase calving difficulty!
4) Over-fattened calves may gain slowly during the first 2 to 3 mo. once moved into the feedlot, and also may finish at lighter weight.
5) Mask the milking ability of the cow & affect her maternal ranking based on the weaning weight.

D. Profitable to use creep feeding? Might be profitable when pasture is short or quality is poor, and obviously when calf prices are high relative to feed prices!

E. Implanting?

1) Implanting both at 60 to 90 days (150 to 200 lb) will boost weaning weight by 20 to 40 lb in addition to that obtained by creep feeding.
2) Breeding heifers? Not recommended, even though implanted at recommended doses at 3 mo. of age may have no effect on the breeding performance!

3. **Weaning**

A. Commonly weaned at 6 to 9 mo. of age, which fits well with vaccinations and performance testing for replacement heifers, or for feeder calf sales.
B. Advantageous to wean earlier?

1) Calves from first-calf heifers? - Reduces stress and increases the possibility of earlier heat and conception.
2) Fall-dropped calves? - Reduces expensive harvested feed for the cow.
3) Bull calves? - May begin riding other animals at 7 to 8 mo. of age, so . . .

C. Generally, "early weaning" is a technique designed to improve rebreeding of the first and second calf heifers because suckling delays the onset of estrus. But, should not be weaned before 5 mo of age unless there is an emergency!
D. At weaning time:

1) Keep calves out of sight and sound of calves if possible - The cow would dry off more effectively!
2) Calves suffer less stress and shrink if they are eating a creep feed when weaned.
3) Clean water & quality hay - Should be made available, and eventually should be fed from bunks to reduce adaptation time when they reach the feedlot.

E. Preconditioning calves before they leave the production site

1) Preconditioned calves? - Better health & more efficient, thus beneficial for the feedlot operator. Often, $3 to 5/cwt premium to the producer!
2) May vary somewhat in different areas of the country, but generally:

a) Mandatory regulations:

(1) Wean & start on feed/grain no less than 30 d before the sale or shipment date.
(2) Adaptation/adjustment to feed bunks and water troughs & start on a similar ration they will get at the feedlot.
(3) Castrate, dehorn, and treat for grubs no less than 3 wk before the sale.
(4) Vaccinate for infectious bovine rhinotracheitis (IBR), para-influenza (PI_3), Pasteurella spp. and Clostridial spp. no less than 3 wk. before the sale.

b) Optional regulations?

(1) Treat for worms, and vaccinate with leptospirosis before the sale.
(2) Vaccinate with bovine virus diarrhea (BVD), and Haemophilus somnus (bovine respiratory disease) no less than 3 wk prior to the sale date.

4. **"Stocker Cattle"**

A. Refers to weaned calves (steers or heifers) that are forage-fed for a period of time before being sold to enter the feedlot - Generally thin & carrying little finish.
B. May be bought in the fal?

1) To be wintered on high-roughage diets in drylot & sold in the spring for further pasture grazing, or enter a feedlot finishing program.
2) To be grazed on small winter grain forage (usually wheat or winter oats) or grass (fescue) pasture - Then, may enter the feedlot as 600- to 800-lb feeder cattle.
3) To be grazed stock fields (corn/sorghum), and then moved to a drylot for the winter, fed corn or sorghum silage with some supplement, and then finished on a high-energy ration in the drylot for slaughter in the summer or fall.

5. **"Backgrounded Cattle"**

A. Weaned calves placed in a drylot or pasture (or both) with more emphasis on growing than described for the stocker calf.
B. Fed a grain in addition to a roughage to reach around an 800-lb weight and then moved into a high-energy finishing ration.
C. Should be in good health and bunk broke & ready to go on a full feed of grain.

HEIFER DEVELOPMENT AND MANAGING BULLS

1. **Heifer Development**

A. Creep Feeding? - Generally not recommended to creep feed replacement heifers.

1) Creed feeding - May enhance growth but masks the effect of cow milk production, which is used to select females.
2) Not marketing the increased weight & not increasing the value of replacement heifers.

B. Developing replacement heifers

1) Expected to calve for the first time as 2-yr-olds? - Should be developed to reach about 55 to 65% of their expected mature wt at 15 mo of age.
2) Would depend on the breed type & environment, but 0.75 to 1.0 lb gain/d from 7 to 15 mo of age.

3) A slower rate of gain may delay puberty and reduce reproductive efficiency, whereas a faster rate of gain may impair mammary development!

C. When spring born heifers are 7 to 15 mo old & are not pregnant, should gain 100 to 200 lb depending on the breed type & weight during the first winter.
D. Pregnant heifers? - Should enter their second winter at 750 to 850 lb, and should weigh 900 to 1,000 lb at calving.
E. During the third winter & pregnant 3-yr -olds should not lose more than 5 to 10% of their fall wt. Maintaining adequate body condition is essential for pregnant heifers!

2. **Managing Bulls**

A. Young bulls

1) Should be creep fed and then full fed a high energy ration (70 to 85% concentrate) from weaning to 12 to 14 mo of age:

a) Should feed (dry feed) about 2½% of the body wight & should gain 2½ lb/day.
b) Should be ready for use at 15 to 18 mo of age.

2) About 15 mo to 3 yr old - Should gain 1¾ to 2¼ lb & consume dry feed equal to 1⅓ to 2¼% of their body wt, with the proportion of roughage increased after the 1st yr.

B. Mature breeding bulls - Usually can maintain condition on the same kind of pasture and wintering management provided for the cow herd.

1) Winter feeding?

a) One-half lb of grain/l00 lb body weight with protein supplement and free choice roughage - Adjust grain to attain desired condition.
b) Using corn silage? - Adjust grain and protein supplement as needed.
c) Free-choice minerals (salt, Ca, P, and trace minerals if poor quality forage), and 20,000 units vitamin A/day if any question on the content in feed.

2) Summer feeding? - Similar to cow herd with free-choice minerals and pasture, and supplement energy only when needed to maintain satisfactory condition, specially young bulls!

GRAZING MANAGEMENT

1. **General**

A. The greatest challenge for the beef cow producer? - To reduce purchased feed costs & increase profitability per cow.

B. One way is to achieve goal is to maximize the use of inexpensive forages, which may not occur under most growing conditions in North America, thus:

1) Use improved pastures early or later in the growing season is the one of the best methods to match forage quality & animal demands.
2) Determining/maintaining the optimum stocking intensity is important in the long-term profitability.

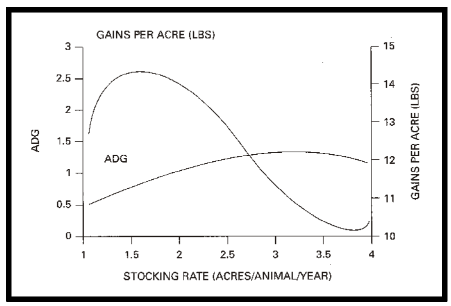
2. **Improved Pastures?**

A. Pastures with introduced forage species are used throughout the US - Higher nutrition values vs. native forages.
B. Some examples:

1) Use of perennial ryegrass (cool season) to meet the winter nutritional needs of grazing cattle & reduce the use of protein supplement in the South.
2) Extensive use of crested wheatgrass for lactating beef cows during in the early spring throughout the western US - Can prevent early spring use of native ranges, which may deplete cool-season grasses.

C. Irrigated pastures can provide a high-quality forage to beef cows following calving, which can improve conception rate.
D. Mixtures of grasses and legumes? - May improve performance vs. poor grass stands, and also legumes eliminate the need for N fertilizer.

3. **Stocking Intensity**



A. As stocking rate is increased, productivity per animal may decrease but productivity per acre would be increased (Bowman and Sowell, 1998).
B. Consequences of high grazing intensity?

1) Remove thebest quality-forage early & only poorer-quality forage would be left behind, and also may increase the loss from some poisonous plants.
2) More time & energy would be spent in grazing.
3) Reduced individual animal performance simply because of the reduced forage intake & quality, even though, again, it can increase higher gains per acre.
4) Lower pregnancy rate, calf crops, etc. because of the quantity/quality of forages.

4. **Grazing Systems**

A. Should manipulate beef cattle to maintain or improve range conditions - Gradual improvement in forage conditions eventually increases the carrying capacity.
B. Continuous grazing - Most common scheme:

1) Animals are left to graze one area for the entire grazing season or sometimes the entire year.
2) Total production/acre is lower vs. other systems, but maintenance costs are low.
3) With managed stocking intensity, can maintain the range condition and meet the nutritional needs of animals better than other systems.

C. Deferred rotational grazing:

1) Used to allow desirable plants to achieve some phenological stage, such as flowering or seed maturity, without being grazed.
2) Example? A 4-pasture deferred rotation - One pasture would not be grazed from spring to mid-summer, and another pasture would not be grazed the following year for the same period , and the deferment would be rotated through all pastures after 4 years.
3) Superior to continuous grazing in improving range condition!?
4) Problems? - Reduce individual animal performance and increase supplementation costs during the deferred period.

D. Rest rotation grazing - Used extensively in the western US:

1) Usually use three to five pastures, and one pasture is not grazed for an entire year, while a single herd utilize other pastures.
2) One-year rest is rotated across all pastures in different years.
3) Better vegetation response vs. continuous grazing, but can reduce animal performance.

E. Short duration grazing - Developed in France with daily cattle:

1) Uses a wagon wheel arrangement of pastures with a central watering point.
2) Usually, with, at least, eight pastures, but some systems have as many as 40 paddocks.
3) Each pasture is grazed intensively (two- to three-fold increase vs. normal intensity) for 2 to 3 days, and then not grazed for several weeks.
4) Some pastures may be grazed two or three times during the grazing season.
5) Best on highly productive soils with grazing-resistant plants (. . . similar palatability).
6) Drawback? - The system leaves no emergency forage for drought conditions. With no regrowth during the resting period, no forage for the next grazing period.

BEEF CATTLE TYPES AND GROWTH

1. **US Cattle feeding Industry (finishing)**

A. Concentrated in the Great Plaines of the US with some midwestern & western states.

B. Thirteen states, AZ, CA, CO, ID, IL, IA, KS, MN, NE, OK, SD, TX, and WA, accounted for about 86% of cattle-on-feed in 1994.

2. **Cattle Types & Growth**:

A. Receiving feeder calves from cow herds across the United States & Mexico with many exotic breeds in recent years, which can add to the variation in the size, body type, and also potential growth.

B. NRC includes medium- & large-frame size in the prediction equations for estimating the nutrient requirement and feed intake:

1) Large-framed - Produce Choice carcasses at live wt of more than 1,200 lb.
2) Medium-framed - Produce Choice carcasses at 1,000 to 1,2000 lb'
3) Small-framed - Produce Choice carcasses at < 1,000 lb.

C. Muscle thickness standards - Indicate the difference in muscle-to-bone ratio with similar fatness: No.1 = Thick, No. 2 = Moderate, and No.3 = Thin.

D. Age, frame size, and muscle thickness of cattle fed to "0.53 in." fat - See the table.

1) Increasing age & decreasing frame size - ↓ days on feed.
2) Slaughter wt & carcass wt - Heavier for long yearlings vs. calves & yearlings.
3) Increasing frame size - Heavier slaughter wt & hot carcass wt.
4) No differences in days on feed between muscle thickness No. 1 & No. 2, but No. 3 needed more days to reach 0.53 in.

Effects of some factors on steers fed to 0.53 inches fat thickness [Dolezal et al. (1993). Cited by Galyean & Diff (1998)]

Item	Days on Feed	Slaughter Wt (lb)	Hot Carcass Wt (lb)	Dressing (%)
Age class				
Calf	251[a]	1,134[b]	712[b]	62.6
Yearling	166[b]	1,181[b]	737[b]	62.2
Long yearling	98[c]	1,301[a]	816[a]	62.7
Frame size				
Large	214[a]	1,421[a]	897[a]	63.2[a]
Medium	163[b]	1,176[b]	739[b]	62.8[a]
Small	139[c]	1,024[c]	631[c]	61.5[b]
Muscle thickness				
No.1	139[b]	1,181[b]	741[b]	62.7
No.2	156[b]	1,197[ab]	749[ab]	62.4
No.3	220[a]	1,239[a]	774[a]	62.5

abcLS means within the same column and item without common superscripts differ ($P < 0.05$).

E. Frame size & muscle thickness combinations on days on feed to reach 0.53 in. of fat thickness - See the table.

1) As frame size ↑, days on feed ↓.
2) As animal age ↑, need fewer days.

Days on feed required to reach 0.53-inch fat thickness by steers [Dolezal et al. (1993). Cited by Galyean & Diff (1998)]

Frame size & Muscle thickness	Age Class: Calf	Yearling	Long Yearling
Large No.1	235	162	105
Large No.2	247	194	135
Large No.3	368	286	189
Medium No.1	196	148	84
Medium No.2	254	142	91
Medium No.3	272	198	78
Small No.1	185	76	55
Small No.2	213	92	42
Small No.3	287	198	100

4. **Effect of Breeds?**

A. Yearling British-cross steers (Angus x Hereford about 16 mo of age) - Need about

112 d on high-concentrate diet to reach Choice quality grade, and feeding beyond 112 d had no effect on the grade or palatability; and increased waste fat.

B. Angus steers following a growing period of 150 d at 1.3 lb/d - Needed only 45 d to reach Choice grade, but need more time to achieve acceptable tenderness.
C. Large breeds (e.g., Chiaina) - Quality grade increased up to 128 d on feed, but reached plateau thereafter; Just increased fat with no changes in the quality grade.

SYSTEMS FOR GROWING AND FINISHING BEEF CATTLE

1. **General**

A. Systems in the United States - Vary by the location and may be affected by feed sources and climate.
B. The eastern and southeastern United States - Support most of the cow-calf production with calves sold at weaning to go either directly to the feedlot or to a backgrounding operation.

1) Increasing interest by cow-calf producers to retain ownership of the calf through the growing period or through slaughter in recent years!
2) In the United States, most cattle go through a backgrounding period after weaning before placement in a feedlot on a finishing diet.

C. Difficult to classify, but the growing system can be classified into two:

1) Intensive systems - Cattle are placed directly in the feedlot.
2) Extensive systems - Cattle are grazed on forages for varied lengths of times, or fed milled diets in a drylot.

2. **Intensive Systems**

A. Some advantages?

1) Can reduce the cost of gain - Because of the use of less expensive source of energy, cereal grains, and the cost of mixing/handling concentrates vs. roughages.
2) Cereal grain feeding can decrease manure production vs. ad libitum consumption of roughage-based diets.
3) Intensively fed calves are generally more efficient than calves subjected to extensive production systems.

B. A major disadvantage? Intensively fed cattle would put on more fat and finish at lighter weights, thus producing light carcasses. But, with large-framed cattle, can produce carcasses within an acceptable range for the packing industry.
C. Limit or programmed feeding - Alternative?

1) Feed a high-concentrate diet to provide a specified rate of gain.

2) Using this approach to achieve similar gains may improve feed conversion dramatically vs. those fed a corn-silage-based diet.
3) No detrimental effects on finishing performance.

a) But, may increase incidence of liver abscesses by feeding all-concentrate diets during both the growing and finishing phases.
b) Concentrate or roughage content/amount may be important in using this approach, even though some data indicating that the percentage of concentrate during the growing phase did not greatly affect finishing performance or carcass traits.

3. **Extensive Systems**

A. Grow cattle at low-moderate rates of gain (1.75-2.5 lb/day) using roughage-based diets.
B. Cattle - Older & yield heavier carcasses vs. those given a finishing diet after weaning.
C. Roughage and yardage costs can be a major disadvantage, but the cost can be reduced with grazing forages:

1) Fescue pastures

a) Cattle previously grazed tall fescue pastures can exhibit signs of heat stress and display rough hair coats - Perhaps, because of endophyte-infected fescue pastures during periods of high ambient temperatures or humidity.
b) When cattle are placed in the feedlot later in the fall when these conditions are not prevalent, no sacrifice in performance may be noted.
c) Anabolic agents (estradiol 17-β) may improve performance by steers grazing endophyte-infected fescue - But, still not compatible with ones grazed noninfected varieties & low-endophyte-infected fescue.

2) Stockpiled forages - Let cattle graze stockpiled forages during the winter to reduce the labor & equipment costs, e.g.:

a) Grazing stockpiled tall fescue from November to April in Virginia gained 0.75 lb/day and required only 527 lb of hay-stocker fed during 36 days.
b) Similar performance between feeding orchard grass-alfalfa hay vs. stockpiled fescue-alfalfa, but more stored feed was required.

3) Winter wheat pasture

a) Cattle that have grazed annual winter wheat pasture generally perform well in the feedlot - Obviously, differences among pastures though!
b) One advantage? - No need for supplementation of the cattle to achieve adequate gains . . . other than a mineral supplement.
c) Disadvantage - A possibility of bloat:

(1) Feed additives like poloxalene and the ionophore monensin help to prevent bloat in cattle grazing wheat pasture.
(2) Preferable to include these products in some type of supplement & not with minerals, so that the animals receive the daily recommended amounts.

d) Wheat varieties are usually selected based on non-animal performance factor, and some data indicate that selecting for grain yield can reduce beef gain per acre.
e) Sometimes, cattle may need to be fed in a drylot before being placed on the wheat pasture.

4. **Systems & Performance?**

A. Beef cattle producers in the United States - Have almost limitless means of feeding cattle from weaning to slaughter.
B. A possibility of taking advantages of "compensatory growth?"

1) Some would pay a premium for cattle subjected to a period of restricted growth because of the compensatory response.
2) Must consider the severity, nature, and duration of the restriction though!

C. Nebraska's computer simulation evaluated the effect of post-weaning production systems on performance and carcass composition of different biological types of cattle:

1) The model used:

a) Steers from Fl crosses of 16 sire breeds mated to Hereford and Angus dams.
b) Steers growing under the following "nine backgrounding systems" & finished at either a low (2.2 lb) or high (3.0 lb) ADG:

(1) High ADG (1.98 lb) for 111, 167, or 222 days.
(2) Medium ADG (l.l0 lb) for 200,300, or 400 days.
(3) Low ADG (0.55 lb) for 300 or 400 days.
(4) 0 day backgrounding.

2) Results?

a) Considerable flexibility exists in the choice of post-weaning production systems for several genotypes of steers to produce acceptable carcass composition and retail product.
b) Carcasses with a specified composition, retail product, or quality can be produced from a mixed group of steers fed and managed similarly from weaning to slaughter.

MANAGING NEWLY RECEIVED CATTLE

1. **General**

A. Bovine respiratory disease (BRD) in newly weaned or received cattle can be a significant economic problem:

1) Death losses may range from 1.5 to 2.7/100 animals marketed, and ⅔ - ¾ may be attributed to respiratory disease.
2) Two factors contribute to the high incidence of BRD in newly received, lightweight (e.g., less than 400 to 500 lb) cattle:

a) Stresses associated with weaning & normal marketing - Negatively affect the immune system when the animal is often challenged by infectious agents.
b) Low feed intake by stressed calves - Averaging about 1.5% of BW during the first 2 wk after arrival.

B. Practices to offset negative factors that affect the health of newly weaned or received cattle include: 1) preconditioning, 2) on-ranch vaccination programs, 3) nutritional management after arrival at the feedlot, and 4) prophylactic medication.

2. **Energy**

A. Stressed calves reduce feed intake, and also tend to prefer & eat greater amounts of a high-concentrate than a high-roughage diet.
B. Receiving diets with high-concentrate can increase the severity of morbidity (days of medical treatment per calf purchased).
C. Feeding alfalfa or good-quality grass hays during the first week of the receiving period can offset the negative effect of high-concentrate receiving diets on morbidity.
D. An effective receiving program? - A diet with about 60% concentrate, with either free-choice or limited quantities of hay (approximately 2 lb/day) during the first week.
E. Feeding good-quality hay plus protein supplement may be sufficient, but calves may not fully compensate for lower gains during the receiving period.

Effect of protein on performance by calves during a 42-day receiving period (Galyean et al., 1993)

	Crude protein, %				
Item	12	14	16	Contrast	SE
Receiving period performance					
No. of calves	40	40	40	-	-
Initial BW, lb	412.4	409.2	403.3	-	2.6
Day BW, lb	520.1	536.6	537.2	-	5.5
Daily gain, lb					
0 to 21 days	1.50	1.85	1.97	-	0.34
21 to 42 days	3.52	4.23	4.40	Ln	0.21
0.42 days	2.51	3.04	3.19	Ln	0.11
Daily DM intake, Ib/steer					
0 to 21 days					
Hay	1.34	1.36	1.34	-	0.05
Concentrate	5.84	6.36	6.67	-	0.34
Hay + concentrate	7.17	7.72	8.01	-	0.35
21 to 42 days	12.55	12.40	13.30	-	0.39
0 to 42 days	9.86	10.06	10.64	Ln	0.27
Feed to gain ratio					
0 to 21 days	5.64	4.72	4.35	-	0.94
21 to 42 days	3.61	2.95	3.04	Ln	0.17
0 to 42 days	3.95	3.32	3.35	Qd	0.08
Calves treated for BRD,%	37.5	22.5	47.5	-	-
Mortality (no.)	2	1	0	-	-
Postreceiving performance					
Daily gain, lb	3.49	3.40	3.21	-	0.18
Daily DMI, lb/steer	15.37	15.76	15.49	-	0.47
Feed-to-gain ratio	4.44	4.66	4.83	-	0.16
Overall performance					
Daily gain, lb	3.00	3.22	3.20	-	0.12
Daily DMI, lb/steer	12.62	12.91	13.07	-	0.33
Feed-to-gain ratio	4.23	4.01	4.09	-	0.09

3. **Protein**

A. Effect of feeding 12, 14, or 16% CP for stressed calves (19.5 h in transit, 6.8% shrink) during the initial 42-d & then fed a 14% CP, 85% concentrate diet (Table).

 1) Increased gain and DM intake linearly with increasing CP during the 42-d receiving period.
 2) Ones fed the 12% CP diet compensated during the subsequent 42-d period, thus no effect on performance during the 84-d trial.

B. A supplemental source of CP may not be crucial in receiving diets as long as a natural source is used, perhaps, because of a low capacity for protein deposition during the first wk or two after arrival due to low feed intake?
C. One exception? - Corn-silage-based receiving diets, which would likely supply a fairly large amount of ruminally degraded N, and improved gain and efficiency were reported when blood meal was the source of supplemental protein vs soybean meal.
D. Practical receiving diets based on hay & other dry roughages - $\geq$ 14% CP!

4. **Minerals & Vitamins**

A. Received cattle? May increase the need for K, but no effects on others. Perhaps, may need to increase the concentration of most minerals because of low feed intake?
B. Zn, Cu, Cr, and Se - May affect the immune function.
C. No consistent effects of B vitamin supplementation on performance and health of newly weaned or received cattle, thus, little economic justification for practical receiving diets?
D. Vitamin E - Feeding 400 to 800 IU/day has increased performance and decreased morbidity in some field studies.

5. **Feed Additives**

A. Ionophores - Often added to receiving diets to control coccidiosis, which can result in the decrease in feed intake, but the effect can be minimized by the choice of ionophore or, with monensin, by decreasing its dietary concentration.
C. Antimicrobial agents - Often added to feed or water of newly received cattle to reduce morbidity:

 1) Chlortetracycline and oxytetracycline in the feed or water? Effective in controlling BRD, especially when morbidity and mortality are low.
 2) A combination of oxytetracycline and sulfadimethoxine as a mass medication treatment for newly received cattle? - Stressed calves decreased morbidity from 63.3% in control to 7.1 % in treated group in one study.
 3) Tilmicosin phosphate? - Reduced the percentage of calves treated for BRD from 46.4 to 0% in one trial and from 32.8 to 12.1% in a second trial in one study.

D. Prophylactic medication of newly received, stressed cattle can be useful in decreasing the incidence of BRD & other adverse conditions.

STARTING CATTLE ON FEED & FEED BUNK MANAGEMENT

1. Transition Period

A. The primary goal of the cattle feeder during the first few days after arrival? - Minimize disease and death loss!
B. Starting cattle on feed? - Refers to the transition between the receiving or growing diet and the final, high-grain finishing diet.
C. No standard way of getting recently purchased cattle on feed.
D. Cattle grown on roughage-based diets - Change the diet from mostly roughage to mostly concentrate gradually.
E. Cattle grown on concentrate or programmed feeding program - No need for step-up in the amount of dietary concentrate but need to increase the quantity of diet.

2. Transition from Grazing or a Roughage-Based Growing Diet

A. Accomplished by using a series of step-up diets to increase the amount of concentrate. A smooth changeover can avoid excess consumption of concentrate, which can lead to acidosis and decreased feed intake.
B. Traditional approach?

1) Feed a relatively low-concentrate diet (40 to 50%) as the starter diet, and in some cases, provide hay on a free-choice basis for the first few days.
2) Transition to the final high-concentrate diet (90% + concentrate):

a) Make in steps of l0 to 20% concentrate over a period of 21 to 28 days - Each step may consist of 3 to 7 days.
b) Too abrupt changes are likely to cause cattle to decrease feed intake because of acidosis - May have to step back to the previous diet.

C. Another approach? (Simply because most commercial feedlots feed 2-3 times/day)

1) Gradual dietary concentrate changes by feeding the next diet in the step-up program as the second or third feeding of the day.
2) On the following day, the next step-up diet may consist two of the three daily feedings, and a complete transition over a 3-day period.
3) Depending on intake, cattle can be held at any step for a few days or the transition can continue.

D. Another approach? - Allow cattle to reach ad libitum intake of a moderate concentrate (60%?) starter diet, followed by a gradual increment, 10% daily for example, until the final high-concentrate diet of 90% + concentrate is achieved.
E. Sound bunk management is critical to any of the approaches to start cattle on feed.

1) During the transition to higher dietary concentrate, may be beneficial to have some feed in the bunks to prevent overconsumption.
2) Monitor feed intake very closely, or intake prediction equations can be used to determine whether feed intake is meeting appropriate targets.

3. **Feedbunk Management**

A. Feed bunk management is one of the most critical jobs in the feedlot.
B Once started on feed, the approach for bunk management changes from the one used during the step-up period:

1) Monitoring of feed intake closely to ensure expected intake is still important.
2) But, once cattle are on the final high-concentrate diet, the main objective might be to achieve a relatively constant intake over time.
3) Ideal? - "*The last mouthful of feed consumed as the feed truck is dumping additional feed in the bunk!*"

C. "Bunk reading" - Critical to ensure that cattle are not short on feed, thus hungry, or fed too much so that excessive feed remains in the bunk, which becomes stale.
D. Recent trends/approaches?

1) Try to achieve a clean bunk in somewhat less that a 24-h cycle - i.e., Feed bunks should be read during the late night hours.
2) Also, constantly challenge cattle to increase their feed intake - e.g.:

a) If a pen of cattle has a clean bunk at 12:00 A.M., the next day's feed call or allowance might be increased by 0.5 to l.0 lb/animal.
b) If the pen fails to clean up the new allotment of feed, feed would be reduced back to the original allotment.
c) Over a period of 2 to 3 days - If the pen cleans up this new amount of feed, cattle are once again challenged with a higher amount.

E. To allow cattle to achieve maximum feed intake with minimal day-to-day variance, a consistent bunk reading is must and typically involves the use of computerized records for each pen to assist the bunk reader!

FINISHING DIETS FOR MARKET CATTLE

Composition of typical beef cattle finishing diets (% DM) [Galyean & Duff (1998)]

Ingredient	Processed Corn & Dry Roughage	Whole Corn & Corn Silage	Dry-rolled Corn & Wet Corn Gluten Feed
Roughages			
Sudan grass hay	4	-	8
Alfalfa hay	6	-	-
Corn silage	-	10	-
Grain and grain by-products			
Steam-flaked corn	74.5	-	-
Dry-rolled corn	-	-	52.5
Whole shelled corn	-	71	-
Wet corn gluten feed	-	-	35
Liquid feeds			
Molasses	5	-	-
Condensed distillers solubles	-	4	-
Fat	3	-	-
Supplement*	7.5	15	4.5

* Supplies Ca and P sources, urea and/or natural protein, trace minerals, vitamins, and feed additives.

1. General

A. The ultimate purpose of finishing process? - Obviously, produce beef that is desirable to the consumer.

B. Finished cattle - Mostly marketed between 1 to 2 yr of age with over 1,000 lb.

C. Some cattle may go into the finishing feedlot at 200 to 300 lb at a few months of age (calves) and some may weigh 600 to 800 lb (yearlings), while other may weigh 900 lb or more & older than 1 yr of age.

D. Because of the differences in kind of cattle being finished, obviously the nutrient requirements differ - See the table for some examples of finishing diets.

E. Complete (mixed) rations for finishing cattle generally need:

1) CP - 9 to 14% depending on age, size, and growth rate.
2) Energy - Need high concentrate diets (TDN = 65 to 85% or NEg = 0.40 to 0.65 Mcal/lb), which can improve performance & carcass traits, and cost less, but more prone to develop acidosis, founder, and liver abscesses.
3) Ca - 0.3 to 0.6%. Supplemental Ca is must when using high-concentrate diets & limited access to forages. Ca:P ratio of 2:1?
4) P - 0.2 to 0.4%. Grains and high-protein supplements are generally high in P, thus little or no need for supplementation in high-concentrate diets!?

2. Roughage in Finishing Diets

A. General:

1) Although some feedlots use all-concentrate diets, usually, high-concentrate finishing diets contain small amounts (3 to 15%) of roughage.
2) On the energy basis, roughage can be one of the most expensive ingredients in finishing diets.
3) Can be an important component of feedlot diets and have a large influence on ruminal function, e.g., the low dietary roughage content has been associated with digestive upsets such as acidosis & liver abscesses.
4) Common sources? Alfalfa hay, grass hays, silages (corn, wheat, and grasses), and by-product feeds (e.g., cottonseed hulls).

B. Roughage inclusion rate can affect cattle performance - Some examples:

1) Faster, more efficient gains by cattle fed either 5 or 10% roughage compared with those fed 0 or 15% roughage in steam-rolled wheat diets.
2) With 0, 3, 6, and 9% 50:50 mixture of alfalfa and corn silage in high-moisture corn and dry-rolled sorghum diets:

a) Observed quadratic effects on DM intake & daily gain, and gain was maximized at 9% roughage.
b) But, reduced the efficiency as dietary roughage increased from 0 to 9%.

C. Source

1) Often, the source is as important as the roughage content & both can interact with grain processing; The effect of source on performance in cattle fed high-concentrate diets may depend on the grain-processing method.
2) Matching sources and amounts with grains for optimal utilization in high-concentrate diets is desirable, even though the data are limited.

D. Effects of roughage on digestion and passage

1) Effects of roughage in high-concentrate diets - e.g., increasing roughage can increase passage rate of grain in the rumen.
2) A source of roughage affects digestion and passage, but the effect could vary with the type of grain in the concentrate.
3) High-grain (starch) diets:

a) Often decrease digestion in the rumen, thus shifting it to the large intestine.
b) The LI may not be able to compensate fully for the ↑ fiber load - Thus, ↓fiber utilization may partially explain ↓ feed efficiency with increasing roughage?!

4) With highly processed grains, which are digested extensively in the rumen, little starch would reach the LI, and compensatory digestion of fiber in the LI could proceed without negative associative effects of starch.
5) With unprocessed grains, more starch would reach the large intestine, which might have negative effects on fiber digestion in that organ.
6) The amount & source of roughage may influence small intestinal digestion of starch - Increased pancreatic α-amylase activity in forage-fed vs concentrate-fed calves at equal energy intakes has been reported.

3. **Grains, Grain Processing, and Other Feedstuffs**

A. Grain sources to use? - Depend on many factors including location of the feedlot, feed availability, cost, equipment, and palatability.

1) Corn - Readily available in the Midwestern and upper Great Plains states.
2) Sorghum grain/milo - Commonly used in Southern Great Plains states.
3) Wheat, barley, or oats - May become available during certain periods of the year or certain locations.
4) Others? - Recent advances in the technology may lead to the increased use of alternative grains, e.g., high-lysine corn.

B. Starch in grains & grain processing

1) Starch granules:

   a) Starch exists in grains as granules in the endosperm, and the properties of starch granules depend on the particular grain.
   b) Highly organized crystalline region contains mostly amylopectin, which is surrounded by a less dense, amorphous region that is high in amylose.
   c) Granules are also embedded in a protein matrix, which, particularly in corn and sorghum, can decrease the potential for enzymatic attack and digestion.

2) Gelatinization:

   a) Occurs with the sufficient energy applied to break bonds in the crystalline region of the granule - e.g., Mechanical, thermal, and chemical agents can initiate the process, but water is necessary.
   b) Processing methods with "heat & moisture" (e.g., steam flaking) can cause extensive gelatinization & rupture of starch granules.
   c) Heating also can denature grain proteins, which could affect starch digestion.

3) Gelatinized grains are typically digested to a greater extent in the rumen and the total tract vs. unprocessed grains.
4) Beneficial effects of processing? - "Inversely" related to the digestibility of the unprocessed grain.
5) Even without processing, barley and wheat are digested well in the rumen, but some processing is needed for the efficient use of sorghum/milo.
6) Bulk density - A practical means of determining the degree of processing, e.g., ↓ bulk density of steam-flaked sorghum from 35 to 18 lb/bu can ↑ both enzymatic and ruminal rates of starch breakdown.
7) Particle size - Affects the rate of digestion; e.g., As particle size decreased in situ, DM and starch digestion for steam-flaked, dry-rolled, and high-moisture corn increased.

☞ Mixing different grains or the same grain processed by different methods? - Can be an effective way to take advantages of different digestion characteristics among grains and grain processing methods?

C. By-products and other feedstuffs

1) Because of lower costs (often), by-product feeds have become important feedstuffs for feedlot diets & others - e.g., whole cottonseed, brewers grains, distillers grains, beet pulp, citrus pulp, soybean hulls, wheat middlings, cull potatoes, and many others.
2) Soybean hulls - Became popular in recent years, and can be used efficiently by feedlot cattle when priced competitively.
3) Depending on manufacturing processes and grains used, the composition of these products can be variable, thus important to determine the composition.
4) Liquid feeds:

   a) e.g., Fat (tallow, animal and vegetable blends, and soap stocks) is commonly added at 2 to 4% of finishing diets depending on the price, and also molasses and liquid by-products of the corn milling industry are commonly used.
   b) Liquid feed - Generally decreases dustiness and often improves palatability.

4. **Protein & Other Nutrients**

A. Protein

1) Dietary CP content has been increasing in recent years:

   a) Based on the old NRC (1984), CP requirements for finishing beef steers started on feed at 700 lb & gaining 3 lb/d ranged from "8.9 to 11.7%," depending on the BW.
   b) But, based on one survey of nutrition consultants, CP in finishing diets ranged from "12.5 to 14.4%," and added urea ranged from 0.5 to 1.5% of the dietary DM.

2) Improved performance with added protein?

   a) More consistent with the use of ruminally degraded sources of CP (e.g., urea and soybean meal), and limited advantages with rumen undegradable protein sources!
   b) Why? - Highly processed grains are readily fermentable in the rumen, and may increase microbial needs for ruminal N, and N in excess of needs might provide ammonia for the maintenance of acid-base balance by the kidney?

B. Vitamins

1) Vitamin A - Usually recommended & a common approach is to supplement the required doses without considering contributions from feedstuffs.
2) Vitamin E - Commonly added to receiving diets, and also to finishing diets?

C. Minerals

1) Generally, diets are formulated to satisfy the needs for required major minerals (Ca, P, K, S, Mg, Na, and Cl) and trace minerals (Co, I, Fe, Mn, Se, and Zn).
2) Organic trace mineral complexes? - Considerable debate on the merit!

5. **Anabolic Agents and Feed Additives**

A. Anabolic agents

1) Currently approved implants for growing-finishing cattle? - Estrogen-based, androgen (trenbolone acetate)-based, and estrogen + trenbolone acetate-based.
2) Implants:

a) Increase the rate of gain, feed efficiency, and carcass weight at Choice grade by 55 to 99 lb.
b) Typically increase daily protein and fat gain in the carcass. The effects of estrogen + trenbolone acetate-based may be greater than estrogen-based.
c) Usually, also increase feed intake, i.e., un-implanted cattle usually consume 6% less DM than implanted cattle.
d) One common procedure? Use an estrogen-based implant initially & an estrogen + trenbolone acetate-based implant as a second implant.
e) Finishing heifers - Often receive an initial estrogen-based implant and a final androgen-based implant.
f) Implant programs may increase dietary protein requirements, presumably because of an increased rate of daily protein gain.

B. Ionophores

1) Fed to the majority of finishing beef cattle.
2) Three compounds are approved for use in confined beef cattle diets - Monensin, lasalocid, and laidlomycin propionate.
3) Effects of ionophores on performance?

a) Monensin - Decreases feed intake, with little change in daily gain, resulting in improved feed efficiency.
b) Lasalocid - Similar or greater intake with increased daily gain, thus improving the feed efficiency.
c) Laidlomycin propionate - Tends to have little effect on feed intake, but increased daily gain, results in improved feed efficiency.

C. Other Feed Additives

1) A variety of other antibiotic feed additives are used:

a) Virginiamycin - Approved for use in confined cattle fed for slaughter to increase weight gain, improve feed efficiency, and decrease the incidence of liver abscesses.
b) Bambermycins - Approved for increased weight gain and improved feed efficiency in confined cattle fed to slaughter and for increased weight gain in pasture cattle.
c) Tylosin - Commonly fed to decrease the incidence of liver abscesses in confined cattle, and approved for combination feeding with monensin.
d) Chlortetracycline (CTC) - Approved for a variety of purposes in various classes of beef cattle; The CTC is generally used to prevent BRD and anaplasmosis and for growth promotion and improvement of feed efficiency.
e) Oxytetracycline - Approved for purposes similar to CTC, and also approved for combination feeding with lasalocid for confined cattle to decrease the incidence of liver abscesses.
e) Decoquinate - A compound approved for feeding to cattle for prevention of coccidiosis in cattle.
f) Melengestrol acetate (MGA) - Used to inhibit estrus in finishing beef heifers, resulting in improved gain and feed efficiency . . . Variable response though!

2) Probiotics - Microbial preparations and growth-media extracts:

a) Used widely in ruminant production - Yeast cultures and live cultures of Lactobacillus acidophilus and Streptococcus faecium are the most common.
b) Microbial cultures have been used primarily for either food preservation, as an aid to restoring gut function, or an agent to enhance feed utilization by ruminants.

NUTRIENT REQUIREMENT TABLES
[Based on NRC, 2000 (Update)]

1. **Table 1. Nutrient Requirements for Growing and Finishing Cattle** (Weight at small marbling, 533 kg; Weight, 200-450 kg; ADG, 0.50-2.50 kg; Breed code, 1 Angus) [NEm = net energy for maintenance; MP = metabolizable protein; ADG = average daily gain]

Body Weight, kg:		200	250	300	350	400	450
Maintenance Requirements:							
NEm	Mcal/d	4.1	4.84	5.55	6.23	6.89	7.52
MP	g/d	202	239	274	307	340	371
Ca	g/d	6	8	9	11	12	14
P	g/d	5	6	7	8	10	11
Growth Requirements (ADG)							
NEg required for gain, Mcal/d							
0.5	kg/d	1.27	1.50	1.72	1.93	2.14	2.33
1.0	kg/d	2.72	3.21	3.68	4.13	4.57	4.99
1.5	kg/d	4.24	5.01	5.74	6.45	7.13	7.79
2.0	kg/d	5.81	6.87	7.88	8.84	9.77	10.68
2.5	kg/d	7.42	8.78	10.06	11.29	12.48	13.64
MP required for gain, g/d							
0.5	kg/d	154	155	158	157	145	133
1.0	kg/d	299	300	303	298	272	246
1.5	kg/d	441	440	442	432	391	352
2.0	kg/d	580	577	577	561	505	451
2.5	kg/d	718	712	710	687	616	547
CalcIum required for gain, g/d							
0.5	kg/d	14	13	12	11	10	9
1.0	kg/d	27	25	23	21	19	17
1.5	kg/d	39	36	33	30	27	25
2.0	kg/d	52	47	43	39	35	32
2.5	kg/d	64	59	53	48	43	38
Phosphoros required for gain, g/d							
0.5	kg/d	6	5	5	4	4	4
1.0	kg/d	11	10	9	8	8	7
1.5	kg/d	16	15	13	12	11	10
2.0	kg/d	21	19	18	16	14	13
2.5	kg/d	26	24	22	19	17	15

2. **Table 2 Nutrient Requirements for Growing Bulls** (Weight at maturity, 890 kg; Weight, 300-800 kg; ADG, 0.50-2.50 kg; Breed code, 1 Angus) [NEm = net energy for maintenance; MP = metabolizable protein; ADG = average daily gain]

Body Weight, kg:		300	400	500	600	700	800
Maintenance Requirements							
NEm	Mcal/day	6.38	7.92	9.36	10.73	12.05	13.32
MP	g/d	274	340	402	461	517	572
Ca	g/d	9	12	15	19	22	25
P	g/d	7	10	12	14	17	19
Growth Requirements (ADG)							
NEg Required for Gain, Mcal/d							
0.5	kg/d	1.72	2.13	2.52	2.89	3.25	3.59
1.0	kg/d	3.68	4.56	5.39	6.18	6.94	7.67
1.5	kg/d	5.74	7.12	8.42	9.65	10.83	11.97
2.0	kg/d	7.87	9.76	11.54	13.23	14.85	16.41
2.5	kg/d	10.05	12.47	14.74	16.90	18.97	20.97
MP Required for Gain, g/d							
0.5	kg/d	158	145	122	100	78	58
1.0	kg/d	303	272	222	175	130	86
1.5	kg/d	442	392	314	241	170	102
2.0	kg/d	577	506	400	299	202	109
2.5	kg/d	710	617	481	352	228	109
Calcium Required for Gain, g/d							
0.5	kg/d	12	10	9	7	6	4
1.0	kg/d	23	19	16	12	9	6
1.5	kg/d	33	27	22	17	12	7
2.0	kg/d	43	35	28	21	14	8
2.5	kg/d	53	43	34	25	16	8
Phosphorus Required for Gain, g/d							
0.5	kg/d	5	4	3	3	2	2
1.0	kg/d	9	8	6	5	4	2
1.5	kg/d	13	11	9	7	5	3
2.0	kg/d	18	14	11	8	6	3
2.5	kg/d	22	17	14	10	6	3

3. **Table 3. Nutrient Requirements of Pregnant Replacement Heifers** (Mature weight, 533 kg; Calf birth weight, 40 kg; Age @ Breeding, 15 months; Breed Code, 1 Angus) [NEm = net energy for maintenance; MP = metabolizable protein; ADG = average daily gain]

	Months Since Conception								
	1	2	3	4	5	6	7	8	9
Requirements									
NEm, Mca1/d									
Maintenance	5.98	6.14	6.30	6.46	6.61	6.77	6.92	7.07	7.23
Growth	2.29	2.36	2.42	2.48	2.54	2.59	2.65	2.71	2.77
Pregnancy	0.03	0.07	0.16	0.32	0.64	1.18	2.08	3.44	5.37
Total	8.31	8.57	8.87	9.26	9.79	10.55	11.65	13.23	15.37
MP, g/d									
Maintenance	295	303	311	319	326	334	342	349	357
Growth	118	119	119	119	119	117	115	113	110
Pregnancy	2	4	7	18	27	50	88	151	251
Tota1	415	425	437	457	472	501	545	613	718
Calcium, g/d									
Maintenance	10	11	11	11	12	12	12	13	13
Growth	9	9	9	8	8	8	8	8	8
Pregnancy	0	0	0	0	0	0	12	12	12
Total	19	19	20	20	20	20	33	33	33
Phosphorus, g/d									
Maintenance	8	8	8	9	9	9	10	10	10
Growth	4	4	3	3	3	3	3	3	3
Pregnancy	0	0	0	0	0	0	7	7	7
Total	12	12	12	12	12	13	20	20	20
Body Weight									
ADG, kg/d									
Growth	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Pregnancy	0.03	0.05	0.08	0.12	0.19	0.28	0.40	0.57	0.77
Tota1	0.42	0.44	0.47	0.51	0.58	0.67	0.79	0.96	1.16
Body weight, kg									
Shrunk body	332	343	355	367	379	391	403	415	426
Gravid uterus mass	1	3	4	7	12	19	29	44	64
Total	333	346	360	375	391	410	432	459	491

4. **Table 4. Nutrient Requirements of Beef Cows** [SNF = solids not fat; NEm = net energy for maintenance; MP = metabolizable protein; ADG = average daily gain]

Mature Weight	533 kg	Milk Fat	4.0 %
Calf Birth Weight	40 kg	Milk Protein	3.4 %
Age @ Calving	60 months	Calving Interval	12 months
Age @ Weaning	30 weeks	Time Peak	8.5 weeks
Peak Milk	8 kg	Milk SNF	8.3 %
Breed Code	1 Angus		

	Month Since Calving											
	1	2	3	4	5	6	7	8	9	10	11	12
NEm Requirement Factor, %:	100	100	100	100	100	100	100	100	100	100	100	100
Requirements												
NEm, Mcal/d												
Maintenance	10.25	10.25	10.25	10.25	10.25	10.25	8.54	8.54	8.54	8.54	8.54	8.54
Growth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lactation	4.78	5.74	5.17	4.13	3.10	2.23	0.00	0.00	0.00	0.00	0.00	0.00
Pregnancy	0.00	0.00	0.01	0.03	0.07	0.16	0.32	0.64	1.18	2.08	3.44	5.37
Total	15.03	15.99	15.43	14.41	13.42	12.64	8.87	9.18	9.72	10.62	11.98	13.91
MP, g/d												
Maintenance	422	422	422	422	422	422	422	422	422	422	422	422
Growth	0	0	0	0	0	0	0	0	0	0	0	0
Lactation	349	418	376	301	226	163	0	0	0	0	0	0
Pregnancy	0	0	1	2	4	7	14	27	50	88	151	251
Total	770	840	799	724	651	591	436	449	471	510	573	672
Calcium, g/d												
Maintenance	16	16	16	16	16	16	16	16	16	16	16	16
Growth	0	0	0	0	0	0	0	0	0	0	0	0
Lactation	16	20	18	14	11	8	0	0	0	0	0	0
Pregnancy	0	0	0	0	0	0	0	0	0	12	12	12
Total	33	36	34	31	27	24	16	16	16	29	29	29
Phosphorus, g/d												
Maintenance	13	13	13	13	13	13	13	13	13	13	13	13
Growth	0	0	0	0	0	0	0	0	0	0	0	0
Lactation	9	11	10	8	6	4	0	0	0	0	0	0
Pregnancy	0	0	0	0	0	0	0	0	0	5	5	5
Total	22	24	23	21	19	17	13	13	13	18	18	18
Body Weight & Milk												
ADG, kg/d												
Growth	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pregnancy	0.00	0.00	0.02	0.03	0.05	0.08	0.12	0.19	0.28	0.40	0.57	0.77
Total	0.00	0.00	0.02	0.03	0.05	0.08	0.12	0.19	0.28	0.40	0.57	0.77
Milk kg/d	6.7	8.0	7.2	5.8	4.3	3.1	0.0	0.0	0.0	0.0	0.0	0.0
Body weight, kg												
Shrunk Body	533	533	533	533	533	533	533	533	533	533	533	533
Conceptus	0	0	1	1	3	4	7	12	19	29	44	64
Total	533	533	534	534	536	537	540	545	552	562	577	597

5. **Table 5. Diet Evaluation for Growing and Finishing Cattle** (Weight at small marbling, 533 kg; Breed code, 1 Angus) [eNDF = effective neutral detergent fiber; TDN = total digestible nutrients; NEm = net energy for maintenance; NEg = net energy for gain; CP = crude protein; DIP = degraded intake protein; DMI = dry matter intake; ADG = average daily gain; UIP = undegraded intake protein; MP = metabolizable protein]

Ration	eNDF % DM	TDN % DM	NEm Mcal/kg	NEg Mcal/kg	CP % DM	DIP % CP	Weight Class	NE Adjuster, %
A	57	50	1.00	0.45	7.4	88	325	100
B	43	60	1.35	0.77	10.0	78	350	100
C	30	70	1.67	1.06	12.6	72.4	375	100
D	5	80	1.99	1.33	14.4	48.5	400	100
E	3	90	2.29	1.59	16.6	44.2	425	100

Body weight, kg/ Ration		DMI Adjuster, %	DMI, kg/d	ADG, kg/d	Balances, g/d			Requirement, % of DM	
					DIP	UIP	MP	Ca	P
300	A	100	7.9	0.32	1	0	0	0.22	0.13
	B	100	8.4	0.89	0	0	0	0.35	0.18
	C	100	8.2	1.36	2	0	0	0.48	0.24
	D	100	7.7	1.69	1	2	1	0.60	0.29
	E	100	7.1	1.90	1	2	1	0.71	0.34
325	A	100	8.4	0.32	1	14	11	0.21	0.13
	B	100	8.9	0.89	0	38	30	0.33	0.18
	C	100	8.7	1.36	2	57	46	0.45	0.22
	D	100	8.2	1.69	1	73	58	0.55	0.27
	E	100	7.6	1.90	1	82	66	0.65	0.31
350	A	100	8.9	0.32	1	27	22	0.20	0.13
	B	100	9.4	0.89	0	75	60	0.31	0.17
	C	100	9.2	1.36	2	114	91	0.42	0.21
	D	100	8.7	1.69	1	143	114	0.51	0.25
	E	100	8.0	1.90	1	160	128	0.60	0.29
375	A	100	9.4	0.32	1	40	32	0.20	0.13
	B	100	9.9	0.89	0	111	89	0.30	0.16
	C	100	9.7	1.36	2	169	135	0.39	0.20
	D	100	9.1	1.69	1	212	169	0.48	0.24
	E	100	8.4	1.90	1	238	190	0.56	0.28
400	A	100	9.8	0.32	1	53	43	0.19	0.12
	B	100	10.4	0.89	0	147	118	0.28	0.16
	C	100	10.2	1.36	2	223	178	0.37	0.19
	D	100	9.6	1.69	2	279	223	0.44	0.23
	E	100	8.8	1.90	1	314	251	0.52	0.26
425	A	100	10.3	0.32	1	66	53	0.19	0.12
	B	100	10.9	0.89	0	182	146	0.27	0.15
	C	100	10.6	1.36	2	276	221	0.35	0.19
	D	100	10.0	1.69	2	346	277	0.42	0.22
	E	100	9.3	1.90	1	388	311	0.48	0.25

6. **Table 6. Diet Eva1uation for Growing Bulls** (Weight at maturity, 890 kg; Breed code, 1 Angus) [eNDF = effective neutral detergent fiber; TDN = total digestible nutrients; NEm = net energy for maintenance; NEg = net energy for gain; CP = crude protein; DIP = degraded intake protein; DMI = dry matter intake; ADG = average daily gain; UIP = undegraded intake protein; MP = metabolizable protein]

Ration	eNDF % DM	TDN % DM	NEm Mcal/kg	NEg Mcal/kg	CP % DM	DIP % CP	Weight Class	NE Adjuster, %
A	43	50	1.00	0.45	8.2	80	325	100
B	37	65	1.51	0.92	10.9	78	350	100
C	30	70	1.67	1.06	12.0	76	375	100
D	20	75	1.83	1.20	13.4	73	400	100
E	5	80	1.99	1.33	13.8	51	425	100

Body weight, kg/	Ration	DMI Adjuster, %	DMI, kg/d	ADG, kg/d	Balances, g/d			Requirement, % of DM	
					DIP	UIP	MP	Ca	P
300	A	100	7.9	0.22	5	103	83	0.18	0.12
	B	100	8.3	1.02	4	8	6	0.39	0.20
	C	100	8.2	1.23	2	-3	-2	0.45	0.23
	D	100	8.0	1.41	3	10	8	0.51	0.25
	E	100	7.7	1.56	5	-2	-2	0.56	0.27
325	A	100	8.4	0.22	5	119	95	0.18	0.12
	B	100	8.8	1.02	5	51	41	0.36	0.19
	C	100	8.7	1.23	2	49	39	0.42	0.21
	D	100	8.5	1.41	3	70	56	0.47	0.24
	E	100	8.2	1.56	6	63	51	0.52	0.26
350	A	100	8.9	0.22	5	134	107	0.18	0.12
	B	100	9.4	1.02	5	94	75	0.34	0.18
	C	100	9.2	1.23	2	100	80	0.39	0.20
	D	100	9.0	1.41	3	129	103	0.44	0.22
	E	100	8.7	1.56	6	128	102	0.48	0.24
375	A	100	9.4	0.22	6	149	119	0.18	0.12
	B	100	9.8	1.02	5	136	109	0.32	0.17
	C	100	9.7	1.23	2	150	125	0.37	0.19
	D	100	9.4	1.41	3	187	149	0.41	0.21
	E	100	9.1	1.56	6	191	153	0.45	0.23
400	A	100	9.8	0.22	6	161	131	0.17	0.12
	B	100	10.3	1.02	5	177	142	0.31	0.17
	C	100	10.2	1.23	2	199	159	0.35	0.19
	D	100	9.9	1.41	3	244	195	0.39	0.20
	E	100	9.6	1.56	7	253	202	0.42	0.22
425	A.	100	10.3	0.22	6	169	143	0.17	0.12
	B	100	10.8	1.02	6	218	174	0.29	0.16
	C	100	10.6	1.23	2	247	198	0.33	0.18
	D	100	10.4	1.41	3	300	240	0.36	0.19
	E	100	10.0	1.56	7	314	251	0.40	0.21

7. **Table 7. Diet Evaluation for Pregnant Replacement Heifers** (Mature weight, 533 kg; Calf birth weight, 40 kg; Age @ breeding, 15 months; Breed Code, 1 Angus) [TDN = total digestible nutrients; NEm = net energy for maintenance; NEg = net energy for gain; CP = crude protein; DIP = degraded intake protein; DMI = dry matter intake; ADG = average daily gain; UIP = undegraded intake protein; MP = metabolizable protein]

Ration	TDN, % DM	NEm, Mcal/kg	NEg, Mcal/kg	CP, % DM	DIP, % DM	DMI Factor, %
A	50	1.00	0.45	8.2	80	100
B	60	1.35	0.77	9.8	80	100
C	70	1.67	1.06	11.4	80	100

		Months Since Conception								
		1	2	3	4	5	6	7	8	9
NEm Requirement Factor, %:		100	100	100	100	100	100	100	100	100
Ration										
A	DM, kg	8.5	8.8	9.0	9.2	9.4	9.7	9.9	10.1	10.3
	NE allowed ADG	0.35	0.34	0.33	0.31	0.28	0.22	0.12	0.00	0.00
	DIP Balance, g/d	5	5	5	6	6	6	6	6	6
	UIP Balance, g/d	75	79	83	87	90	92	90	66	-53
	MP Balance, g/d	60	63	67	69	72	74	72	52	-42
	Ca, % DM	0.22	0.21	0.21	0.20	0.19	0.18	0.28	0.25	0.25
	P, % DM	0.17	0.17	0.16	0.16	0.15	0.14	0.19	0.16	0.16
B	DM, kg	9.0	9.3	9.5	9.7	10.0	10.2	10.4	10.7	10.9
	NE allowed ADG	0.96	0.96	0.95	0.92	0.88	0.82	0.71	0.54	0.30
	DIP Balance, g/d	4	4	4	4	4	4	4	4	4
	UIP Balance, g/d	5	14	22	30	38	49	54	46	18
	MP Balance, g/d	4	11	18	24	31	40	43	37	14
	Ca, % DM	0.36	0.35	0.33	0.32	0.31	0.29	0.38	0.34	0.29
	P, % DM	0.27	0.27	0.26	0.26	0.25	0.23	0.27	0.24	0.20
C	DM, kg	8.8	9.1	9.3	9.5	9.8	10.0	10.2	10.4	10.7
	NE allowed ADG	1.47	1.46	1.45	1.42	1.38	1.31	1.19	1.02	0.77
	DIP Balance, g/d	2	2	2	2	2	2	2	2	2
	UIP Balance, g/d	-66	-54	-43	-32	-19	-1	10	8	-18
	MP Balance, g/d	-53	-43	-34	-26	-15	-1	8	6	-14
	Ca, % DM	0.48	0.47	0.45	0.43	0.41	0.39	0.48	0.43	0.38
	P, % DM	0.37	0.36	0.35	0.35	0.33	0.31	0.35	0.32	0.28

☞NOTE: Requirements are for NE allowed ADG and target weight. NE allowed ADG is ADG independent of conceptus gain.

8. **Table 8. Diet Evaluation for Beef Cows** [TDN = total digestible nutrients; ME = metabolizable energy; NEm = net energy for maintenance; CP = crude protein; DIP = degraded intake protein; DMI = dry matter intake; UIP = undegraded intake protein; MP = metabolizable protein]

Mature Weight	533 kg	Milk Fat	4.0 %
Calf Birth Weight	40 kg	Milk Protein	3.4 %
Age @ Calving	60 months	Calving Interval	12 months
Age @ Weaning	30 weeks	Time Peak	8.5 weeks
Peak Milk	8 kg	Milk SNF	8.3 %
Breed Code	1 Angus		

Ration	TDN, % DM	ME, Mcal/kg	NEm, Mcal/kg	CP, % DM	DIP, % CP	DMI Factor, %
A	50	1.84	1.00	7.9	82.5	100
B	60	2.21	1.35	7.8	100.0	100
C	70	2.58	1.67	9.1	100.0	100

		Months Since Calving											
		1	2	3	4	5	6	7	8	9	10	11	12
	NEm Requirement Factor, %:	100	100	100	100	100	100	100	100	100	100	100	100
	Milk kg/d:	6.7	8.0	7.2	5.8	4.3	3.1	0.0	0.0	0.0	0.0	0.0	0.0
A	DM, kg	11.14	11.40	12.12	11.83	11.54	11.30	10.68	10.68	10.68	10.68	10.68	10.68
	Energy Balance, Mcal/d	-3.00	-4.59	-3.31	-2.58	-1.88	-1.34	1.81	1.50	0.95	0.06	-1.30	-3.24
	DIP Balance, g/d	7	7	7	7	7	7	6	6	6	6	6	6
	UIP Balance, g/d	-201	-270	-169	-96	-24	34	175	170	142	93	14	-110
	MP Balance, g/d	-161	-216	-136	-77	-19	27	149	136	113	75	11	-88
	Ca, % DM	0.65	0.70	0.62	0.57	0.52	0.47	0.34	0.34	0.34	0.59	0.59	0.59
	P, % DM	0.20	0.21	0.19	0.18	0.16	0.15	0.12	0.12	0.12	0.17	0.17	0.17
	Reserves Flux/mo, Mcal	-148	-174	-126	-98	-71	-51	55	46	29	2	-50	-123
B	DM, kg	11.96	12.23	12.72	12.43	12.14	11.00	11.28	11.28	11.28	11.28	11.28	11.28
	Energy Balance, Mcal	1.07	0.47	1.69	2.32	2.92	3.38	6.32	6.00	5.46	4.56	3.20	1.27
	DIP Balance, g/d	5	5	5	5	5	5	5	5	5	5	5	5
	UIP Balance, g/d	18	-47	44	114	182	233	221	221	221	221	209	85
	MP Balance, g/d	14	-38	35	91	146	189	304	291	269	230	167	68
	Ca, % DM	0.27	0.30	0.27	0.25	0.22	0.20 0	.15 0.15 0.15 0.25 0.25 0.25					
	P, % DM	0.19	0.20	0.18 0.17 0.16 0.14 0.11 0.11 0.11 0.16 0.16 0.16									
	Reserves Flux/mo, Mcal	32	14	51	71	89	103	192	183	166	139	97	39
C	DM, kg	13.16	13.42	13.79	13.50	13.21	12.97	12.35	12.35	12.35	12.35	12.35	12.35
	Energy Balance, Mcal/d	6.99	6.48	7.65	8.18	8.69	9.07	11.80	11.49	10.95	10.05	8.69	6.76
	DIP Balance, g/d	3	3	3	3	3	3	2	2	2	2	2	2
	UIP Balance, g/d	295	233	314	308	301	296	282	282	282	282	282	282
	MP Balance, g/d	236	187	256	308	360	401	509	496	473	435	371	272
	Ca, % DM	0.25	0.27	0.25	0.23	0.20	0.19	0.13	0.13	0.13	0.23	0.23	0.23
	P, % DM	0.17	0.18	0.17	0.15	0.14	0.13	0.10	0.10	0.10	0.14	0.14	0.14
	Reserves Flux/mo, Mcal	212	197	233	249	264	276	359	349	333	306	264	205

DAIRY CATTLE NUTRITION AND FEEDING

- *References: Aseltine (1998) & Schingoethe (1998) in Kellems & Church (1998), NRC (2001), and Jurgens (2002).*

FEEDING DAIRY CALVES

1. **General**

A. On a commercial scale, necessary to separate newborn calves form their dams as soon as possible. Essentially, no space for calves in milking system/facilities!
B. Fresh cows need special nutrition and feeding facilities to maximize their milking ability, thus calves can be housed more efficiently in separate facilities.
C. Health and vigor of calves at birth depend on the nutrition of the cow during the last 60 days or so of gestation; Developing about 70% of birth wt of the calf during that time.
D. Colostrum:

1) Not only provide antibodies that a newborn calf lacks, but also "laxative" to help starting digestive functions.
2) Under commercial conditions, calves rarely receive colostrum from their own dams, but no apparent difference in the effectiveness among "fresh, frozen/thawed, and fermented" colostrum, so . . .

2. **Birth to 4 Months of Age**

A. Newborn calves have all the necessary organs associated with the ruminant digestive system, but their processes are similar to nonruminant species.
B. The rumen is not populated with the typical microbes until close to 60 d of age, thus necessary to provide milk/milk replacer in the beginning.
C. Common feeds for calves? - Including colostrum, whole milk replacers, and calf starters along with hay or pasture.

1) Colostrum - Depends, but a calf may be left with its dam less than 24 hr, and then placed on one of several milk feeding programs.
2) Whole milk - An excellent feed, but too expensive, especially in areas where a good milk market exists.
3) Milk replacers - See the table:

Milk replacer (Aseltine, 1998)

Nutrient	Recommendation
Crude protein, %	22.0
Ether extract, %	10.0
Calcium, %	0.70
Phosphorus, %	0.60
Magnesium,%	0.07
Potassium,%	0.65
Sodium, %	0.10
Sulfur, %	0.29
Iron, ppm	100
Cobalt, ppm	0.10
Copper, ppm	10
Manganese, ppm	40
Zinc, ppm	40
Iodine, ppm	0.25
Selenium , ppm	0.30
Vitamin AIU/lb	1,730
Vitamin D, IU/lb	273
Vitamin E, IU/lb	18

* Should be considered as minimums. Many commercial products exceed the NRC on certain nutrients

a) High milk by-product feeds that are sold as a powder and reconstituted with water for feeding.
b) High-quality milk replacer should be used for, at least, the first 3 wk.
c) Perhaps, too complex to mix at home, thus may want to purchase!?

d) A typical milk replacer contains dried skim milk or whey or both with 10 to 30% animal fat for energy and also contains supplemental vitamins, trace minerals, and antibiotic(s).

4) Calf starters:

a) At about 1 wk of age, calves should be offered a starter ration.
b) Starter rations - High-energy, high-protein (16 to 20%), and low-fiber grain mixes fed to young calves (Table).
c) Usually, based on corn and SBM, with added oats for bulk and palatability?
d) Usually, added Ca, P, trace minerals, and salt.
e) Low doses of antibiotic (10 mg/1b starter) may improve appetite, whereas therapeutic doses (100 to 500 mg/day) can combat scours.
f) Grains should be rolled or coarsely ground.

Suggested calf starter rations[a,b] (Jurgens, 2002)

	1	2	3	4	5	6
Ingredient, %						
Corn, rolled	50	39	54	50	34	28
Oats, rolled	35	-	12	26	34	30
Barley, rolled	-	39	-	-	-	-
Beet pulp	-	-	-	-	-	20
Corn cobs, gr.	-	-	-	-	14	-
Wheat bran	-	10	11	-	-	-
Soybean meal	13	10	8	17	16	15
Linseed meal	-	-	8	-	-	-
Molasses, liquid	-	-	5	5	-	5
Oicalcium phosphate	1	1	1	1	1	1
TM salt & vitamin[c]	1	1	1	1	1	1
	100	100	100	100	100	100
Calculated analysis;						
As-fed basis						
Crude protein, %	14.5	14.0	14.5	15.4	14.7	14.8
TDN, %	73.1	73.0	72.5	72.9	68.2	70.5
NEm, Mcal/kg	1.83	1.76	1.80	1.83	1.68	1.75
NEg, Mcal/kg	1.25	1.19	1.22	1.25	1.11	1.19
Calcium, %	0.29	0.29	0.35	0.34	0.32	0.45
Phosphorus, %	0.54	0.61	0.64	0.54	0.52	0.49
Dry matter, %	88.5	88.4	87.8	87.8	88.9	88.5
Dry matter basis						
Crude protein,%	16.4	15.8	16.5	17.5	16.5	16.7
TDN, %	82.6	82.6	82.5	83.0	76.7	79.7
NEm, Mcal/kg	2.07	1.99	2.05	2.08	1.89	1.98
NEg, Mcal/kg	1.41	1.35	1.39	1.42	1.25	1.34
Calcium, %	0.33	0.33	0.40	0.39	0.36	0.51
Phosphorus, %	0.61	0.69	0.73	0.61	0.58	0.55

[a]Formulations are on an as-fed basis. Rations I, 2, 3, and 4 recommended for calves weaned after 4 weeks of age and receiving forage. Rations 5 and 6 recommended for calves weaned after 4 weeks and not receiving forage.
[b]Calf starter should be fed from about 3 days of age until 12 weeks of age. Intake should be limited to about 3 to 4 Ib (1.4 to 1.8 kg) per calf daily.
[c]Vitamin premix should supply the following per pound (or kg) of ration: vitamin A, 2,000 IU (900) & vitamin D, 500 IU (225).

B. Milk feeding programs - Two general types:

1) Liberal milk system:

a) Veal calves - Calves fed for veal are given maximum amounts of milk or milk replacer, and also many diets/ratios contain high concentrations of lipids to increase energy intake.
b) Herd replacements

(1) An expensive system, especially where milk is sold! But, calves do quite well. In addition to milk, grain & salt would be fed/provided.
(2) Feed 8 to 10% of body wt (or an equivalent amount of milk replacer) until 3 to 4 mo of age.

2) Limited milk system

a) Conventional system

(1) Feed milk, milk replacer, or stored colostrum at 8 to 10% of body wt until they start consuming 2 to 3 lb starter/day, at which time "milk feeding" can be decreased & no milk by 4 to 7 wk of age.
(2) Start feeding hay at 1 wk of age. Or, perhaps, delay feeding hay until l mo of age to encourage early starter consumption.
(3) Most economical under the midwest conditions, i.e., abundant grain supply and generally good milk prices.

b) Early weaning

(1) Off milk entirely by 1 mo of age. Requires good management practices and early adjustment to starter feeding.
(2) Calves may not appear as thrifty at 1 mo of age, but may look no different vs. others at 3 to 4 mo of age.
(3) Suggested milk feeding program? - 4-6, 5-7, and 3-4 lb milk/d for 0-3, 4-24, and 25-31 d of age, respectively.
(4) At the time of weaning, in addition to milk, should be consuming "dry feed" at the rate of 1.5% of body wt.

C. Calf scours?

1) A major concern for calves before weaning.
2) With a mild case [i.e., not off-feed, depressed, and(or) no fever], providing an oral electrolyte solution usually may be beneficial.
3) Remove or substantially reduce the amount of milk or milk replacer offered?

a) Recommended practice by some, but others insist calves should be fed a usual amount of milk replacer!
b) Provide/feed electrolytes 3-6 times depending on how soon feces become firm. A 100-lb calf should consume about 5 qt (10% of body wt) daily?

D. Hay or silage for the young calf

1) May start nibbling a good quality hay as early as 5 to 10 days of age, but will not consume appreciable quantities before 8 to 10 wk of age.
2) Inconvenient to feed forages?

a) May want to incorporate a forage factor (i.e., fiber) into the starter ration (20 to 25%)?
b) Adequate fiber is essential for proper health of the rumen papillae and calves will crave roughage.

3) Silages should be limited before 3 mo of age because of the moisture content.

FEEDING HEIFERS, BULLS, AND DAIRY BEEF

1. Four to 12 Months of Age

A. If heifers are properly introduced to solid feeds before weaning, a growing ration can be changed gradually so that they reach puberty at 15 mo of age.

B. Rumen capacity? - Not sufficient for the animal to satisfy the energy need from forages alone, thus feeding some grain is necessary until l yr of age.

1) Summer - Pasture, hay, and grain mix (3-7 1b/d depending on body size and forage quality)?

2) Winter - Hay, silage, and grain mix (3 - 71b/d depending on body size and forage quality)?

C. The same forage and grain mix used for the milking herd can be used for heifers.

1) Should vary "inversely" the protein content between the grain mix & forage.

2) A free-choice mineral mix is recommended. Should include Ca, P, salt, and trace minerals with a poor forage.

3) Suggested grain mixes for the growing calf? - Should be limited to no more than 5 to 7 lb daily along with free-choice forage consumption (Table).

D. Excess fat? If necessary, limit grain to keep calves from becoming too fat.

1) Excess fat can develop breeding problems.

2) Also, produce less in later life vs. those reared on a more moderate nutrition possibly because of excess fatty tissues in the udder.

Suggested grower rations for 440-1b (200-kg) dairy calves (4-12 months of age)[a,b] [Jurgens, 2002]

Ingredients	1	2	3	4
Ingredient, %				
Corn, cracked	78	-	-	50
Oats, rolled	20	35	-	27
Barley, rolled	-	50	-	-
Gr. ear corn	-	-	76	-
Molasses, liquid	-	5	5	-
Soybean meal	-	8	17	20
Limestone	-	-	-	1
Dicalcium phosphate	1	1	1	1
Trace mineral salt	1	1	1	1
	100	100	100	100
Calculated ana/ysis:				
As-fed basis				
Crude protein, %	9.2	13.8	13.9	16.7
TDN, %	74.9	70.0	71.1	72.8
NEm,Mcal/kg	1.87	1.71	1.84	1.82
NEg,Mcal/kg	1.29	1.16	1.27	1.25
Calcium, %	0.25	0.33	0.35	0.68
Phosphorus, %	0.48	0.56	0.49	0.56
Dry matter, %	87.9	88.4	86.7	88.6
Dry matter basis				
Crude protein, %	10.5	15.6	16.0	18.8
TDN, %	85.2	79.2	82.0	82.2
NEm, Mcal/kg	2.13	1.93	2.12	2.05
NEg, Mcal/kg	1.47	1.31	1.46	1.41
Calcium, %	0.28	0.37	0.40	0.77
Phosphorus, %	0.55	0.63	0.56	0.63

[a]Formulations are on an as-fed t-asis. Ration 1 is recommended to be fed with legume hay (14-17% CP). Rations 2 and 3 should be fed with a legume-grass mixed hay (10-13% CP). Ration 4 is recommended to be fed with a grass hay (6-9% CP).
[b]Dairy calves should consume daily: 2.0 to 2.5% of their body weight as dry matter forage and 0.5 to 1.0% as dry matter grain mix.

2. From 12 Months of Age to Calving

A. Should have sufficient rumen capacity to meet their nutrient needs from good quality forages.

1) Should be gaining 1.5 to 1.8 1b per day.
2) Feed grain mix only when/if forages are poor or limited in amount.
3) Summer? - Use pasture and(or) hay, and feed 2 to 8 lb of grain mix if necessary (. . . depending on the body size).
4) Winter? - Use hay and silage, and also feed 2 to 8 lb of grain mix if necessary (. . . depending on body size).
5) Provide minerals free-choice. Include Ca, P, & salt, and trace minerals if feeding poor forages.

B. To breed at 15 mo, heifers should be weighing 550 (Jerseys) to 800 lb (Holstein and Brown Swiss). Should gain about 1.75 lb/day from birth!?

C. Growing heifers use available nutrients in an irreversible order: 1) Daily maintenance, 2) growth, and 3) ovulation and conception.

D. Avoid over-conditioning to prevent impairment of reproductive efficiency and also reduced milk production because of fatty deposits in the udder.

E. Some management techniques for early conception?

1) "Flushing" - Increase the intake of all the nutrients to heifers with appropriate age.
2) "Bypass protein" - Use during the first breeding period?
3) "Proteinated trace minerals" - May improve the breeding efficiency.
4) "Ionophores" - Not only reduce waste caused by methane production (& also acting as coccidiostats?) but also spare intake protein by reducing ruminal ammonia production.

F. Nutrition of bred heifers:

1) Feeding to about 60 days before the expected calving date? Should aim for growth, yet avoid excess fat deposition, especially in the udder.
2) The last 60 days of gestation or transition period? Start feeding a grain mix and increase gradually to adapt heifers to high grain intake, which will be necessary for lactation after calving. By doing so:

    a) Can adjust the rumen population to increase microbes that ferment specific feeds in a lactation ration.
    b) Can increase nutrient intakes to increase body reserves necessary to support early lactation . . . plus own growth.
    c) Can provide for the increased demand for nutrients because of rapidly developing fetus.

3. **Feeding Bulls**

A. Bull calves for breeding purposes?

1) Because of today's widespread use of artificial insemination, only a few dairy bull calves are raised for breeding purposes.

2) Should be fed and handled much the same way as heifers, but bulls grow faster than heifers, thus should receive more feed.

B. Older bulls:

1) Should be kept in thrifty, vigorous condition, but not too fat.
2) Mature bulls can be maintained on forage with about 0.5 lb of grain per 100 lb of body wt, if needed - The same grain ration as the one being fed to lactating cows.

4. **Feeding Dairy Breeds for Beef**

A. In the US, about 4 million Holstein steer calves are produced annually.
B. A small portion for veal, and the rest of calves are fed for the commercial beef market.
C. Calves not developed as replacement heifers or bulls are fed and marketed as beef.
D. Types of programs for finishing Holstein? Some e.g.:

1) Raised in hutches and small group pens, weaned along with replacement heifers, and then put on full feeding program.
2) Weaned calves going through an on-the-farm growing program before being put on a finishing program
3) Weaned calves going to the pasture before finishing.

E. Two most common finishing programs and market wt?

1) High-energy diet/light market wt - Full feed a high-grain diet from about 300 lb to market wt of 800 to 1,000 lb.
2) High-roughage/heavy market wt - Grown on roughages (corn or sorghum stalks, wheat or other excess pasture) to 600 to 800 lb, then feed a high-grain diet during a finishing period in the feedlot. Generally marketed at 1,150 to 1,400 lb.

FEEDING FOR MILK PRODUCTION

1. **General**

A. Milk and milk products:

1) In the American diet? Annual per capita consumption of about 280 kg of dairy products, and they supply about 75% of dietary Ca. Also, an important source of other nutrients, i.e., energy, protein, vitamins, and other minerals.
2) Other countries? Consumption could be 50 to 100% higher than the US in some countries, and world consumption is more than 100 kg per capita . . . even when including those countries with consumption of much less milk products.

B. In the US, about 9.5 million dairy cows, each producing an average of 7,500 kg milk/year.

C. Systems used in the US? The type of system used is partially dependent on the geographic area and availability of feedstuffs.

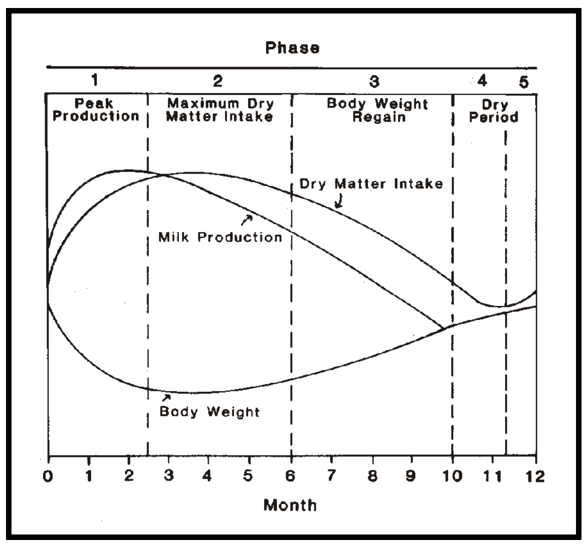
1) Pasture system - Traditional system is continuing in areas of sparse human population.
2) Drylot systems with minimum roughage and higher quantities of less bulky feeds such as concentrates - Being used in areas surrounding some of the larger cities.

D. Dairy cows need to consume a lot of feed/nutrients to achieve today's expected milk production, and feed represents about 50% of the total production costs.

1) Thus, feeding program, more than any other single factor, can determine the productivity of lactating dairy cows & profitability!?.
2) About 75% of the differences in milk production between cows is determined by environmental factors, with feed making up the largest portion.
3) At peak production, may require 3 to 10 times as much as protein & energy vs. late gestation, but the cow's appetite usually lags behind her nutritional needs.

2. **The lactation and Gestation Cycle**

A. The relationships among milk production, DM intake, and body wt changes [See the figure (Schingoethe, 1998)].
B. Milk production? - Increases rapidly and reaches peak 6-8 wk after calving.
C. Feed intake? - Lags behind milk production, i.e., maximum DM intake does not reach until 12 to 15 wk after calving.
D. Body reserves? - Make up the difference in the need & supply by mobilizing body stores. Often loose 90 to 135 kg of body wt!?



3. **Forages**

A. The cow cannot consume enough forage to meet her nutrient needs during lactation, even though they have a considerable capacity!

Forage quality	Daily intake (% BW)
Excellent	3.0
Good	2.5
Average	2.0
Fair	1.5
Poor	1.0

1) Daily intake for forages is estimated based on body wt and forage quality (Table - DM basis).
2) Allowed to consume all the forage at their will? Then, may not have enough room left to consume necessary grains to meet the energy needs of high milk production, thus limit forage intake to 1.75 to 2.0% of boy wt!?
3) Estimated silage intake (as-fed basis)? - 3 lb for each l lb of expected hay intake.

4) Pasture intake? - Usually, higher than silage at the same dry matter percentages.

B. Increase forage intake by feeding several times/day and providing a variety of forages?!

4. Concentrates

A. A concentrate mixture contains grains, mill feeds, protein supplements, and minerals (See the table for some examples).

1) The kind of mixture to feed will vary with the kind of forage fed (e.g., a high-protein mix will be needed with a low-protein forage), availability, and cost.
2) The amount of concentrate mix fed will depend on:
   a) The amount of forage consumed.
   b) The amount of milk produced.
   c) The composition (fat %) of the milk produced.
3) Limit % of concentrates to a maximum of about 60% regardless of comparative cost of grains and roughages.
4) Rations with more than 60% of concentrates may result in changes in proportion of ruminal VFA, which in turn can result in the reduction of milk fat.

Suggested concentrate mixtures for lactating dairy cows fed different quality forages[a] (Jurgens, 2002)

	High protein		Medium protein			Low protein	
	1	2	3	4	5	6	7
Ingredient							
Corn, gr.	-	70	-	-	-	50	-
Ground ear corn	92	-	85	74	78	-	61
Oats, gr. or rolled	-	28	-	-	-	-	-
Wheat bran	-	-	-	-	-	23	-
Molasses, liquid	-	-	-	-	-	-	6
Urea (281% CPE)[b]	-	-	1	-	-	-	-
Soybean mea1[c]	6	-	12	-	20	24	30
Soybeans,cracked	-	-	-	24	-	-	-
Dicalcium phosphate[d]	1	1	1	1	1	1	1
Limestone	-	-	-	-	-	1	1
TM salt & vitamin	1	1	1	1	1	1	1
	100	100	100	100	100	100	100
Calculated analysis:							
As-fed basis							
Crude protein, %	9.9	9.5	14.9	15.2	15.2	18.9	18.7
TDN, %	71.4	74.2	70.8	73.5	71.7	71.6	70.5
NEL, Mcal/kg	1.65	1.72	1.63	1.70	1.65	1.66	1.63
Calcium, %	0.29	0.25	0.30	0.34	0.32	0.70	0.76
Phosphorus, %	0.45	0.48	0.47	0.51	0.51	0.76	0.55
Dry matter, %	86.9	88.1	87.3	88.1	87.4	88.6	87.1
Dry matter basis							
Crude protein, %	11.4	10.8	17.1	17.2	17.4	21.3	21.4
TDN, %.	82.2	84.2	81.1	83.4	82.0	80.8	80.9
NEL, Mcal/kg	1.90	1.95	1.87	1.93	1.89	1.87	1.87
Calcium, %	0.33	0.28	0.34	0.38	0.37	0.79	0.87
Phosphorus, %	0.52	0.54	0.54	0.58	0.58	0.86	0.63

[a]Formulations are on an as-fed basis; [b]Urea may be included up to I% of the concentrate mix to supply protein; [c]Other high-protein feeds or commercial supplements can be substituted for soybean meal on a protein basis; [d]Other high Ca-P mineral mixes as steamed bone meal or commercial mixtures can replace dicalcium phosphate.

B. Intake of a concentrate mixture is affected by palatability and the time available to consume concentrates in the barn or milking parlor.

C. Depends, but tend to overfeed the low producer and underfeed the high producer?!

5. Phase Feeding Program/Feeding Guidelines

A. Feeding periods/phases can be divided into four or five - See "2. The Lactation and Gestation Cycle."

1) Phase 1 - First 10 wk of lactation. Peak milk production & body stores are being used to make up deficits in the nutrient intake.
2) Phase 2 - 10 to 20 wk or so of lactation. Maximum DM intake, and the intake is in balance with the needs?!
3) Phase 3 - The intake exceed the needs. The main period to restore body reserves for the next lactation.
4) Phases 4 & 5 - Dry period, and can be considered as only one phase, but:

    a) Phase 4 - Most of the dry period, and replete body reserves & regenerate secretory tissues for the next lactation.
    b) Phase 5 - The last 1 to 3 wk of pre-partum. Start increasing grain intake as a means to prepare the rumen for the increased nutritional demands?!

B. Dry period & bred heifers (Phases 4 & 5)

1) Cows need a short dry period as rest to prepare for the next lactation. The optimum dry period would be 6 to 8 wk!

    a) Shorter that 40 d? - Not enough time for udder regeneration, thus may reduce the production rate.
    b) Longer than 60 d? - Do not increase the production, and may result in excess body condition & calving difficulties.

2) Bred heifers

    a) Nutrient needs are slightly higher vs. dry cows of similar size - Still growing!
    b) Good-quality hay can provide all the nutrient needs during the early gestation.
    c) Need some grains along with forages during the last 3 to 4 mo of gestation to support growth & provide nutrients for fetus.
    d) As with dry cows, should be in good condition but not too fat at calving.

3) Quality of forage may not be as critical during the dry period, but cows need sufficient feed to support both the unborn calf and to meet body reserves not replaced in the previous period.
4) Nutrient needs can be met with only forages and no grain, but may be fed up to 4 to 6 lb of grain per day (0.5% of body wt) depending on the condition. (DM intake is approximately 2% of body wt!)
5) "Fat cow syndrome" - Feeding high levels of corn silage or grains may cause excess fat deposits in the liver area:

    a) Characterized by high blood lipids & fatty livers.
    b) May result in calving difficulties, displaced abomasum, ketosis, and others.
    c) Less likely to have problems with hay and(or) haylage vs. corn silage.

6) About 2 wk before calving, increase grain feeding, so cows are consuming 12 to 16 lb grain/day at calving (1% of body weight).

   a) Helps cows get accustomed to high grain intake needed after calving, and can reduce the occurrence of ketosis during lactation.
   b) Best to increase the amount of grains gradually, which may minimize the chance for milk fever. Most grain mixes have a more desirable Ca to P ratio?
   c) Feed a low-Ca ration (< 0.20%, reduce Ca intake to 14 to 18 g/d) 2 wk before parturition to those with milk fever problems may be beneficial?!
   d) Also, feed a diet with a negative dietary electrolyte balance (-10 to -15 mEQ/100 g DM) may alleviate milk fever problems!?

C. Peak milk production (Phase 1)

1) Cows should be brought into peak milk production as soon as possible after calving. Can be done by feeding slightly more grain than recommended until there is no increase in production & then adjusting the amount of grain accordingly.
2) Milk production increases rapidly, peaking at 6 to 8 wk after calving.
3) The most critical period for a dairy cow is "from parturition until peak milk production:"

   a) Objective for this phase? - To increase feed intake as rapidly as possible!
   b) Increase grain intake 1 to 2 lb per day after calving to meet the energy needs.
   c) May want to avoid excessive grain (> 65% total DM) and maintain 17 to 19% acid detergent fiber in diet to reduce rumen disorders.
   d) Extra dietary protein permits more efficient use of body fat for milk production because cows are usually losing body weight.
   e) More ruminally undegradable protein source (i.e., bypass protein) might be recommended for high-producing cows in early lactation.

      - The protein need of cows producing up to 5 kg/100 kg body wt can be met by rumen microbial protein, plus normal amount of bypass protein, but cows producing more would benefit form additional bypass protein.

   f) Limit urea to 0.2 to 0.4 lb/day. Some research indicates urea is utilized less efficiently when total ration protein level is high.
   g) Increasing the energy density of the ration may help cows meet the energy requirement. Feed 1 to 1.5 lb of added fat per day may increase energy intake while maintaining adequate fiber intake.
   h) Buffers, such as Na bicarbonate alone or in combination with Mg oxide, may be beneficial during the early lactation - May aid in maintaining ruminal pH, which minimizes acidosis, reduce digestive upsets, and result in increased DM intake.

D. Peak dry matter intake (Phase 2)

1) To maintain peak milk production, should achieve maximum DM intake as early in lactation as possible. Usually, reached at 12 to 14 wk
2) With maximum DM intake:

   a) Can minimize the negative nutrient balance experienced during the early lactation.
   b) A conception rate is greater for ones in positive energy balance, which is an important consideration because cows are usually being bred during this phase.

3) Maximum DM intake will likely to reach 3.5 to 4% of body wt for most cows, but some variations. (Some may consume as much as 5% of body wt?)

   a) Grain intake may reach 2½% of cow's body wt, and forage intake (DM) should be at least 1-1¼% of cow's body wt to maintain rumen function and milk-fat test.
   b) Should feed forages and grain several times daily.
   c) High-producing cows (i.e., > 70 lb 4% FCM) should be fed only natural protein and not urea!?
   d) Protein?

      (1) Percent protein needed may be lower than the early lactation possibly because of the absolute amount of protein being consumed?
      (2) Less beneficial effect of bypass protein? - Increased microbial protein synthesis can be stimulated by the increased DM intake?! Still, should try to maintain a balance between ruminally degradable & undegradable protein.

E. Mid to late lactation (Phase 3)

1) Perhaps, the easiest phase to manage because milk production is declining and the nutrient intake exceeds the needs. (The cow is pregnant at this phase though.)
2) Should keep in mind that young cows are still growing, i.e., the nutrient requirements for growth are 20% of the maintenance requirements for 2-yr-olds and 10% maintenance for 3-yr-olds.
3) Match grain intake to milk production, and avoid wasteful grain feeding to low producers - Perhaps, an opportunity to minimize feed costs during this phase?
4) The NPN may be well utilized, thus can use urea (0.4 to 0.5 lb/cow/day) if needed to, again, reduce feed costs.
5) Feed extra nutrients, if needed, to replace any body tissue lost during the early lactation. Cows are more efficient in replacing body tissue while lactating than during the dry period, but avoid over-conditioning.

6. **Some Considerations in Feeding for Milk Production?**

A. Optimizing feed intake during lactation

1) Water content of feed:

   a) Important consideration when using ensiled or fresh forages, or other high-moisture feedstuffs such as high-moisture corn, wet brewers grains, liquid whey.
   b) The effect on DM intake is less when water is present in the form of fresh forages than it is in the form of silage or other fermented feeds - e.g., DM intake can be reduced when the moisture content exceeds 50% from ensiled feeds, perhaps, partially caused by chemicals in the feed rather than by moisture per se?

2) Frequency of feeding:

   a) A minimum of four daily feedings? - Alternating between forages and concentrates might be the best to increase intake.
   b) Total mixed ration? - Feeding frequency may not increase DM intake, but may help to stabilize rumen fermentation though!

3) High-producing cows? Obviously, necessary to maximize feed intake:

   a) Should have access to feeds for at least 18 to 20 hr/d? May consume their daily intake in 12 to 22 meals & increase the intake!
   b) Consuming more than 4.5 kg of concentrate mix/meal at once can cause acidosis.
   c) Many electronic grain feeders are programmed to limit the amount of concentrate consumed by a cow within a short period of time, which would be helpful in alleviating acidosis problem.

B. Feed young growing cows enough to allow for growth, as well as for maintenance and milk production. Best to group cows by production as a means of challenge feeding.
C. In general, more cows are underfed energy than protein. [Most lactation rations will contain 13 to 17% CP and 60 to 70% TDN (0.6 to 0.8 Mcal/lb NEl).]
D. Finely ground or pelleted forages or grains should not be fed alone to lactating cattle because it can lower milk fat test.
E. Best to feed some hay when using silage.
F. Cows in full production will consume 3 to 5 lb of water (including water in feed) for each l lb of milk produced. Have water available at all times and warm water during winter?
G. Give considerations to the relationship of feeds & milk flavor, e.g., cows must be removed from wheat pasture several hours before milking to prevent an off-flavor problem.
H Added Fat

1) High-producing cows during the first 12 to 16 wk of lactation will benefit most. Cows under heat stress may also benefit.

2) Lactating cows can be fed 1 to 1.5 lb of added fat per day to increase the energy density:

   a) Can be blended into the concentrate mix up to 8% or up to 4% to the total ration. Higher percentages may reduce feed intake, reduce fiber digestibility, and cause digestive upsets, especially with unsaturated fatty acids?
   b) Whole or processed oilseeds may be fed as a source of added fat.

      (1) Oilseeds contain polyunsaturated fatty acids, but they are slowly digested and the oil is gradually released into the rumen, thus allowing for saturation of the fatty acids and less chance of reduced fiber digestibility or milk fat depression.
      (2) Oilseeds also provide some protein and fiber. Perhaps, feed 5 to 7 lb oilseeds (whole or rolled) per head daily.
      (3) Heat-treated soybeans may have greater protein bypass properties than unheated soybeans.

3) When feeding fat, increase the dietary Ca to 0.9% +, Mg to 0.3%, acid detergent fiber to 20%, and also increase the CP content by 1 or 2%.

I. Protein

1) The need for protein increases even more dramatically at the onset of lactation than the increase in energy needs because milk solids contain about 27% CP.
2) Achieving optimal protein utilization?

   a) Supply sufficient amounts of ruminally degradable protein & fermentable energy for maximum microbial protein synthesis.
   b) Supply the remainder of the protein needs with high-quality ruminally undegradable protein.
   c) Relative proportion in a typical ration? - 60% ruminally degradable protein & 40% ruminally undegradable protein.
   d) Supplementing with ruminally protected amino acids can be another means to increase the amount of amino acids presented to the GI tract. But, must supplemet with the most limiting amino acid, which might be difficult to determine.
   e) Microbial protein synthesis:

      (1) The amount of microbial protein varies with many factors, but perhaps, limited to 2 to 3 kg/d?
      (2) High-producing cows (> 5 kg milk/100 kg BW) will likely to benefit form more bypass protein.

J. Bovine somatotropin (BST):

1) Has been approved for use in lactating cows to increase milk production. Expected increase milk production by 8 to 10 + lbs milk per day.
2) It is marketed as "Posilac," a 14-day prolonged-release BST, and the dose is 500 mg BST injected every 14 days (36 mg/cow per day).
3) Should be given to healthy cows from 9th wk of lactation until drying off.
4) Has no effect on basal metabolism and maintenance or digestion of feeds:

    a) Directs nutrients away from other body tissues towards the mammary gland.
    b) The efficiency of nutrient utilization is not altered, thus increased milk production, and results in a greater requirement for energy and nutrients.
    c) Feed intake of BST cows increases within 3-6 wk to support the increase in milk production, thus cows will lose body condition initially.

5) When using BST, dairy producers should score cows for body condition to reduce the incidence of lowered reproductive performance.

NUTRIENT REQUIREMENT TABLES FOR NON-LACTATING DAIRY ANIMALS
(Based on NRC, 2001)

1. **Table 1. Daily Energy and Protein Requirements of Young Replacement Calves Fed Only Milk or Milk Replacer**[a] [NEm = net energy for maintenance; NEg = net energy for gain; ME = metabolizable energy; DE = digestible energy; ADP = apparent digestible protien; CP = crude protein]

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

[a]**Dry Matter Intake** = necessary to meet ME requirements for calves fed milk replacer composed primarily of milk proteins and containing ME at 4.75 Mcal/kg of dry matter; NEm (Mcal) = 0.086 $LW^{0.75}$, where LW is live weight in kilograms; **NEg** (Mcal) = (0.84 $LW^{0.355}$ x $LWG^{1.2}$) x 0.69, where LW and LWG (live weight gain) are in kilograms; **ME** (Mcal) = 0.1 $LW^{0.75}$ + (0.84 $LW^{0.355}$ x $LWG^{1.2}$), where LW and LWG are in kilograms; **DE** (Mcal) = ME/0.96; **ADP**(g/d) = 6.25 [l/BV(E + G + M x D) - M x D]. BV (biologic value) is assumed to be 0.8. E (endogenous urinary nitrogen) is 0.2 $LW^{0.75}$/d, where LW is in kilograms. M (metabolic fecal nitrogen) is 1.9 g/kg of dry matter intake (D). G (nitrogen in live weight gain) is 30 g/kg of LWG; **CP** = ADP/0.93. The digestibility of undenatured milk proteins is assumed to be 93 percent; **Vitamin A** (IU) = 110 IU/kg of LW.

2. **Table 2. Daily Energy and Protein Requirements of Calves Fed Milk and Starter or Milk Replacer and Starter**[a] [NEm = net energy for maintenance; NEg = netenergy for gain; ME = metabolizable energy; DE = digestible energy; ADP = apparent digestible protien; CP = crude protein]

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

[a]These data apply to calves fed milk replacer (MR) plus starter. MR contains ME at 4.75 Mca/kg of DM and starter ME at 3.28 McaVkg. It is assumed that MR provided 60 percent and starter 40 percent of dry matter intake; thus, dry matter consumed contained ME at 4.16 Mca/kg. The DMI here is the total necessary to meet ME requirements and is not intended to predict voluntary intake; **NEm** (Mcal) = 0.086 $LW^{0.75}$, where LW is live weight in kilograms; **NEg** (Mcal) = (0.84 $LW^{0.355}$ x $LWG^{1.2}$) x 0.69, where LW and LW gain (LWG) are in kilograms; ME (Mcal) was computed as follows: **ME** (maintenance) = NEm/0.825. Efficiency of use of ME for maintenance (0.825) was computed as average of efficiencies of 0.86 for MR and 0.75 for starter, weighted according to proportions of ME supplied by each feed. ME (gain) = NEg/0.652. Efficiency of use of ME for gain (0.652) was computed as weighted average of efficiencies of 0.69 and 0.57 for MR and starter, respectively; **DE** (Mcal) = ME/0.934. Efficiency of conversion of DE to ME is assumed to be 0.96 for MR and 0.88 for starter; **ADP** (g/d) = 6.25 [1/BV(E + G + M x D) - M x D]. BV (biologic value) = 0.764 (weighted average of MR = 0.8 and starter = 0.70). E (endogenous urinary nitrogen, 9) = 0.2$LW^{0.75}$. G (nitrogen content of gain, g) = 30 g/kg gain. M (metabolic fecal nitrogen, g/d) = 2.46 x dry matter intake, D, kg). Metabolic fecal nitrogen for MR assumed to be 1.9 g/kg of DMI and for starter 3.3 g/kg of DMI.; **CP** (g) = ADP/0.8645. Digestibility of protein was assumed to be weighted average of 93 percent for MR and 75 percent for starter; MR was assumed to contain 21 percent CP and starter 18 percent CP; **Vitamin A** (IU) = 110 IU/kg of LW.

3. Table 3. Daily Energy and Protein Requirements of Veal Calves Fed Only Milk or Milk Replacer[a] [NEm = net energy for maintenance; NEg = net energy for gain; ME = metabolizable energy; DE = digestible energy; ADP = apparent digestible protien; CP = crude protein]

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

[a]**Dry Matter Intake** = necessary to meet ME requirements when veal calves are fed milk replacer containing ME at 4.75 Mcal/kg of DM; **NEm** (Mcal) = 0.086 $LW^{0.75}$, where LW is live wt in kg; **NEg** (Mcal) = (0.84 $LW^{0.355}$ x $LWG^{1.2}$) x 0.69, where LW and LWG (live wt gain) are in kg; **ME** (Mcal) = 0.1 $LW^{0.75}$ + (0.84 $LW^{0.355}$ x $LWG^{1.2}$), where LW and LWG are in kg; **DE** (Mcal) = ME/0.93; **ADP** (g/d) = 6.25 [l/BV(E + G + M x D) - M x D]. BV (biologic value) is assumed to be 0.8. E (endogenous urinary nitrogen) is 0.2 $LW^{0.75}$/d, where LW is in kg. M (metabolic fecal nitrogen) is 1.9 g/kg of dry matter intake (D). G (nitrogen in live wt gain) is 30 g/kg of LWG; **CP** = ADP/0.93. The digestibility of undenatured milk proteins is assumed to be 93%; **Vitamin A** (IU) = 110 IU/kg of LW.

4. **Table 4. Daily Energy and Protein Requirements of Weaned (Ruminant) Calves**[a] [NEm = net energy for maintenance; NEg = net energy for gain; ME = metabolizable energy; DE = digestible energy; ADP = apparent digestible protien; CP = crude protein]

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

[a]These data apply to small-breed female calves from 50 to 80 kg gairung 0.4 to 0.5 kg/d and large-breed calves from 60 to 100 kg gaining from 0.6 to 0.9 kg/d; **NEm** (Mcal) = 0.086 $LW^{0.75}$ (NRC 1989), where LW is live weight in kilograms; **NEg** (Mcal) = (0.84 $LW^{0.75}$ x $LWG^{1.2}$) x 0.69, where LW and LW gain (LWG) are in kilograms; **ME**, maintenance (Mcal) = NEm/0.75. ME values of diets (Mcal/kg of DM) are 3.10 for calves weighing 60, 10, and 80 kg and 2.90 for calves weighing 90 and 100 kg. ME, gain (Mcal) = NEg/0.57. Sum of ME values for maintenance plus gain equals total ME requirement; **DE** (Mcal) = (ME + 0.45) /1.01; **ADP** (g/d) as follows: ADP (g/d) = 6.25 [l/BV(E + G + M x D) - M x D] where BV is biologic value set at 0.10. E (endogenous urinary rutrogen) = 0.2$LW^{0.75}$. G is rutrogen content of gain, assuming 30 g/kg of gain. M is metabolic fecal rutrogen computed as 3.3 g/kg of dry matter consumed (D); **CP** calculated as ADP/0.75; **Vitamin A** (IU) = 110 IU/kg of LW.

5. **Table 5. Daily Nutrient Requirements (DM basis) of Small Breed (Mature Weight = 450 kg) Non-Bred Heifers**[a] [BW = body weight; ADG = average daily gain; DMI = dry matter intake; TDN = total digestible nutrients; NEm = net energy for maintenance; NEg = net energy for gain; ME = metabolizable energy; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

BW kg	ADG kg/d	DMI kg/d	TDN %	NEm Mcal/d	NEg Mcal/d	ME Mcal/d	RDP g/d	RUP g/d	RDP %	RUP %	CP %	Ca g/d	P g/d
100	0.3	3.0	56.5	2.64	0.47	6.0	255	110	8.6	3.7	12.4	14	7
	0.4	3.0	58.6	2.64	0.64	6.4	270	143	9.0	4.7	13.7	18	8
	0.5	3.1	60.7	2.64	0.82	6.7	284	175	9.3	5.7	15.0	21	10
	0.6	3.1	62.9	2.64	1.00	7.0	298	207	9.6	6.7	16.3	25	11
	0.7	3.1	65.2	2.64	1.19	7.3	310	239	10.0	7.7	17.7	28	12
	0.8	3.1	67.7	2.64	1.37	7.6	323	270	10.4	8.7	19.0	31	13
150	0.3	4.0	56.5	3.57	0.63	8.2	346	95	8.6	2.4	11.0	15	8
	0.4	4.1	58.6	3.57	0.87	8.7	366	124	9.0	3.0	12.0	19	10
	0.5	4.1	60.7	3.57	1.11	9.1	385	152	9.3	3.7	12.9	22	11
	0.6	4.2	62.9	3.57	1.36	9.5	403	180	9.6	4.3	13.9	25	12
	0.7	4.2	65.3	3.51	1.61	9.9	421	207	10.0	4.9	14.9	28	13
	0.8	4.2	67.7	3.57	1.86	10.3	437	234	10.4	5.5	15.9	31	14
200	0.3	5.0	56.5	4.44	0.79	10.2	429	81	8.6	1.6	10.3	17	10
	0.4	5.1	58.6	4.44	1.08	10.7	454	106	9.0	2.1	11.1	20	11
	0.5	5.1	60.7	4.44	1.38	11.3	478	131	9.3	2.6	11.8	23	12
	0.6	5.2	62.9	4.44	1.68	11.8	500	156	9.6	3.0	12.6	26	13
	0.7	5.2	65.3	4.44	1.99	12.3	522	179	10.0	3.4	13.4	29	14
	0.8	5.2	67.7	4.44	2.31	12.8	543	202	10.4	3.9	14.2	32	15
250	0.3	5.9	56.5	5.24	0.93	12.0	508	69	8.6	1.2	9.8	19	11
	0.4	6.0	58.6	5.24	1.28	12.7	537	91	9.0	1.5	10.5	21	12
	0.5	6.1	60.7	5.24	1.63	13.4	565	113	9.3	1.9	11.1	24	13
	0.6	6.1	62.9	5.24	1.99	14.0	592	135	9.6	2.2	11.8	27	14
	0.7	6.2	65.3	5.24	2.36	14.6	617	155	10.0	2.5	12.5	30	15
	0.8	6.2	67.7	5.24	2.73	15.2	642	175	10.4	2.8	13.2	32	16
300	0.3	6.7	56.5	6.01	1.07	13.8	582	58	8.6	0.9	9.5	20	12
	0.4	6.9	58.6	6.01	1.46	14.6	616	79	9.0	1.1	10.1	23	13
	0.5	7.0	60.7	6.01	1.87	15.3	648	98	9.3	1.4	10.7	26	14
	0.6	7.0	62.9	6.01	2.28	16.0	678	117	9.6	1.7	11.3	28	15
	0.7	7.1	65.3	6.01	2.70	16.7	707	135	10.0	1.9	11.9	31	16
	0.8	7.1	67.7	6.01	3.13	17.4	736	151	10.4	2.1	12.5	34	17

[a]Crude protein required on1y if ration is perfectly balanced for RDP and RUP.

6. **Table 6. Daily Nutrient Requirements (DM basis) of Large Breed (Mature Weight = 650 kg) Non-Bred Heifers**[a] [BW = body weight; ADG = average daily gain; DMI = dry matter intake; TDN = total digestible nutrients; NEm = net energy for maintenance; NEg = net energy for gain; ME = metabolizable energy; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

BW kg	ADG kg/d	DMI kg/d	TDN %	NEm Mcal/d	NEg Mcal/d	ME Mcal/d	RDP g/d	RUP g/d	RDP %	RUP %	CP %	Ca g/d	P g/d
150	0.5	4.1	58.4	3.57	0.84	8.6	364	167	8.9	4.1	13.0	23	11
	0.6	4.1	60.0	3.57	1.03	9.0	379	199	9.2	4.8	14.0	26	12
	0.7	4.2	61.7	3.57	1.22	9.3	393	230	9.4	5.5	14.9	30	13
	0.8	4.2	63.4	3.57	1.41	9.6	407	261	9.7	6.2	15.9	33	15
	0.9	4.2	65.3	3.57	1.61	9.9	421	292	10.0	6.9	16.9	37	16
	1.0	4.2	67.2	3.57	1.80	10.3	434	322	10.3	7.6	17.9	40	17
	1.1	4.2	69.2	3.57	2.00	10.6	446	352	10.6	8.3	18.9	43	18
200	0.5	5.1	58.4	4.44	1.05	10.7	452	148	8.9	2.9	11.9	24	12
	0.6	5.1	60.0	4.44	1.28	11.1	470	177	9.2	3.4	12.6	27	13
	0.7	5.2	61.7	4.44	1.51	11.5	488	205	9.4	4.0	13.4	30	14
	0.8	5.2	63.4	4.44	1.75	11.9	505	233	9.7	4.5	14.2	34	15
	0.9	5.2	65.3	4.44	1.99	12.3	522	260	10.0	5.0	15.0	37	17
	1.0	5.2	67.2	4.44	2.24	12.7	538	287	10.3	5.5	15.8	40	18
	1.1	5.2	69.2	4.44	2.49	13.1	554	314	10.6	6.0	16.6	43	19
250	0.5	6.0	58.4	5.24	1.24	12.6	534	131	8.9	2.2	11.1	25	13
	0.6	6.1	60.0	5.24	1.51	13.1	556	156	9.2	2.6	11.8	28	14
	0.7	6.1	61.7	5.24	1.79	13.6	577	182	9.4	3.0	12.4	31	15
	0.8	6.2	63.4	5.24	2.07	14.1	597	207	9.7	3.4	13.1	34	16
	0.9	6.2	65.3	5.24	2.36	14.6	617	232	10.0	3.7	13.7	37	17
	1.0	6.2	67.2	5.24	2.65	15.0	636	256	10.3	4.1	14.4	40	18
	11.1	6.2	69.2	5.24	2.94	15.5	655	280	10.6	4.5	15.1	43	19
300	0.5	6.9	58.4	6.01	1.42	14.5	612	114	8.9	1.7	10.6	27	14
	0.6	6.9	60.0	6.01	1.73	15.1	637	138	9.2	2.0	11.2	30	15
	0.7	7.0	61.7	6.01	2.05	15.6	661	161	9.4	2.3	11.7	33	16
	0.8	7.1	63.4	6.01	2.38	16.2	685	183	9.7	2.6	12.3	35	17
	0.9	7.1	65.3	6.01	2.70	16.7	707	205	10.0	2.9	12.9	38	18
	1.0	7.1	67.2	6.01	3.03	17.2	729	227	10.3	3.2	13.5	41	19
	1.1	7.1	69.2	6.01	3.37	17.7	751	248	10.6	3.5	14.1	44	20
350	0.5	7.7	58.4	6.75	1.59	16.2	687	99	8.9	1.3	10.2	28	15
	0.6	7.8	60.0	6.75	1.94	16.9	715	121	9.2	1.5	10.7	31	16
	0.7	7.9	61.7	6.75	2.30	17.6	742	141	9.4	1.8	11.2	34	17
	0.8	7.9	63.4	6.75	2.67	18.2	769	162	9.7	2.0	11.7	37	18
	0.9	8.0	65.3	6.75	3.03	18.8	794	181	10.0	2.3	12.3	40	19
	1.0	8.0	67.2	6.75	3.41	19.4	819	200	10.3	2.5	12.8	42	20
	1.1	8.0	69.2	6.75	3.78	19.9	843	218	10.6	2.7	13.3	45	21
400	0.5	8.5	58.4	7.46	1.76	18.0	760	86	8.9	1.0	9.9	30	16
	0.6	8.6	60.0	7.46	2.15	18.7	791	105	9.2	1.2	10.4	33	17
	0.7	8.7	61.7	7.46	2.55	19.4	821	124	9.4	1.4	10.9	35	18
	0.8	8.8	63.4	7.46	2.95	20.1	850	142	9.7	1.6	11.3	38	19
	0.9	8.8	65.3	7.46	3.35	20.7	878	159	10.0	1.8	11.8	41	20
	1.0	8.8	67.2	7.46	3.76	21.4	905	176	10.3	2.0	12.3	44	21
	1.1	8.8	69.2	7.46	4.18	22.0	931	192	10.6	2.2	12.8	46	22

[a]CP = crude protein required only if ration is perfectly balanced for RDP and RUP.

7. **Table 7. Daily Nutrient Requirements (DM basis) of Small Breed (Mature Weight = 450 kg) Bred Heifers**[a] [BW = body weight; ADG = average daily gain; DMI = dry matter intake; TDN = total digestible nutrients; NEm = net energy for maintenance; NEg = net energy for gain; ME = metabolizable energy; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

BW kg	ADG kg/d	DMI kg/d	TDN %	NEm Mcal/d	NEg Mcal/d	ME Mcal/d	RDP g/d	RUP g/d	RDP %	RUP %	CP %	Ca g/d	P g/d
300	0.3	7.7	56.5	5.42	0.96	15.7	663	291	8.6	3.8	12.4	36	19
	0.4	7.7	58.6	5.42	1.32	16.4	693	310	9.0	4.0	13.0	39	20
	0.5	7.7	60.8	5.42	1.68	17.0	721	329	9.3	4.2	13.5	41	21
	0.6	7.7	63.1	5.42	2.06	17.7	748	346	9.7	4.5	14.1	44	22
	0.7	7.7	65.5	5.42	2.44	18.3	774	364	10.0	4.7	14.7	47	23
	0.8	7.7	68.1	5.42	2.82	18.9	798	380	10.4	5.0	15.4	49	24
	0.9	7.6	70.9	5.42	3.21	19.4	822	395	10.8	5.2	16.1	52	24
350	0.3	8.6	56.2	6.18	1.10	17.5	739	282	8.6	3.3	11.9	38	20
	0.4	8.7	58.3	6.18	1.50	18.3	773	299	8.9	3.4	12.4	40	21
	0.5	8.7	60.5	6.18	1.92	19.0	805	315	9.3	3.6	12.9	43	22
	0.6	8.7	62.8	6.18	2.35	19.8	836	330	9.6	3.8	13.4	46	23
	0.7	8.7	65.3	6.18	2.78	20.4	865	345	10.0	4.0	14.0	48	24
	0.8	8.6	67.8	6.18	3.22	21.1	893	358	10.4	4.2	14.5	51	25
	0.9	8.5	70.6	6.18	3.66	21.8	921	371	10.8	4.3	15.1	53	25
400	0.3	9.5	56.0	6.91	1.23	19.2	813	275	8.6	2.9	11.5	40	21
	0.4	9.6	58.1	6.91	1.68	20.1	851	291	8.9	3.0	11.9	42	22
	0.5	9.6	60.3	6.91	2.15	21.0	887	305	9.2	3.2	12.4	45	23
	0.6	9.6	62.6	6.91	2.62	21.8	921	319	9.6	3.3	12.9	47	24
	0.7	9.6	65.0	6.91	3.11	22.5	953	331	9.9	3.5	13.4	50	25
	0.8	9.5	67.6	6.91	3.60	23.3	985	342	10.3	3.6	13.9	52	26
	0.9	9.4	70.3	6.91	4.09	24.0	1,015	352	10.8	3.7	14.5	55	26
450	0.3	10.4	55.8	7.62	1.35	20.9	884	273	8.5	2.6	11.2	41	22
	0.4	10.5	57.9	7.62	1.85	21.9	926	288	8.9	2.8	11.6	44	23
	0.5	10.5	60.1	7.62	2.37	22.8	965	301	9.2	2.9	12.1	46	24
	0.6	10.5	62.4	7.62	2.89	23.7	1,003	313	9.5	3.0	12.5	49	25
	0.7	10.5	64.8	7.62	3.42	24.5	1,038	324	9.9	3.1	13.0	51	26
	0.8	10.4	67.4	7.62	3.96	25.4	1,073	333	10.3	3.2	13.5	54	27
	0.9	10.3	70.1	7.62	4.51	26.1	1,106	341	10.7	3.3	14.0	56	28

[a]240 days pregnant (Conceptus weight of 39 kg and ADG of 0.4 kg/day); CP = crude protein required only if ration is perfectly balanced for RDP and RUP.

8. **Table 8. Daily Nutrient Requirements (DM basis) of Large Breed (Mature Weight = 650 kg) Bred Heifers**[a] [BW = body weight; ADG = average daily gain; DMI = dry matter intake; TDN = total digestible nutrients; NEm = net energy for maintenance; NEg = net energy for gain; ME = metabolizable energy; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

BW kg	ADG kg/d	DMI kg/d	TDN %	NEm Mcal/d	NEg Mcal/d	ME Mcal/d	RDP g/d	RUP g/d	RDP %	RUP %	CP %	Ca g/d	P g/d
450	0.5	10.5	59.3	7.49	1.77	22.5	951	402	9.1	3.8	12.9	47	25
	0.6	10.5	61.1	7.49	2.16	23.2	981	418	9.3	4.0	13.3	50	25
	0.7	10.5	62.9	7.49	2.55	23.9	1,010	433	9.6	4.1	13.7	53	26
	0.8	10.5	64.8	7.49	2.96	24.5	1,038	448	9.9	4.3	14.2	55	27
	0.9	10.4	66.8	7.49	3.37	25.2	1,066	462	10.2	4.4	14.7	58	28
	1.0	10.4	68.9	7.49	3.78	25.8	1,092	475	10.5	4.6	15.1	61	29
	1.1	10.3	71.2	7.49	4.19	26.4	1,118	488	10.9	4.8	15.6	63	30
500	0.5	11.3	59.0	8.17	1.93	24.2	1,024	391	9.0	3.4	12.5	49	26
	0.6	11.4	60.8	8.17	2.36	25.0	1,057	405	9.3	3.6	12.9	52	27
	0.7	11.4	62.6	8.17	2.79	25.7	1,088	419	9.6	3.7	13.3	54	27
	0.8	11.3	64.5	8.17	3.23	26.4	1,119	432	9.9	3.8	13.7	57	28
	0.9	11.3	66.5	8.17	3.67	27.2	1,149	444	10.2	3.9	14.1	59	29
	1.0	11.2	68.6	8.17	4.13	27.8	1,177	455	10.5	4.1	14.5	62	30
	1.1	11.1	70.8	8.17	4.58	28.5	1,206	465	10.8	4.2	15.0	65	31
550	0.5	12.2	58.8	8.84	2.09	25.9	1,094	382	9.0	3.1	12.1	51	27
	0.6	12.2	60.5	8.84	2.55	26.7	1,130	395	9.3	3.2	12.5	53	28
	0.7	12.2	62.3	8.84	3.02	27.5	1,164	407	9.5	3.3	12.9	56	29
	0.8	12.2	64.2	8.84	3.49	28.3	1,197	418	9.8	3.4	13.3	58	29
	0.9	12.1	66.2	8.84	3.98	29.1	1,229	428	10.1	3.5	13.7	61	30
	1.0	12.1	68.3	8.84	4.46	29.8	1,260	437	10.4	3.6	14.1	64	31
	1.1	12.0	70.5	8.84	4.95	30.5	1,291	445	10.8	3.7	14.5	66	32
600	0.5	13.0	58.6	9.50	2.24	27.5	1,163	375	9.0	2.9	11.8	53	28
	0.6	13.0	60.3	9.50	2.74	28.4	1,202	387	9.2	3.0	12.2	55	29
	0.7	13.0	62.1	9.50	3.24	29.3	1,238	397	9.5	3.0	12.5	58	30
	0.8	13.0	64.0	9.50	3.75	30.1	1,274	407	9.8	3.1	12.9	60	30
	0.9	13.0	66.0	9.50	4.27	30.9	1,308	416	10.1	3.2	13.3	63	31
	1.0	12.9	68.0	9.50	4.79	31.7	1,342	423	10.4	3.3	13.7	65	32
	1.1	12.8	70.2	9.50	5.32	32.5	1,374	430	10.7	3.4	14.1	68	33
650	0.5	13.8	58.4	10.14	2.39	29.1	1,231	371	8.9	2.7	11.6	54	29
	0.6	13.8	60.1	10.14	2.92	30.1	1,272	382	9.2	2.8	12.0	57	30
	0.7	13.8	61.9	10.14	3.46	31.0	1,311	392	9.5	2.8	12.3	59	31
	0.8	13.8	63.8	10.14	4.00	31.9	1,349	400	9.8	2.9	12.7	62	31
	0.9	13.8	65.8	10.14	4.56	32.7	1,385	408	10.1	3.0	13.0	64	32
	1.0	13.7	67.8	10.14	5.11	33.6	1,421	414	10.4	3.0	13.4	67	33
	1.1	13.6	70.0	10.14	5.68	34.4	1,456	418	10.7	3.1	13.8	69	34

[a]240 days pregnant (Conceptus weight of 48 kg and ADG of 0.6 kg/day); CP = crude protein required only if ration is perfectly balanced for RDP and RUP.

9. **Table 9. Nutrient Requirements of Growing Holstein Heifers Using Model to Predict Target Average Daily Gain Needed to Attain a Mature Body Weight of 680 Kg** [BCS = body condition score; ME = metabolizable energy; MP = metabolizable protein; RDP = rumen degradable protein; RUP = rumen undegradable protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; TDN = total digestible nutrients]

Month (& weight):	6 (200 kg)	12 (300 kg)	18 (450 kg)
BCS to calve at 24 mo. of age:	3.0	3.0	3.0
Dry matter intake predicted by model, kg	5.2	7.1	11.3
Energy			
ME, Mcal/d	10.6	16.2	20.3
ME, Mcal/kg	2.04	2.28	1.79
Protein			
Metabolizable protein, g/d	415	550	635
Diet % MP	8.0	7.7	5.6
Rumen degradable protein, g/d	481	667	970
Diet % RDP	9.3	9.4	8.6
Rumen undegradable protein, g/d	176	209	88
Diet % RUP	3.4	2.9	0.8
% RDP + % RUP (crude protein)[a]	12.7	12.3	9.4
Fiber and carbohydrate[b]			
NDF, min %	30-33	30-33	30-33
ADF, min %	20-21	20-21	20-21
NFC, max %	34-38	34-38	34-38
Minerals			
Absorbable calcium, g/d	11.3	15.0	13.0
Dietary Ca, %	0.41	0.41	0.37
Absorbable phosphorus, g/d	9.1	10.6	13.0
Dietary P, %	0.28	0.23	0.18
Mg[c], %	0.11	0.11	0.08
Cl, %	0.11	0.12	0.10
K, %	0.47	0.48	0.46
Na, %	0.08	0.08	0.07
S, %	0.2	0.2	0.2
Co, mg/kg	0.11	0.11	0.11
Cu, mg/kg[d]	10	10	9
I, mg/kg[e]	0.27	0.30	0.30
Fe, mg/kg	43	31	13
Mn, mg/kg	22	20	14
Se, mg/kg	0.3	0.3	0.3
Zn, mg/kg	32	27	18
Vitamin A, IU/d	16,000	24,000	36,000
Vitamin D, IU/d	6,000	9,000	13,500
Vitamin E, IU/d	160	240	360
Vitamin A, IU/kg	3,076	3,380	3,185
Vitamin D, IU/kg	1,154	1,268	1,195
Vitamin E, IU/kg	31	34	32
Sample Diets used in model to generate tables:			
Ingredient, kg/d			
Corn silage, normal	2.90	4.08	1.51
Soybean meal, solv. 48% CP	0.30	0.41	0
Grass silage, C-3, mid-mat	1.68	2.29	9.52
Limestone	0.03	0.02	0
Vitamin premix	0.30	0.27	0.30
Diet ME, Mcal/kg	2.24	2.29	2.08
Diet undiscounted TDN, %	61	62	56
Target ADG without conceptus, kg	0.65	0.87	0.59
Target ADG with conceptus, kg	0.65	0.87	0.59
ME allowable ADG without conceptus of diet	0.82	0.87	0.86
ME allowable ADG with conceptus of diet	0.82	0.87	0.86
MP allowable ADG without conceptus of diet	0.76	1.09	1.30
MP allowable ADG with conceptus of diet	0.76	1.09	1.30

[a]Equivalent to crude protein requirement only if RDP and RUP are perfectly balanced; [b]These are the miuimum fiber (or maximum NFC) concentrations needed to maintain rumen health. Actual concentrations may need to be higher (or lower for NFC) depending on energy requirements of the heifer; [c]Assumes that active transport of magnesium across the rumen wall is intact. High dietary potassium and excess non-protein nitrogen often interfere with Mg absorption. Under these conditions dietary Mg should be increased; [d]High dietary Mo, sulfur, and Fe can interfere with Cu absorption increasing the requirement; [e]Diets high in goitrogenic substances increase the iodine requirement.

10. **Table 10. Nutrient Requirements and Diet Concentrations Needed to Meet Requirements for Dry Cows as Determined Using Example Diets** (Holstein Cow - Mature Body Weight Without Conceptus = 680 kg; Body Condition Score (BCS) = 3.3; Calf Weight = 45 kg; Gaining 0.67 kg/day with conceptus) [NEl = net energy for lactation; MP = metabolizable protein; RDP = rumen degradable protein; RUP = rumen undegradable protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; NFC = nonfibrous carbohydrate; TDN = total digestible nutrients; DMI = dry matter intake]

Days pregnant	240	270	279
Current body wt (with conceptus), kg	730	751	757
Age (months)	57	58	58
Dry matter intake, kg/d	14.4	13.7	10.1
Energy			
NEl (Mcal/d required)	14.0	14.4	14.5
NEl (Mcal/kg required)	0.97	1.05	1.44
Protein			
Metabolizable protein, g/d	871	901	810
Diet % MP	6.0	6.6	8.0
Rumen degradable protein, g/d	1,114	1,197	965
Diet % RDP	7.7	8.7	9.6
Rumen undegradable protein, g/d	317	292	286[a]
Diet % RUP	2.2	2.1	2.8[a]
% RDP+ % RUP (crude protein)[b]	9.9	10.8	12.4
Fiber and carbohydrate[c]			
Minimum % NDF	33	33	33
Minimum % ADF	21	21	21
Maximum % NFC	42	42	42
Minerals			
Absorbable calcium, g/d	18.1	21.5	22.5
Dietary Ca, %	0.44	0.45	0.48
Absorbable phosphorus, g/d	19.9	20.3	16.9
Dietary P, %	0.22	0.23	0.26
Mg[d], %	0.11	0.12	0.16
Cl, %	0.13	0.15	0.20
K, %	0.51	0.52	0.62
Na, %	0.10	0.10	0.14
S, %	0.2	0.2	0.2
Co, mg/kg	0.11	0.11	0.11
Cu, mg/kg[e]	12	13	18
I, mg/kg	0.4	0.4	0.5
Fe, mg/kg	13	13	18
Mn, mg/kg	16	18	24
Se, mg/kg	0.3	0.3	0.3
Zn, mg/kg	21	22	30
Vitamin A, IU/d	80,300	82,610	83,270
Vitamin D, IU/d	21,900	21,530	22,710
Vitamin E, IU/d	1,168	1,202	1,211
Vitamin A, IU/kg	5,576	6,030	8,244
Vitamin D, IU/kg	1,520	1,645	2,249
Vitamin E, IU/kg	81	88	120
Sample diets used in model to generate tables			
Ingredient, kg DM			
Corn silage, normal	-	4.32	4.03
Soybean meal, solv. 48% CP	-	-	0.27
Grass silage, C-3, mid-mat	8.1	7.35	3.73
Corn grain, ground hi moist	-	-	0.31
Beet sugar pulp, dried	-	-	1.42
Wheat straw	5.79	1.56	-
Sodium chloride	0.02	0.02	0.02
Vitamin and mineral premix	0.46	0.41	0.31
Calcium carbonate	-	-	-
Monosodium phosphate (1 H_2O)	-	-	-
Magnesium oxide	-	-	-
Calcium phosphate (Di-)	-	-	-
Sample dry cow diet evaluation			
NDF, %	62.2	53.9	46.5
Forage NDF, %	62.2	53.9	39.5
ADF, %	39.7	33.5	27.8
NFC, %	19.6	27.2	34.7

Undiscounted TDN, %	51	57	63
Diet NEl (Mcal/kg), dependent on DMI	1.12	1.33	1.49
NEl (Mcal/d supplied by example diet)	16.1	18.1	15

[a]RUP corrected from model prediction to provide actual RUP requirement if diet had been formulated to meet RDP requirement. Protein in many cases will not be balanced for RDP before the metabolizable protein requirement of the dry cow is met. when this occurs the RUP requirement determined by the model increases to compensate for the lost microbial protein. When RDP is inadequate the energy derived from the diet may be less than predicted by model due to incomplete digestion as a result of reduced bacterial activity in the rumen; [b]% RUP + % RDP = Crude protein required only if ration is perfectly balanced for RDP and RUP. Rumen function may require that the crude protein content of the dry cow ration be 12%, despite the needs of the cow being met at lower CP levels; [c]These are the minimum fiber (or maximum NFC) concentrations needed to maintain rumen health and milk fat test. Actual concentrations may need to be higher (or lower for NFC) depending on energy requirements of the cow. For transition and early lactation cows, diets should meet these minimum and maximum constraints and be formulated to contain 1.60 Mcal/kg of NEl; [d]High dietary potassium and excess non-protein nitrogen can interfere with Mg absorption; [e]High dietary molybdenum, sulfur, and iron can interfere with copper absorption increasing the requirement; [f]Diets high in goitrogenic substances increase the iodine requirement.

NUTRIENT REQUIREMENT TABLES FOR LACTATING DAIRY ANIMALS
(Based on NRC, 2001)

1. **Table 11. Daily Nutrient Requirements of Small Breed Cows (Live Weight = 454 kg) in *Early Lactation* - 11 Days in Milk** (Values are Appropriate for the ***Diet Below With 78% TDN***)[a] [DMI = dry matter intake; LW = live weight; NEl = net energy for lactation; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

Milk (kg)	Fat (%)	TrueProtein (%)	DMI (kg)	LW change (kg)	NEl (Mcal)	RDP (g)	RUP (g)	RDP (%)	RUP (%)	CP (%)
15	4.0	3.0	9.4	-0.3	19.0	1,060	500	11.3	5.3	16.6
15	4.0	3.5	9.4	-0.3	19.4	1,060	630	11.3	6.7	18.0
15	4.0	4.0	9.4	-0.4	19.8	1,060	760	11.3	8.1	19.4
15	4.5	3.0	9.7	-0.3	19.7	1,090	490	11.2	5.1	16.3
15	4.5	3.5	9.7	-0.4	20.1	1,090	620	11.2	6.4	17.6
15	4.5	4.0	9.7	-0.5	20.5	1,090	750	11.2	7.7	18.9
15	5.0	3.0	9.9	-0.4	20.4	1,110	480	11.2	4.8	16.0
15	5.0	3.5	9.9	-0.5	20.8	1,110	610	11.2	6.2	17.4
15	5.0	4.0	9.9	-0.5	21.2	1,110	740	11.2	7.5	18.7
30	4.0	3.0	12.9	-1.4	30.1	1,410	1,170	10.9	9.1	20.0
30	4.0	3.5	12.9	-1.6	30.9	1,410	1,430	10.9	11.1	22.0
30	4.0	4.0	12.9	-1.7	31.8	1,410	1,690	10.9	13.1	24.0
30	4.5	3.0	13.5	-1.5	31.5	1,460	1,150	10.8	8.5	19.3
30	4.5	3.5	13.5	-1.7	32.3	1,460	1,410	10.8	10.4	21.2
30	4.5	4.0	13.5	-1.9	33.2	1,460	1,670	10.8	12.4	23.2
30	5.0	3.0	14.0	-1.6	32.8	1,510	1,140	10.8	8.1	18.9
30	5.0	3.5	14.0	-1.8	33.7	1,510	1,400	10.8	10.0	20.8
30	5.0	4.0	14.0	-2.0	34.6	1,510	1,660	10.8	11.9	22.7

[a]Diet used for tlris table consisted of 15% immature legume silage, 33% normal corn silage, 34% ground lrigh moisture shelled corn, 12% soybean meal (48% crude protein), 2.5% tallow, 1.5% menhaden fish meal, and 2% mineral and vitamin mix. Requirements are dependent upon the diet fed. Requirements shown do not include nutrients needed for Jive weight change. Live weight change is based on assumed NEl intake minus requirements. Requirements for RUP do not include protein provided by loss in body reserves or required for gain in body reserves. Requirement for total CP assumes RDP and RUP are met. Requirement for total CP will increase if RDP requirement is not met.

2. **Table 12. Daily Nutrient Requirements of Small Breed Cows (Live Weight = 454 kg) in *Midlactation - 90 Days in Milk*** (Values Are Appropriate for the ***Diet Below with 78% TDN***)[a] [DMI = dry matter intake; LW = live weight; NEl = net energy for lactation; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

Milk (kg)	Fat (%)	TrueProtein (%)	DMI (kg)	LW change (kg)	NEl (Mcal)	RDP (g)	RUP (g)	RDP (%)	RUP (%)	CP (%)
20	4.0	3.0	16.0	1.0	22.7	1,680	560	10.5	3.5	14.0
20	4.0	3.5	16.0	0.8	23.2	1,680	740	10.5	4.6	15.1
20	4.0	4.0	16.0	0.7	23.8	1,680	910	10.5	5.7	16.2
20	4.5	3.0	16.5	0.9	23.6	1,730	550	10.5	3.3	13.8
20	4.5	3.5	16.5	0.8	24.2	1,730	720	10.5	4.4	14.9
20	4.5	4.0	16.5	0.7	24.8	1,730	900	10.5	5.5	16.0
20	5.0	3.0	17.0	0.9	24.5	1,770	540	10.4	3.2	13.6
20	5.0	3.5	17.0	0.8	25.1	1,770	710	10.4	4.2	14.6
20	5.0	4.0	17.0	0.6	25.7	1,770	880	10.4	5.2	15.6
30	4.0	3.0	19.5	0.4	30.1	1,980	1,010	10.2	5.2	15.4
30	4.0	3.5	19.5	0.2	30.9	1,980	1,270	10.2	6.5	16.7
30	4.0	4.0	19.5	0	31.8	1,980	1,530	10.2	7.8	18.0
30	4.5	3.0	20.3	0.3	31.5	2,040	990	10.0	4.9	14.9
30	4.5	3.5	20.3	0.1	32.3	2,040	1,250	10.0	6.2	16.2
30	4.5	4.0	20.3	-0.1	33.2	2,040	1,510	10.0	7.4	17.4
30	5.0	3.0	21.1	0.2	32.8	2,100	980	10.0	4.6	14.6
30	5.0	3.5	21.1	0	33.7	2,100	1,240	10.0	5.9	15.9
30	5.0	4.0	21.1	-0.2	34.6	2,100	1,500	10.0	7.1	17.1
40	4.0	3.0	23.1	-0.3	37.5	2,240	1,470	9.7	6.4	16.1
40	4.0	3.5	23.1	-0.6	38.6	2,240	1,820	9.7	7.9	17.6
40	4.0	4.0	23.1	-0.8	39.8	2,240	2,160	9.7	9.4	19.1
40	4.5	3.0	24.2	-0.5	39.3	2,310	1,460	9.5	6.0	15.5
40	4.5	3.5	24.2	-0.7	40.5	2,310	1,800	9.5	7.4	16.9
40	4.5	4.0	24.2	-1.0	41.7	2,310	2,150	9.5	8.9	18.4
40	5.0	3.0	25.2	-0.7	41.2	2,390	1,450	9.5	5.8	15.3
40	5.0	3.5	25.2	-0.9	42.3	2,390	1,790	9.5	7.1	16.6
40	5.0	4.0	25.2	-1.1	43.5	2,390	2,140	9.5	8.5	18.0

[a]Diet used for this table consisted of 15% immature legume silage, 33% normal corn silage, 34% ground high moisture shelled corn, 12% soybean meal (48% crude protein), 2.5% tallow, 1.5% menhaden fish meal, and 2% mineral and vitamin mix. Requirements are dependent upon the diet fed. Requirements shown do not include nutrients needed for live weight change. Live weight change is based on assumed NEl intake minus requirements. Requirements for RUP do not include protein provided by loss in body reserves or required for gain in body reserves. Requirement for total CP assumes RDP and RUP are met. Requirement for total CP will increase if RDP requirement is not met.

3. **Table 13. Daily Nutrient Requirements of Small Breed Cows (Live Weight = 454 kg) in *Midlactation* - 90 Days in Milk** (Values are Appropriate for the ***Diet Below with 68% TDN***)[a] [DMI = dry matter intake; LW = live weight; NEl = net energy for lactation; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

Milk (kg)	Fat (%)	TrueProtein (%)	DMI (kg)	LW change (kg)	NEl (Mcal)	RDP (g)	RUP (g)	RDP (%)	RUP (%)	CP (%)
10	4.0	3.0	12.4	0.9	15.3	1,240	230	10.0	1.9	11.9
10	4.0	3.5	12.4	0.8	15.6	1,240	320	10.0	2.6	12.6
10	4.0	4.0	12.4	0.8	15.9	1,240	420	10.0	3.4	13.4
10	4.5	3.0	12.7	0.9	15.7	1,270	230	10.0	1.8	11.8
10	4.5	3.5	12.7	0.8	16.0	1,270	320	10.0	2.5	12.5
10	4.5	4.0	12.7	0.8	16.3	1,270	410	10.0	3.2	13.2
10	5.0	3.0	12.9	0.9	16.2	1,290	220	10.0	1.7	11.7
10	5.0	3.5	12.9	0.8	16.5	1,290	310	10.0	2.4	12.4
10	5.0	4.0	12.9	0.8	16.8	1,290	400	10.0	3.1	13.1
20	4.0	3.0	16.0	0.4	22.7	1,560	680	9.8	4.3	14.1
20	4.0	3.5	16.0	0.3	23.2	1,560	860	9.8	5.4	15.2
20	4.0	4.0	16.0	0.2	23.8	1,560	1,040	9.8	6.5	16.3
20	4.5	3.0	16.5	0.4	23.6	1,610	660	9.8	4.0	13.8
20	4.5	3.5	16.5	0.3	24.2	1,610	840	9.8	5.1	14.9
20	4.5	4.0	16.5	0.2	24.8	1,610	1,030	9.8	6.2	16.0
20	5.0	3.0	17.0	0.4	24.5	1,660	650	9.8	3.8	13.6
20	5.0	3.5	17.0	0.2	25.1	1,660	830	9.8	4.9	14.7
20	5.0	4.0	17.0	0.1	25.7	1,660	1,010	9.8	5.9	15.7
30	4.0	3.0	19.5	-0.1	30.1	1,870	1,130	9.6	5.8	15.4
30	4.0	3.5	19.5	-0.3	30.9	1,870	1,400	9.6	7.2	16.8
30	4.0	4.0	19.5	-0.4	31.8	1,870	1,670	9.6	8.6	18.2
30	4.5	3.0	20.3	-0.2	31.5	1,940	1,110	9.6	5.5	15.1
30	4.5	3.5	20.3	-0.3	32.3	1,940	1,380	9.6	6.8	16.4
30	4.5	4.0	20.3	-0.5	33.2	1,940	1,650	9.6	8.1	17.7
30	5.0	3.0	21.1	-0.2	32.8	2,000	1,090	9.5	5.2	14.7
30	5.0	3.5	21.1	-0.4	33.7	2,000	1,360	9.5	6.4	15.9
30	5.0	4.0	21.1	-0.6	34.6	2,000	1,630	9.5	7.7	17.2

[a]Diet used for this table consisted of 40% mid-maturity legume bay, 27% normal corn silage, 23% cracked dry shelled corn, 8% soybean meal (48% crude protein), and 2% mineral and vitamin mix. Requirements are dependent upon the diet fed. Requirements shown do not include nutrients needed for live weight change. Live weight change is based on assumed NEl intake minus requirements. Requirements for RUP do not include protein provided by loss in body reserves or required for gain in body reserves. Requirement for total CP assumes RDP and RUP are met. Requirement for total CP will increase if RDP requirement is not met.

4. **Table 14. Daily Nutrient Requirements Of Large Breed Cows (Live Weight = 680 kg) In *Early Lactation* - 11 Days in Milk** (Values Are Appropriate For The ***Diet Below With 78% TDN***)[a] [DMI = dry matter intake; LW = live weight; NEl = net energy for lactation; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

Milk (kg)	Fat (%)	TrueProtein (%)	DMI (kg)	LW change (kg)	NEl (Mcal)	RDP (g)	RUP (g)	RDP (%)	RUP (%)	CP (%)
20	3.0	2.5	12.0	0	23.0	1,360	500	11.3	4.2	15.5
20	3.0	3.0	12.0	-0.2	23.6	1,360	670	11.3	5.6	16.9
20	3.0	3.5	12.0	-0.3	24.2	1,360	850	11.3	7.1	18.4
20	3.5	2.5	12.4	-0.1	23.9	1,400	480	11.3	3.9	15.2
20	3.5	3.0	12.4	-0.2	24.5	1,400	660	11.3	5.3	16.6
20	3.5	3.5	12.4	-0.4	25.1	1,400	840	11.3	6.8	18.1
20	4.0	2.5	12.7	-0.2	24.9	1,440	470	11.3	3.7	15.0
20	4.0	3.0	12.7	-0.3	25.4	1,440	650	11.3	5.1	16.5
20	4.0	3.5	12.7	-0.4	26.0	1,440	820	11.3	6.5	17.8
30	3.0	2.5	14.0	-0.6	29.2	1,570	860	11.2	6.1	17.4
30	3.0	3.0	14.0	-0.8	30.1	1,570	1,130	11.2	8.1	19.3
30	3.0	3.5	14.0	-1.0	30.9	1,570	1,390	11.2	9.9	21.1
30	3.5	2.5	14.5	-0.7	30.6	1,620	850	11.2	5.9	17.0
30	3.5	3.0	14.5	-0.9	31.4	1,620	1,110	11.2	7.7	18.8
30	3.5	3.5	14.5	-1.1	32.3	1,620	1,370	11.2	9.4	20.6
30	4.0	2.5	15.1	-0.9	32.0	1,670	830	11.1	5.5	16.6
30	4.0	3.0	15.1	-1.0	32.8	1,670	1,090	11.1	7.2	18.3
30	4.0	3.5	15.1	-1.2	33.7	1,670	1,350	11.1	8.9	20.0
40	3.0	2.5	16.0	-1.2	35.3	1,760	1,230	11.0	7.7	18.7
40	3.0	3.0	16.0	-1.5	36.5	1,760	1,580	11.0	9.9	20.9
40	3.0	3.5	16.0	-1.7	37.7	1,760	1,930	11.0	12.1	23.1
40	3.5	2.5	16.7	-1.4	37.2	1,830	1,210	11.0	7.2	18.2
40	3.5	3.0	16.7	-1.6	38.4	1,830	1,560	-11.0	9.3	20.3
40	3.5	3.5	16.7	-1.9	39.6	1,830	1,910	11.0	11.4	22.4
40	4.0	2.5	17.4	-1.6	39.1	1,900	1,190	10.9	6.8	17.8
40	4.0	3.0	17.4	-1.8	40.2	1,900	1,540	10.9	8.9	19.8
40	4.0	3.5	17.4	-2.0	41.4	1,900	1,890	10.9	10.9	21.8

[a]Diet used for this table consisted of 15% immature legume silage, 33% normal corn silage, 34% ground high moisture shelled corn, 12% soybean meal (48% crude protein), 2.5% tallow, 1.5% Menbaden fish meal, and 2% mineral and vitamin mix. Requirements are dependent upon the diet fed. Requirements shown do not include nutrients needed for live weight change. Live weight change is based on assumed NEl intake minus requirements. Requirements for RUP do not include protein provided by loss in body reserves or required for gain in body reserves. Requirement for total CP assumes RDP and RUP are met. Requirement for total CP will increase if RDP requirement is not met.

5. **Table 15. Daily Nutrient Requirements Of Large Breed Cows (Live Weight = 680 kg) In *Midlactation* - 90 Days in Milk** (Values Are Appropriate For The ***Diet Below With 78% TDN***)[a] [DMI = dry matter intake; LW = live weight; NEl = net energy for lactation; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

Milk (kg)	Fat (%)	TrueProtein (%)	DMI (kg)	LW change (kg)	NEl (Mcal)	RDP (g)	RUP (g)	RDP (%)	RUP (%)	CP (%)
35	3.0	2.5	22.7	1.3	32.2	2,370	820	10.4	3.6	14.1
35	3.0	3.0	22.7	1.1	33.2	2,370	1,130	10.4	5.0	15.4
35	3.0	3.5	22.7	0.9	34.2	2,370	1,430	10.4	6.3	16.7
35	3.5	2.5	23.6	1.2	33.8	2,450	800	10.4	3.4	13.8
35	3.5	3.0	23.6	1.0	34.8	2,450	1,110	10.4	4.7	15.1
35	3.5	3.5	23.6	0.8	35.9	2,450	1,410	10.4	6.0	16.4
35	4.0	2.5	24.5	1.1	35.4	2,520	780	10.3	3.2	13.5
35	4.0	3.0	24.5	0.9	36.5	2,520	1,090	10.3	4.4	14.7
35	4.0	3.5	24.5	0.7	37.5	2,520	1,390	10.3	5.7	16.0
45	3.0	2.5	25.7	0.8	38.3	2,620	1,190	10.2	4.6	14.8
45	3.0	3.0	25.7	0.5	39.7	2,620	1,580	10.2	6.1	16.3
45	3.0	3.5	25.7	0.3	41.0	2,620	1,970	10.2	7.7	17.9
45	3.5	2.5	26.9	0.7	40.4	2,710	1,170	10.1	4.3	14.4
45	3.5	3.0	26.9	0.4	41.8	2,710	1,560	10.1	5.8	15.9
45	3.5	3.5	26.9	0.2	43.1	2,710	1,950	10.1	7.2	17.3
45	4.0	2.5	28.1	0.5	42.5	2,800	1,150	10.0	4.1	14.1
45	4.0	3.0	28.1	0.3	43.8	2,800	1,540	10.0	5.5	15.4
45	4.0	3.5	28.1	0	45.2	2,800	1,930	10.0	6.9	16.8
55	3.0	2.5	28.7	0.3	44.5	2,850	1,570	9.9	5.5	15.4
55	3.0	3.0	28.7	0	46.1	2,850	2,060	9.9	7.2	17.1
55	3.0	3.5	28.7	-0.4	47.7	2,850	2,540	9.9	8.9	18.8
55	3.5	2.5	30.2	0.1	47.1	2,960	1,560	9.8	5.2	15.0
55	3.5	3.0	30.2	-0.2	48.7	2,960	2,040	9.8	6.8	16.6
55	3.5	3.5	30.2	-0.6	50.7	2,960	2,510	9.8	8.3	18.1
55	4.0	2.5	31.7	-0.1	49.6	3,060	1,540	9.7	4.9	14.5
55	4.0	3.0	31.7	-0.5	51.2	3,060	2,020	9.7	6.4	16.0
55	4.0	3.5	31.7	-0.8	52.8	3,060	2,490	9.7	7.9	17.5

[a]Diet used for this table consisted of 15% immature legume silage. 33% normal corn silage, 34% ground high moisture shelled corn, 12% soybean meal (48% crude protein), 2.5% tallow, 1.5% menhaden fish meal, and 2% mineral and vitamin mix. Requirements are dependent upon the diet fed. Requirements shown do not include nutrients needed for live weight change. Live weight change is based on assumed NEl intake minus requirements. Requirements for RUP do not include protein provided by loss in body reserves or required for gain in body reserves. Requirement for total CP assumes RDP and RUP are met. Requirement for total CP will increase if RDP requirement is not met.

6. **Table 16. Daily Nutrient Requirements Of Large Breed Cows (Live Weight = 680 kg) In *Midlactation* - 90 Days in Milk** (Values Are Appropriate For The ***Diet Below With 68% TDN***)[a] [DMI = dry matter intake; LW = live weight; NEl = net energy for lactation; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein]

Milk (kg)	Fat (%)	TrueProtein (%)	DMI (kg)	LW change (kg)	NEl (Mcal)	RDP (g)	RUP (g)	RDP (%)	RUP (%)	CP (%)
25	3.0	2.5	19.6	1.0	26.0	1,940	620	9.9	3.2	13.1
25	3.0	3.0	19.6	0.8	26.8	1,940	840	9.9	4.3	14.2
25	3.0	3.5	19.6	0.7	27.5	1,940	1,070	9.9	5.5	15.4
25	3.5	2.5	20.3	0.9	27.2	2,000	600	9.9	3.0	12.9
25	3.5	3.0	20.3	0.8	27.9	2,000	820	9.9	4.0	13.9
25	3.5	3.5	20.3	0.6	28.7	2,000	1,050	9.9	5.2	15.1
25	4.0	2.5	21.0	0.9	28.4	2,060	580	9.8	2.8	12.6
25	4.0	3.0	21.0	0.7	29.1	2,060	810	9.8	3.9	13.7
25	4.0	3.5	21.0	0.6	29.8	2,060	1,030	9.8	4.9	14.7
35	3.0	2.5	22.7	0.6	32.2	2,210	990	9.7	4.4	14.1
35	3.0	3.0	22.7	0.4	33.2	2,210	1,300	9.7	5.7	15.4
35	3.0	3.5	22.7	0.2	34.2	2,210	1,620	9.7	7.1	16.8
35	3.5	2.5	23.6	0.5	33.8	2,290	960	9.7	4.1	13.8
35	3.5	3.0	23.6	0.3	34.8	2,290	1,280	9.7	5.4	15.1
35	3.5	3.5	23.6	0.1	35.9	2,290	1,600	9.7	6.7	16.4
35	4.0	2.5	24.5	0.4	35.4	2,370	940	9.7	3.8	13.5
35	4.0	3.0	24.5	0.2	36.5	2,370	1,260	9.7	5.1	14.8
35	4.0	3.5	24.5	0	37.5	2,370	1,570	9.7	6.4	16.1
45	3.0	2.5	25.7	0.1	28.3	2,470	1,370	9.6	5.3	14.9
45	3.0	3.0	25.7	-0.1	39.7	2,470	1,780	9.6	6.9	16.5
45	3.0	3.5	25.7	-0.4	41.0	2,470	2,180	9.6	8.5	18.1
45	3.5	2.5	26.9	0	40.4	2,570	1,340	9.6	5.0	14.6
45	3.5	3.0	26.9	-0.2	41.8	2,570	1,750	9.6	6.5	16.1
45	3.5	3.5	26.9	-0.5	43.1	2,570	2,160	9.6	8.0	17.6
45	4.0	2.5	28.1	-0.1	42.5	2,670	1,310	9.5	4.7	14.2
45	4.0	3.0	28.1	-0.3	43.8	2,670	1,720	9.5	6.1	15.6
45	4.0	3.5	28.1	-0.6	45.2	2,670	2,130	9.5	7.6	17.1

[a]Diet used for this table consisted of 40% mid-maturity legume hay, 27% normal com silage, 23% cracked dry shelled com. 8% soybean meal (48% crude protein), and 2% mineral and vitamin mix. Requirements are dependent upon the diet fed. Requirements shown do not include nutrients needed for live weight change. Live weight change is based on assumed NEl intake minus NEl requirements. Requirements for RUP do not include protein provided by loss in body reserves or required for gain in body reserves. Requirement for total CP assumes RDP and RUP are met. Requirement for total CP will increase if RDP requirement is not met.

7. **Table 17. Nutrient Requirements and Required Diet Nutrient Concentrations for *Fresh Cows* Fed an Example Fresh-Cow Ration** [BW = body weight; BCS = body condition score; NEl = net energy for lactation; MP = metabolizable protein; RDP = rumen degradable protein; RUP = rumen undegradable protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; NFC = nonfibrous carbohydrate; TDN = total digestible nutrient]

Breed, mature BW, and BW:	Holstein, 680 kg, and 680 kg				Jersey, 454 kg, and 454 kg	
BCS at 58 mo. of age:	3.3				3.3	
Milk fat, true protein, and lactose:	3.5, 30.0, and 4.8%, respectively				4.2, 3.6, and 4.8%, respectively	
Day in milk:	11	11	11	11	11	11
Dry matter intake input:	Model Predicted	Model Predicted + 20%	Model Predicted	Model Predicted + 20%	Model Predicted	Model Predicted + 20%
Milk production (kg)	25	25	35	35	25	25
Dry matter intake (kg)	13.5	16.1	15.6	18.8	11.9	14.3
Daily wt change (kg)	-0.9	0	-1.6	-0.6	-1.4	-0.7
Days to gain one condition score						
Days to lose one condition score	99	4,886	55	143	41	83
Energy[a]						
NEl (Mcal/day)	27.9	27.9	34.8	34.8	27.7	27.7
NEl (Mcal/kg)	2.06	1.73	2.23	1.85	2.33	1.93
Protein[b]						
Metabolizable protein (g/d)	1,643	1,725	2,157	2,254	1,801	1,875
Diet % MP	12.2	10.7	13.8	12.0	15.1	13.1
Rumen degradable protein (g/d)	1,421	1,683	1,634	1,931	1,244	1,469
Diet % RDP	10.5	10.5	10.5	10.3	10.5	10.3
Rumen undegradable protein (g/d)	949	863	1,405	1,045	1,265	1,202
Diet % RUP	7.0	5.4	9.0	5.6	10.6	8.4
% RDP+ % RUP (crude protein)[c]	17.5	15.9	19.5	15.9	21.1	18.7
Fiber and carbohydrate[d]						
NDF, min %	25-33	25-33	25-33	25-33	25-33	25-33
ADF, min %	17-21	17-21	17-21	17-21	17-21	17-21
NFC, max %	36-44	36-44	36-44	36-44	36-44	36-44
Minerals						
Absorbable calcium (g/day)	52.1	52.1	64.0	64.0	51.0	51.0
Dietary Ca, %	0.74	0.65	0.79	0.68	0.80	0.70
Absorbable phosphorus (g/day)	37.3	40.0	49.0	52.0	35.0	37.7
Dietary P, %	0.38	0.34	0.42	0.37	0.40	0.36
Mg[e], %	0.27	0.23	0.29	0.24	0.27	0.22
Cl, %	0.36	0.30	0.40	0.33	0.36	0.30
K[f], %	1.19	1.11	1.24	1.14	1.19	1.10
Na, %	0.34	0.29	0.34	0.28	0.31	0.26
S, %	0.2	0.2	0.2	0.2	0.2	0.2
Co, mg/kg	0.11	0.11	0.11	0.11	0.11	0.11
Cu, mg/kg[g]	16	13	16	13	15	12
I, mg/kg[h]	0.88	0.74	0.77	0.64	0.67	0.56
Fe, mg/kg	19	16	22	19	21	17
Mn, mg/kg	21	17	21	17	19	15
Se, mg/kg	0.3	0.3	0.3	0.3	0.3	0.3
Zn, mg/kg	65	54	73	60	67	56
Vitamin A (IU/day)	75,000	75,000	75,000	75,000	49,900	49,900
Vitamin D (IU/day)	21,000	21,000	21,000	21,000	13,600	13,600
Vitamin E (IU/day)	545	545	545	545	363	363
Vitamin A (IU/kg)	5,540	4,646	4,795	3,978	4,193	3,490
Vitamin D (IU/kg)	1,511	1,267	1,308	1,085	1,143	951
Vitamin E (IU/kg)	40	34	35	29	31	25

Sample diet used in model to generate tables. Ingredients listed as % DM

Corn silage, normal	36.44
Corn grain, steam flaked 18.29	
Soybean meal, expellers	7.65
Soybean meal, solv. 48% CP	2.53
Legume forage hay, immature	20.17
Cottonseed, whole with lint	8.41
Calcium soaps of fatty acids	0.65
Blood meal, ring dried	1.02
Calcium carbonate	0.56
Monosodium phosphate (1 H20)	0.4
Sodium chloride	0.7
Vitamin and mineral premix	3.18

Sample "fresh cow" diet evaluation						
NDF, %	31.6					
Forage NDF, %	23.7					
ADF, %	21					
NFC, %	41.4					
Undiscounted TDN, %	71					
Diet NEl (Mcal/kg), dependent on DMI	1.75	1.73	1.73	1.70	1.72	1.69
Crude protein, %	17.4					

[a] Recommended energy content of early lactation rations must be limited to prevent rumen acidosis. Cow must therefore be expected to utilize body reserves to meet energy and protein requirements of early lactation. See fiber and NFC restrictions; [b]It will be nearly impossible to meet the metabolizable protein needs of the high producing fresh cow due to low dry matter intake and the difficulty formUlating rations with such high RUP; [c]Equivalent to crude protein requirement only if RDP and RUP are perfectly balanced; [d]These are the minimum fiber (or maximum NFC) concentrations needed to maintain rumen health and milk fat test; [e]Assumes that active transport of magnesium across the rumen wall is intact. High dietary potassium and excess non-protein nitrogen often interfere with Mg absorption. Under these conditions dietary Mg should be increased to 0.3%-0.35%; [f]Heat stress may increase the need for potassium; [g]High dietary molybdenum, sulfur, and iron can interfere with copper absorption increasing the requirement; [h]Diets high in goitrogenic substances increase the iodine requirement.

8. **Table 18. Nutrient Requirements of Lactating Dairy Cows as Determined Using Sample Diets** [BW = body weight; BCS = body condition score; NEl = net energy for lactation; MP = metabolizable protein; RDP = rumen degradable protein; RUP = rumen undegradable protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; NFC = nonfibrous carbohydrate; TDN = total digestible nutrient]

Breed, mature BW, and BW:	Holstein, 680 kg, and 680 kg				Jersey, 454 kg, and 454 kg					
BCS at 65 mo. of age:	3.0				3.0					
Milk fat, true protein, and lactose:	3.5, 3.0, and 4.8%, respectively				4.2, 3.6, and 4.8%, respectively					
Day in milk:	90	90	90	90	90	90	90	50	120	90
Dry matter intake input:	Model Predicted	Model Predicted	Model Predicted	Model Predicted	Model Predicted	Model Predicted[a]	Model Predicted	Model Predicted[a]	Model Predicted[a]	Model Predicted + 5%[a]
Milk production (kg)	25	35	45	54.4	25	35	40	35	35	35
Dry matter intake (kg)	20.3	23.6	26.9	30	18	21.7	23.5	19.8	22.2	22.7
Daily wt change (kg)	0.5	0.3	0.1	-0.2	0	-0.2	-0.5	-0.7	-0.1	0
Days to gain one condition score	221	316	1166		3777					4247
Days to lose one condition score				544		241	110	80	532	
Energy[b]										
NEl (Mcal/day)	27.9	34.8	41.8	48.3	27.7	35.6	39.5	35.6	35.6	35.6
NEl (Mca1/ kg)	1.37	1.47	1.55	1.61	1.54	1.64	1.68	1.8	1.6	1.57
Protein										
Metabolizable protein (g/d)	1,862	2,407	2,954	3,476	1,991	2,639	2,965	2,579	2,656	2,672
Diet % MP	9.2	10.2	11	11.6	11.1	12.2	12.6	13.0	12.0	11.8
Rumen degradable protein (g/d)	1,937	2,298	2,636	2,947	1,747	2,125	2,288	1,971	2,167	2,206
Diet % RDP	9.5	9.7	9.8	9.8	9.7	9.8	9.7	10.0	9.8	9.7
Rumen undegradable protein (g/d)	933	1,291	1,677	2,089	1,151	1,632	1,865	1,670	1,619	1,611
Diet% RUP	4.6	5.5	6.2	6.9	6.4	7.5	7.9	8.4	7.3	7.1
% RDP+ % RUP (crude protein)[c]	14.1	15.2	16.0	16.7	16.1	17.3	17.6	18.4	17.1	16.8
Fiber and carbohydrate[d]										
NDF, min %	25-33	25-33	25-33	25-33	25-33	25-33	25-33	25-33	25-33	25-33
ADF, min %	17-21	17-21	17-21	17-21	17-21	17-21	17-21	17-21	17-21	17-21
NFC, max %	36-44	36-44	36-44	36-44	36-44	36-44	36-44	36-44	36-44	36-44
Minerals										
Absorbable calcium (g/day)	52.1	65.0	76.5	88.0	50.7	65.2	72.4	65.2	65.2	65.2
Dietary Ca, %	0.62	0.61	0.67	0.60	0.57	0.57	0.63	0.66	0.54	0.53
Absorbable phosphorus (g/day)	44.2	56.5	68.8	80.3	41.4	54.1	60.4	52.2	54.6	55.1
Dietary P, %	0.32	0.35	0.36	0.38	0.33	0.37	0.36	0.44	0.35	0.34
Mg[e], %	0.18	0.19	0.20	0.21	0.18	0.19	0.20	0.21	0.19	0.19
Cl, %	0.24	0.26	0.28	0.29	0.24	0.26	0.27	0.28	0.25	0.25
K[f], %	1.00	1.04	1.06	1.07	1.02	1.03	1.04	1.07	1.03	1.02
Na, %	0.22	0.23	0.22	0.22	0.20	0.20	0.20	0.22	0.20	0.19
S, %	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Co, mg/kg	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Cu, mg/kg[g]	11	11	11	11	10	10	10	11	10	9
I, mg/kg[h]	0.60	0.50	0.44	0.40	0.44	0.40	0.34	0.40	0.36	0.35
Fe, mg/kg	12.3	15	17	18	14	16	17	18	16	15
Mn, mg/kg	14	14	13	13	12	12	12	13	12	12
Se, mg/kg	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Zn, mg/kg	43	48	52	55	45	49	51	54	48	47
Vitamin A (IU/day)	75,000	75,000	75,000	75,000	49,500	49,500	49,500	49,500	49,500	49,500
Vitamin D (IU/day)	21,000	21,000	21,000	21,000	13,500	13,500	13,500	13,500	13,500	13,500
Vitamin E (IU/day)	545	545	545	545	360	360	360	360	360	360
Vitamin A (IU/kg)	3,665	3,169	2,780	2,500	2,772	2,300	2,123	2,520	2,247	2,198
Vitamin D (IU/kg)	1,004	864	758	680	755	621	579	687	613	600
Vitamin E (IU/kg)	27	23	20	18	20	17	16	18	16	16
Sample diets used in model to generate tables. Ingredients listed as kg /day DM										
Corn silage, normal	8.48	8.21	5.61	12.02	8.96	7.77	7.39	7.10	7.96	8.15
Soybean meal, solv. 48% CP	1.01	1.62	1.41	2.39	2.16	2.78	1.67	2.54	2.85	2.91
Legume forage silage, mid-maturity	3.85	4.57	-	-	2.67	3.10	-	2.83	3.18	3.25
Corn grain, steam flaked	1.80	4.33	7.08	6.35	2.6	4.91	5.88	4.48	5.03	5.15
Calcium carbonate	0.04	0.07	0.09	0.02	0.06	0.04	0.03	0.04	0.04	0.04
Monosodium phosphate (1 H2O)	0.02	0.02	0.04	0.06	0.01	0.01	0.03	0.01	0.01	0.01
Soybean meal, expellers	-	-	-	-	-	-	1.16	-	-	-
Legume forage hay, immature			6.16	5.42			4.59			
Sodium chloride	0.12	0.01	0.12	0.14	0.10	0.10	0.12	0.09	0.10	0.1
Grass hay, c-3, mid-mat	4.47	3.21	0.98	0.93	0.85	0.95	0.97	-	-	-
Vitamin and mineral premix	0.54	0.49	0.51	0.49	0.50	0.50	0.50	0.45	0.51	0.52
Bermudagrass hay, coastal	-	-	0.87	-	-	-	-	-	-	-
Cottonseed. whole with lint	-	-	2.53	2.24	-	1.02	1.64	0.94	1.05	1.07
Tallow	-	-	-	0.29	-	0.24	0.21	0.22	0.24	0.25
Calcium soaps of fatty acids	-	-	-	0.29	-	0.18	0.21	0.17	0.19	0.19
Blood meal, ring dried	-	-	0.23	0.31	-	0.11	0.10	0.10	0.11	0.12
Sorghum, sudan type. silage	-	-	2.26	-	-	-	-	-	-	-

Sample diet evaluation										
NEl (Mcal/kg)	1.49	1.55	1.57	1.58	1.54	1.59	1.57	1.62	1.58	1.57
Undiscounted TDN, %	65	69	71	74	69	73	75	73	73	73

[a]Diet composition is the same in all four cases of the Jersey cow producing 35 kg milk. Amount of dry matter consumed varies with days in milk and the use of predicted vs. actual dry matter intake in the model; [b]Recommended energy content of early lactation rations must be limited to prevent rumen acidosis. Cow must therefore be expected to utilize body reserves to meet energy needs at highest levels of milk production. See fiber and NFC restrictions; [c]Equivalent to crude protein requirement only if RDP and RUP are perfectly balanced; [d]These are the minimum fiber (or maximum NFC) concentrations needed to maintain rumen health and milk fat test; [e]Assumes that active transport of magnesium across the rumen wall is intact. High dietary potassium and excess non-protein nitrogen often interfere with Mg absorption. Under these conditions dietary Mg should be increased to 0.3%-0.35%; [f]Heat stress may increase the need for potassium; [g]High dietary molybdenum. sulfur. and iron can interfere with copper absorption increasing the requirement; [h]Diets high in goitrogenic substances increase the iodine requirement.

SHEEP NUTRITION AND FEEDING

- *References: NRC (1985), Kott (1998) in Kellems & Church (1998), and Jurgens (2002).*

INTRODUCTION

1. **General**

   A. Supplying energy and nutrients to satisfy their needs is the largest single cost associated with producing sheep regardless of the type of operation.
   B. The production of sheep is controlled by the efficiency in converting feed resources into products of economical value, i.e., meat, wool, and milk.
   C. Diets must be formulated and fed in such ways that support optimum production and efficiency, and also minimize nutritionally related problems.
   D. Throughout the world, the common denominator in sheep production is "pasture & forage," and productivity/quality of the pasture, rangeland, and forage crop can influence success of sheep production.
   E. Most of the world's sheep are located in arid to semiarid ecosystem, i.e., arid rangeland of Australia, Africa, South America, and SW US.
   F. About 5% of all ewes fail to lamb and about 15 to 20% of all lambs born die between birth and weaning. Although there are many causes, faulty nutrition is a major contributing factor in such losses, thus affecting the success of sheep production.

2. **Nutrient Needs**

   A. Water:

      1) Daily water consumption in ewes varies from 0.72 gal during the cold winter months to 2.2. gal during the summer months.
      2) Water intake increases with the increased intake of DM, protein, or minerals, the temperature above 70°F, and the stage of production such as during the late gestation and lactation.
      3) Sheep can get water from feed, snow and dew, oxidation of feed or metabolic water, as well as drinking water. Thus, depending on the situation, perhaps, can get by without drinking water!?

   B. Energy;

      1) Inadequate energy limits performance of sheep more than any other nutritional deficiency, especially during the late gestation and lactation.
      2) Deficiency? - Results in reduced growth, fertility, wool quantity and quality, etc.
      3) Generally, can satisfy the needs with good quality pasture, hay, or silage, but may need supplement (e.g., grains) immediately before and after lambing and conditioning for breeding, and also for finishing lambs.

C. Protein

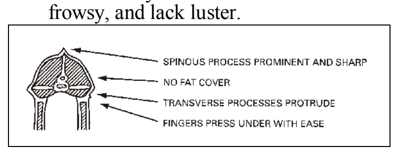
1) In most instances, the amount of protein is more critical than quality, i.e., microbial protein is often adequate.
2) Green pastures provide adequate protein. But, with mature and bleached or have been dry for an extended period of time, may need additional protein.
3) Bypass protein might be beneficial in some instances, and can use nonprotein nitrogen or NPN in some instances.

D. Minerals & vitamins

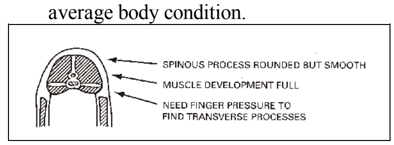
1) In practice, the true "dietary" requirements vary considerably, depending on the amount and nature of minerals (& also their associated minerals).
2) Most requirements can be met with normal grazing and their feeding habits, but a trace mineral salt containing Na, Cl, I, Co, Fe, Mn, and Zn is usually fed free-choice.
3) Although sheep need all the fat-soluble vitamins, normally, the forage & feed supply all the vitamins in adequate amounts. But, vitamin A (e.g., grazing on dry or winter pasture for an extended period time) and vitamin D (e.g., under confinement) may be deficient under certain circumstances.
4) The B vitamins are synthesized in the rumen, thus usually there is no need for supplementation.

Ewe body condition scores (Kott, 1998)

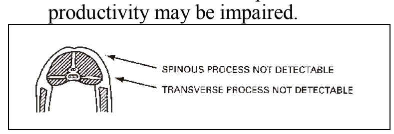
Score	Description
1	An extremely emaciated ewe, with no fat between skin and bone. Ewes in this body condition have no fat and very limited muscle energy reserves. They appear weak and unthrifty. Wool fleeces are often tender, frowsy, and lack luster.



Score	Description
2	Ewes in this body condition have only a slight amount of fatty tissue detectable between skin and bone. Spinous processes are relatively prominent. These ewes appear thrifty but have only minimal fat reserves.
3	Ewes in this body condition have average flesh but do not have excess fat reserves. This condition score includes ewes in average body condition.



Score	Description
4	This condition score includes ewes that are moderately fat. Moderate fat deposits give sheep a smooth external appearance.
5	Ewes that are extremely fat. Excess fat deposits can easily be seen in the brisket, flank, and tailhead regions. These ewes have excess fat reserves to the point that productivity may be impaired.



3. **Body Condition Scores**

A. The use of body weight alone is not adequate because of differences in mature body size among different breeds and within a breed, thus useful to consider body condition scoring along with the body weight.
B. Conditioning scoring is a system to describe or classify breeding animals by differences in relative body fatness - Subjective system but provides fairly reliable assessment of body composition.
C. Example? - See the table/figures.

1) Scores of 1 to 10 can be used but scores between 1 and 5 are commonly used in the US.

2) Usually, 90% or so of ewes fall withing the 2, 3 or 4 range, and 70 to 80% of animals usually fall within a range of 2 conditioning scores.
3) Usually, more individual variation in older ewes than young, developing breeding animals (i.e., ewe lambs up to 2 yr old).
4) Perhaps, scoring 10 to 20% of the flock might be adequate?

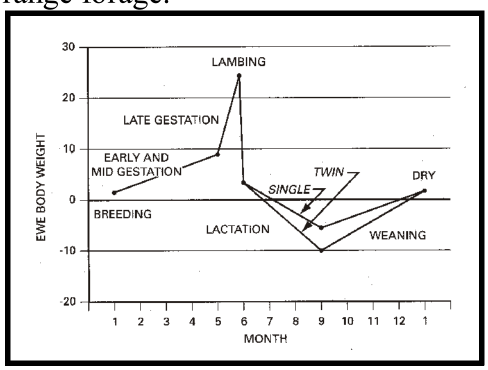
FEEDING EWES

1. General

1) Ewes are the backbone of the sheep enterprise. Raising lambs & producing wool.
2) The nutritional status of the ewe during the all stages of production is critical for optimum production, even though breeding and selection programs should not be overlooked.

    a) Nutrition during pregnancy? - Determine the number of lambs born alive and lamb birth weight, and also survivability?
    b) Nutrition during lactation? - Critical for milk production.

3) Optimum feeding systems vary based on the production system, i.e., intense feeding of "confined sheep" to supplementation of flocks "on range forage."
4) How the ewe should be fed? - Monitoring changes in body weight during lactation. [See the figure on "Weight changes expected for a 150-lb ewe throughout various stages (Kott, 1998)"]



    a) Should lose about 5 to 7% of the body wt during lactation, recover this during the post-weaning period, and then gain weight appropriately during gestation.
    b) Nutritional needs differ depending on the size, body conditions, and levels of production, thus may be useful to divide the flock into groups of ewes with similar needs?

2. Choosing a Lambing System

A. Considerations for early lambing - January through February

    a) Prices? - Highest in May and June, which coincides with marketing of most early lambs.
    b) Labor? - Good care and management is needed during flushing, breeding, and lambing periods, but more labor should be available to provide extra care and attention during lambing.
    c) Lambing facilities? - Should be adequate, even though no need for a fancy or expensive accommodation.

d) More ewes can be carried in the flock for a given acreage of pasture.
e) Less serious parasite problems!?

B. Considerations for late lambing - March through April

a) Prices? - Substantially lower in the fall and early winter when late lambs are marketed.
b) Labor? - Less care & management is needed before & during the breeding season for good conception.
c) Lambing facilities? - Do not have to be as good as for early lambs.
d) Roughages provide most feed needed for both ewes and lambs, and lambs can be marketed from pasture (or cornfields) with a minimum of concentrate feeding. But, need high quality pastures!
e) Parasite problems are serious, and need prevention and control.

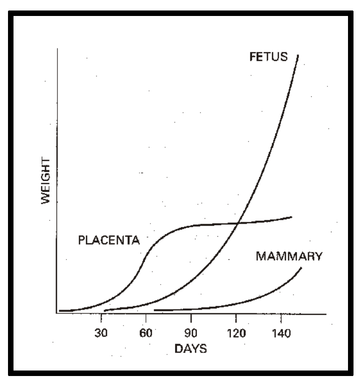
3. **Flushing & Breeding**

A. Flushing?

1) Increase the intake of ewes prior to and during mating to increase ovulation rate (& also have some beneficial effects of increased body weight?), thus lambing rate.
2) Start about 2 wk before breeding until 2-3 wk into the breeding season.

B. Accomplished by turning ewes onto a lush, high-quality pasture just prior to breeding. If not, can be done by supplementing ¼ to ½ lb of grain or pellets/day.
C. Mature ewes may respond better vs. yearlings or fat ewes (or, ewes in good body condition), thus flushing may not be economical for ewe lambs/yearlings (no lambs in previous year) or fat ewes.
D. Both energy and protein intake might be important based on some data, but, perhaps, energy intake is the single most important factor?
E. Based on many studies, can expect the increase in the lambing rate by 10 to 20%.

4. **Gestation**



A. See the figure on "Placenta, fetal, and mammary growth during pregnancy (Kott, 1998)."
B. Many lamb deaths shortly after birth can be attributed to nutrition during gestation because of placental growth, fetal development, and mammary gland development.
C. The mature (3 to 8 years) ewe during the first 15 wk of pregnancy:

1) Assuming no substantial weight loss during the previous lactation, can be fed to just maintain her "normal" weight from weaning her lambs until about 15 wk into her next pregnancy.

2) Nutritional needs are slightly higher than the maintenance, but severe under- or over-nutrition during this phase can be detrimental.
3) Pasture and other "field feeds," when available, are adequate for maintaining ewes and used often because of the cost.
4) When harvested feed must be fed, a variety of feeds or combination can be used, e.g., hay, haylage, and corn or sorghum silage.

D. Last 6 wk of gestation:

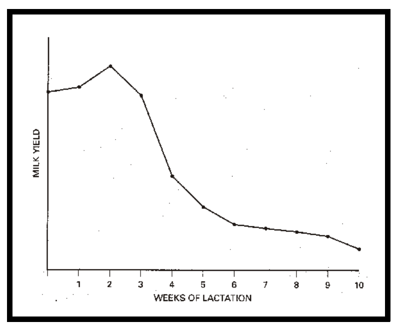
1) About 70% of fetal growth during this phase, thus this is the most critical period!
2) Poor nutrition? - May result in lighter lambs at birth, nonuniform birth wt in twin and triplets, impaired wool follicle development, lower energy reserves of newborns, etc.

a) Birth wt (may vary from 3.5 to 20 lb) is a major factor affecting lamb mortality.
b) Although other factor are involved, nutrition, especially energy, during the last month can play a major role in determining the birth wt.
c) Need 50 or 75% more feed if bearing single or twin lambs, respectively.
d) Also, nutrition during this phase can influence milk production after parturition.

5. **Parturition**

A. Generally, recommended to provide a good-quality forage and plenty of fresh water.
B. Start feeding grain or supplement about 12 to 24 hr after lambing.

6. **Lactation**



A. Nutrient needs? - Usually 2 to 3 times greater during lactation than during maintenance.
B. Ewes with twin lambs produce 20 to 40% more milk than those with singles, thus have higher nutrient requirements.
C. Milk production:

a) Peaks early (2 to 3 wks after lambing) and then declines. See the figure on "Ewe's milk production (Kott, 1998)."
b) Ewes produce 3 to 6 + lb milk daily.
c) Milk provides essentially all the lamb's nutritional needs during the first mo. and a significant proportion during the first 2 mo.

D. Lambs can be weaned successfully at 8 wk (perhaps earlier). More efficient to feed the lamb directly than to feed the ewe to feed the lamb beyond 8 to 10 wk.
E. How to feed ewes?

1) Not necessary to feed the ewe very much for a day or so after lambing. Important to have plenty of fresh water and a light feed during this period though.
2) By the third day, can be brought up to a regular ration (as-fed basis) - e.g., 2½ - 3 lb each of hay and ground ear corn, 4 - 5½ lb hay plus 1 to 1½ lb shelled corn, 8 to 10 lb corn silage plus ¾ to 1½ lb shelled corn + ½ lb soybean meal, or 10 lb alfalfa haylage plus 1½ lb shelled corn.
3) Daily feed intake can be increased by feeding frequently:

   a) A rule of thumb? If the ewe is nursing one lamb, feed once a day, if she is nursing two lambs, twice a day, etc.
   b) Splitting the amount fed per day into more frequent feedings reduces the potential for acidosis when more concentrates are fed.

F. Ewes lambing in late April and May:

1) Normally on pasture. The pasture should be productive, and should provide most of the needs unless it is overstocked.
2) Can be fed supplemental grain if needed, and also can be trained to return to drylot for grain feeding.
3) If pasture is short, lambs can be kept in drylot, and ewes kept with them during the day, then turned to pasture during the evening and night.

G Fall lambing ewes (September and October):

1) Most flocks would lamb on pasture, which should have been set aside for them - Should provide most of the needs during the first 4 to 6 wk of lactation.
2) After that, start supplemental grain feeding depending on the ewe & lamb conditions. Keep lambs in drylot and bringing the ewes to the lambs for nursing during the day. If so, lambs should be creep fed.

H. The mineral requirements during lactation are greater than during other periods - A greater intake of feed may provide all the increased needs, but free-choice feeding of a complete mineral is suggested as insurance.

I. Late lactation (last 4 - 6 wk)? Milk production is low and minor importance for lambs after 8 - 10 wk, and their nutritional needs can be met by good quality pasture or range.

J. Range supplements?

1) Range sheep production is entirely dependent on weather and moisture conditions, and the necessity of supplementation is variable between ranges and between years.
2) Supplementation usually increases production, but may not be economical to supplement for maximum production because of the increased costs.

7. **Postweaning**

A. This is the time of rest for the ewes, but also the time that the ewes can be "conditioned" for the breeding period.
B. Still, desirable to use the poor-quality pasture or feed so that better quality forages can be saved for more critical periods.

FEEDING VERY YOUNG LAMBS

1. General

A. Lambs:

1) Born with a nonfunctional rumen, thus need dietary sources of nutrients such as milk and milk replacer.
2) Important to make sure that a lamb nurses within 1 hr or its chance of survival is rather limited. But, most lambs nurse within 30 min after birth.
3) With access to dry feed immediately, some degree of rumen functionality become apparent within 2 wk or so.
4) With continued consumption of dry feed, milk is no longer essential for efficient growth by 45 to 60 d of age.

B. Colostrum:

1) Not only important in terms of nutrition but also plays an important role in disease resistance because it contains antibodies.
2) Also, important as a laxative to clean out the fecal matter accumulated during fetal life.
3) Transfer of antibodies through the umbilical cord does not occur in sheep and cattle as it does in many other animals.
4) If colostrum is not available (or insufficient; at least 6 to 8 oz!?) from the ewe, then should provide colostrum from another ewe; Or, frozen ewe or cow colostrum warmed to body temperature with a bottle is an adequate alternative.

C. Most of lamb death losses are due to starvation during the first week after birth. May require rearing on milk replacer to save those lambs?

1) Lambs that are orphans due to death of the mother, one side of udder nonfunctional on ewe with twins, mis-mothered, etc.
2) A weak lamb(s) twins or in triplets.
3) Any lamb showing symptoms of progressive weakness during the first week after birth, which can be traced to inadequate milk supply.

2. Milk Replacer

A. Raising lambs on milk replacer is relatively time consuming and expensive process, thus should be as short as possible. Can be weaned from milk replacer at 3 wk of age?

B. The decision to switch to milk replacer? Should be made as soon after birth as possible. Perhaps, easier to train?
C. Place lambs in a warm, dry enclosed area with others on milk replacer, and they should not be allowed to hear their dams.
D. May want to inject with the followings when they are placed in the nursery? - Vitamin A, D, E, Se (in low Se areas), etc.
E. Typical composition of milk replacers (DM basis)? - e.g., fat, 30-32%; CP, 22-24%; and lactose, 22-25%.
F. The dry replacer should be diluted with water to a minimum of 17 to 20% DM (i.e., 1¾ to 2 lb milk replacer per gallon of water).
G. Make sure that the milk replacer contains a high dose of antibiotics to avoid scours and other digestive disorders.
H. Use one of the multiple nipple pails or similar systems for self feeding the milk replacer (should be cold), or hand feed with warm milk.

3. **Creep Feeding**

A. Healthy baby lambs show interest in dry feed at 10 days of age, thus they might be able to start on dry feed very early?
B Creep feeding:

1) Advantages?

a) Increased weight gains, especially in twins & triplets. Up to 0.25 lb /d more?
b) Can be marketed at younger age. Perhaps, 1 to 2 mo earlier?
c) Moving lambs to the drylot earlier, which allows more ewes on available pasture.

2) To be successful, start as soon as possible. May want to set up when lambs are 7 to 10 d of age & on the location where they spend most of their time.

C. Scientifically formulated and commercially prepared complete creep feeds:

1) Often available in pelleted form & in 50-lb bags, which make creep feeding simple.
2) Relatively costly, but lambs don't consume much during this period, so can be justified?

D. Examples of palatable feeds offered to lambs (in addition to commercial feeds)? - Cracked, shelled corn, bran, rolled oats, molasses, soybean meal, and high quality, leafy alfalfa hay.
E. Make fresh feed available in clean bunks at least twice daily. Should give only the quantity lambs clean up between each feeding.
F. When feeding simple cracked corn and hay-based creep rations, a complete supplement should be top-dressed on corn to provide added CP, Ca, vitamin E, Se, antibiotic, etc.

4. **Weaning**

A. Artificially reared lambs weighing 25 lb can be weaned at 25 to 30 days of age.
B. Lambs raised by ewes in peak milk production are seldom weaned, and lambs are not normally weaned before 7- to 8-wk old and weighing more than 40 lb.
C. To reduce weaning stress, a lamb should be consuming about a pound of palatable, nutritious dry feed daily.
D. May want to keep lambs in familiar surroundings at weaning and no change in their diet for about a week or so.
E. Very early weaned 25-lb lambs need an 18-19% CP, high-energy, well-fortified diet until reaching about 50 lb. Can be fed as a "typically weaned lamb" thereafter.

FEEDING GROWING AND FINISHING LAMBS

1. **General**

A. Under excellent forage conditions, lambs may reach slaughter weight while nursing ewes. Typical in high mountain ranges?
B. Most of lambs produced in the US, however, are not slaughter at weaning, and must be finished by the producer or sold to commercial lamb feedlots.
C. Feeder lambs:

1) Most are available in the fall from western & southwestern ranges.
2) Usually about 5 to 6 mo of age and weigh between 60 to 90 lb.
3) But, many producers are beginning to wean & market lambs at an earlier age. It is especially true for fall- or winter-born lambs.
4) Might be more profitable for some producers to wean lambs early & feed them to slaughter market wt. For instance, market their grains through lambs when grain prices are relatively low?
5) Many are placed on high-quality pastures or crop aftermath such as alfalfa fields & beet tops before a short feedlot phase.

D. Slaughter or market lambs?

1) Should have between 0.1 and 0.2" in backfat.
2) Between 95 to 145 lb because of differences in frame size among lambs, i.e., 95-105 lb for small-frame, 105-120 lb for medium-frame, and 120-145 lb for large-frame lambs.

E. Feedstuffs?

1) Many types can be used to furnish necessary nutrients to economically finish lambs.
2) With high-concentrate diets, can expect the fastest gain but may not be the most economical!? Programs using pastures or crop aftermath may be more economical, even though gains would be slower!

3) Lightweight lambs (50-70 lb) can use more roughage but heavier lambs (70-80 lb) need more concentrates. Thus, perhaps lightweight or small-frame lambs might be more suitable for pasture finishing, and heavyweight or larger-frame lambs might do better in the drylot?

2. **Handling New Lambs**

A. To succeed in a feeder lamb finishing, the first 2 to 3 wk after arrival are crucial!
B. Death loss? - High during the first 2-3 wk & about 2% for the total finishing period with good management.
C. Unload lambs to a dry, clean area and let them rest before processing. Also, important to provide shelter from wind, rain, and snow!
D. Offer grass or grass-legume hay and clean, fresh water. Getting lambs to drink water is the key to getting them on feed quickly.
E. Adapt lambs to their rations gradually, especially when changing to grain-based diets, to avoid digestive upsets (acidosis).
☛ Most feedlot operators try to shear all lambs during the feeding period:

1) Feed consumption and gain may improve with shearing, especially in warm weather.
2) Lambs with No. 1 pelt (0.5 to 1" of wool) usually sell at a premium to full-fleeced lambs. Usually need 40 to 60 days to produce a No. 1 pelt after shearing.

3. **Feeding Method?**

A. Pasture feeding - Pasture can be used for the entire fattening period or for the early part and then placed in the feedlot for finishing.

1) Plants must be palatable and nutritious, and generally the most nutritious ones are the legumes or a mixture of legumes and grasses, which can reduce bloat problems.
2) May be less expensive per pound of gain, but it takes longer to finish lambs.

B. Hand feeding - Fed twice daily on a regular basis:

1) Has the advantage of being able to identify sick or off feed animals easily.
2) Feeding silage? - Usually the method of choice.

C. Self feeding:

1) Rations generally contain between 60 and 85% concentrate.
2) In recent years, grain, as a source of energy, has become less costly in relation to hay, and the current practice is to feed rations containing more grain.

☛ Regardless of feeding method used, care should be taken in changing from high-forage to high-grain diets (i.e., change "gradually"). If not, may have problems with acidosis, diarrhea, and enterotoxemia.

4. Growing or Finishing Lambs on Pasture

A. Using pasture or field crop residues can reduce the production cost!

1) Can be used to clean weed fields, fence rows, soybean stubble, and corn fields.
2) Lush, cool-season grasses or alfalfa provide excellent fall & winter (in some areas) pasture.

B. Depending on the targeted marketing date, supplemental concentrates can be fed ad libitum throughout the finishing period or during the last 30 to 40 days.

1) Grazing cool-season grasses? - Need only an energy source such as whole grains.
2) Cleaning fields? - May need grain-protein supplement.

C. In many areas in the US, the most profitable pasture is winter wheat, oat, or rye. A possibility of nitrate poisoning preclude their use in some areas though!

5. Finishing Lambs in Drylot

Estimated production of a 100-pound lamb fed varying grain (barley)-to-roughage (alfalfa) rations [Kott (1998)]

Grain (%)	Hay (%)	Intake, as fed (lb/d)	Gain (lb/d)	Feed:gain (lb//lb)
0	100	7.40	0.38-0.43	17.17-19.24
20	80	6.50	0.51-0.57	11.50-12.86
40	60	5.75	0.60-0.67	8.64-9.66
60	40	5.20	0.68-0.75	6.89-7.70
80	20	4.75	0.74-0.83	5.73-6.39

*Based on NE equations reported by NRC (1985).

A. Feedlots vary from large outside lots with self feeders to complete confinement pen on slotted floors.

B. Equipment used also varies considerably - e.g., Automated feeders, bunk fence-line feeders (feed twice a day), self feeders, or hay and grain feeders for hand feeding.

C. No best ration for feedlot lambs, and rations are based on locally available feeds & prices. Thus, may consist of any combination of hay & grains, ranging from all hay to 20% hay % 80% grain. (See the table)

D. A simple diet of shelled corn, long alfalfa hay, and supplement can be hand-fed to growing-finishing lambs (see the table).

Feeding guide for hand feeding growing-finishing lambs, simplified ration (Kott, 1998)

Wt (lb)	Feed intake (lb/d)	Alfalfa hay (lb/d)	Protein suppl. (lb/d)	Grain (lb/d)	Composition			
					CP	TDN	Ca	P
50	2.0	0.4	0.5	1.1	18.4	73.4	0.85	0.46
70	2.5	0.5	0.5	1.5	16.7	75.4	0.73	0.43
80	3.0	0.6	0.5	1.9	15.6	76.1	0.65	0.40
90	3.5	0.7	0.5	2.3	14.8	76.6	0.60	0.39
100	4.0	0.8	0.5	2.7	14.2	77.0	0.55	0.37
105	4.5	0.9	0.5	3.1	13.8	77.3	0.52	0.36

Source: Thomas, V.M. 1990. In: A Practical Guide to Sheep Disease Management. N. Gates ed. News-Review Publishing Co., Moscow.

E. Feed bunk management practices to follow?

1) At least 12 linear inches of feed bunk space are needed per lamb. Make sure all lambs come to the troughs at each feeding time.
2) Start lambs on a complete feed (pellet/complete ground-mixed), and make sure that they eat feed readily.
3) Change to a simplified ration gradually over a 7-10 day period by top dressing shelled corn and supplement:

a) Corn-supplement would be increased while the starter ration would be reduced.
b) Restrict hay to about ½ lb/lamb/day, and should be fed in separate bunks.

4) Feed twice daily at regular times. Shelled corn is put in feed bunks, and supplement is top dressed or premixed with shelled corn.
5) Feed high-quality alfalfa hay twice daily, following feeding of corn and supplement. Important to feed only the amount they can clean up!
6) Reduce the concentrate feed fed by one half for one or two feedings if the lambs do not clean up the feed from one feeding to the next.
7) Observe the consumption of corn and supplement carefully. Supplement should not be left uneaten in the bunks & also pay attention to sorting by lambs.
8) For spring and summer feeding, place feed bunks in the shade.
9) Be sure plenty of fresh, clean water is available, and salt should also be provided free-choice.

6. **Other Considerations?**

A. Research does not clearly show the need for vitamin supplementation for early lambs, but it has become a common practice to fortify diets with vitamins A, D, and E.

1) Vitamin A? - The more dehydrated alfalfa or alfalfa in the ration, the lower the level of fortification needed.
2) Vitamin D? - Lambs kept indoors in strict confinement would need a high level of fortification. Natural feedstuffs and sun are uncertain sources of vitamin D!
3) Vitamin E? - In areas where white muscle disease or vitamin E/Se deficiency problems are known to exist, fortification at a higher level would be needed.

B. Nitrogen to S ratio:

1) Should maintain a dietary N to S ratio of 10:1, i.e., a diet containing 13% CP (2.1% N) would require 0.21% S.
2) Most grains contain 0.10 to 0.15% S, thus possible that lambs on high-grain diets may be deficient in S, especially when a portion of the protein in the diet was from urea.

C. Ca:P ratio for wether lamb diets? Should be at least 2:1 to minimize urinary calculi problem.

POTENTIAL NUTRITIONAL PROBLEMS

- The incidence of nutritional problems with finishing lambs depends on the severity of stress, individual variation, and management practices.

1. **Enterotoxemia**

A. Perhaps, the most common nutritionally related problem, which is caused by the toxins produced by *Clostridium perfringens* type D, and usually affects larger, fast-gaining lambs.
B. Treatments/prevention:

1) For young lambs under 2 mo of age, should use antitoxin to provide an immediate immunity, which can last 2 to 3 wk.

a) Being used to stop death losses following an outbreak of entertoxemia.
b) Being used to immunize feedlot lambs on a short-term feeding for up to 3 wk.

2) Vaccination? - With bacterin or toxoid will provide a more long-term prevention.

a) The vaccination program is effective for 5-6 mo. Some producers will vaccinate the pregnant ewe about a month before lambing.
b) Early-weaned? Should be vaccinated twice (2 to 3 wk apart) prior to weaning.
c) Older feeder lambs that are transported to the finishing area should be vaccinated twice during the first 2 wk after arrival.
☛ There may be a reaction at the injection site, which may persist for at least 30 days, thus not to use bacterin if intended to slaughter within that time period.

2. **Urinary Calculi**

A. Commonly occur in rams or wethers in drylot.
B. Prevention?

1) Maintaining a proper Ca to P ratio would help. The ratio closer to 1:1? - Greater the probability of having the problem.
2) Providing a continuous supply of clean, cool water with adequate water space can be useful in prevention. Addition of salt or trace mineral salt may enhance water intake, thus less calculi problem?
3) Ammonium chloride or ammonium sulfate at 0.5% may reduce the incidence?

3. **Rectal Prolapse**

A. The tendency to develop prolapse may be associated with genetics, but . . .
B. Feeding pelleted, high-roughage rations may increase the incidence of rectal prolapse.
C. Excessive dustiness of the ration may lead to increase coughing, thus increase prolapse?

D. Lambs with short-docked tails are more prone to develop prolapse vs. long docks.

FEEDING REPLACEMENT EWES AND RAMS

1. **General**

A. Sheep production economics are dictated by the overhead costs of maintaining ewes.
B. Nutrients needs for replacement ewe lambs after weaning will vary with the age of lambs at their first breeding.
C. Two options in terms of breeding replacement ewes?

1) Breed ewe lambs to lamb at 1-yr-old, or
2) More traditional approach of breeding ewes at yearlings to lamb first as 2-yr-olds.

2. **Breeding Ewe Lambs**

A. More producers are replacing ewes with selected ewe lambs rather than yearlings.
B. Advantages of breeding ewes as lambs (7 to 8 mo of age) to lamb at about a year of age:

1) Gets ewes into production about a year earlier, thus reducing maintenance cost.
2) Shortens generation interval, resulting in more rapid gain from selection.
3) Increases lifetime production.
4) Identifies ewes that are more productive.

C. If they are to be bred to lamb when they are 12 to 14 mo of age, nutrition between weaning and breeding must be on a high plane.

1) In general, ewe lambs' weight must be about 65% of their mature body weight at start of the breeding season.

a) For more traditional breeds, such as Ramboullet, Targhee, Columbia, and Suffolk, perhaps, 70% of their mature body wt? - e.g., Columbia with mature body wt of 165 lb, ewe lambs should weigh 115 lb at the start of the breeding season.
b) Others that may contain one-quarter or more of Finn breed? - Can get by with 60 to 65% of their target body wt? Example - If mature ewes weigh 145 lb, then ewe lambs should weigh between 87 & 94 lb at the beginning of the breeding season.

2) Most early-born ewe lambs (January- or February-born) - Should be fed relatively high-energy creep and starter rations.

a) Most feeding program after weaning should produce 0.4 to 0.5 lb of gain/day?
b) That target weight gain is not possible with good-quality forage alone (e.g., may be only 0.25 to 0.33 lb/day with alfalfa hay), thus need to feed some grain!

3) After identifying the selected ewe lambs at about 90 to 120 days of age (80 to 90 lb):

   a) Remove them from the market lamb finishing lot and off the high-energy finishing type ration.
   b) Replacement ewe lambs should neither get fat nor have the udder infiltrated with fat cells. Could easily happen to ewe lambs left in a finishing lot too long!

3. **Breeding Yearling Ewes**

A. Generally, producers will not try to breed ewe lambs under range conditions.
B. Replacement ewes are bred frist at 18 to 19 mo of age to produce their first lambs when they are 2 yr of age.
C. Nutrition may not be nearly critical as ewe lambs, and the nutritional needs can be met fairly easily, except when grazing on mature or weathered grasses during the winter.
D. Can be moved to farm areas & let them graze crop aftermath/pastures, or even fed forage diets in drylot. Supplement would be needed only when they are wintered on dryland pastures.

4. **Feeding Rams**

A. Replacement ram lambs (about 130 lb) or yearlings (about 220 lb) need, respectively, 5 to 5½ lb or 6½ to 7 1b of feed/day to gain at the recommended rate of 0.3 to 0.4 lb/day.
B. Summer pasture alone is not adequate & good pasture could take the place of only about half the hay.
C. Continue to feed grain during the breeding period.
D. Mature rams should be provided with a maintenance ration (pasture) throughout the year, except during a 30- to 45-day period prior to breeding:

   1) Should be gaining approximately 0.3 to 0.5 lb/day during that period.
   2) Can be done by feeding dehydrated alfalfa pellets or a combination of hay and grain with no more than ⅓ of the ration composed of grain.

E. Feedstuffs should be similar to those a ram will be consuming during the breeding season so that he will not go off feed.

UREA AND FEED ADDITIVES & IMPLANTS

1. **Urea**

   A. Urea & other nonprotein N can be used to replace up to ⅓ of the protein equivalent of the sheep ration. About 1.5% urea would be the maximum amount usable in a grower-finisher lamb diet.
   B. Increased attention may be needed in mixing procedures and during the adjustment or early stages of the feeding period.
   C. Should not be used in creep, range sheep, or lamb rations containing low or limited energy.
   D. The usefulness of urea depends on the amount of fermentable energy present in a feed and the amount of ammonia formed by protein degradation by bacterial fermentation of the feed in the rumen.

2. **Additives and Implants**

   A. The inclusion of antibiotics in creep rations for suckling lambs and lamb-finishing rations can improve gain and feed efficiency. The greatest response under stressful conditions?
   B. Chlortetracycline or oxytetracycline is particularly effective for protecting against low level disease infections and also offering some protection against enterotoxemia.
   C. Aureomycin (chlortetracycline)? - 20 to 50 g/ton to stimulate gains and improve feed efficiency.
   D. Terramycin (oxytetracycline)? - 10 to 20 g/ton to stimulate gains and improve feed efficiency, and 10 mg/lb BW (7-14 d) as an aid in the prevention or treatment of bacterial diarrhea.
   E. Lasalocid (Bovatec)? - 20 to 30 g/ton complete feed for prevention of coccidiosis.
   F. Ralgro? - Results from implanting lambs with Ralgro (12 mg) are rather inconsistent.
   G. Ammonium chloride or sulfate? - Addition of 0.5% ammonium chloride or sulfate to diets can be used to prevent problems with urinary calculi in wethers.

NUTRIENT REQUIREMENTS TABLES
(Based on NRC, 1985)

1. **Table 1. Daily Nutrient Requirements of Sheep** [TDN = total digestible nutrients; DE = digestible energy; ME = metabolizable energy]

Body weight (kg)	Weight change/day (g)	Dry Matter[a] Intake (kg)	Dry Matter[a] Percent Body weight.	Energy[b] TDN (kg)	Energy[b] DE (Mcal)	Energy[b] ME (Mcal	Crude protein (g)	Ca (g)	P (g)	Vitamin A activity (IU)	Vitamin E activity (IU)
***Ewes*[c]**											
Maintenance											
50	10	1.0	2.0	0.55	2.4	2.0	95	2.0	1.8	2,350	15
60	10	1.1	1.8	0.61	2.7	2.2	104	2.3	2.1	2,820	16
70	10	1.2	1.7	0.66	2.9	2.4	113	2.5	2.4	3,290	18
80	10	1.3	1.6	0.72	3.2	2.6	122	2.7	2.8	3,760	20
90	10	1.4	1.5	0.78	3.4	2.8	131	2.9	3.1	4,230	21
Flushing - 2 Weeks prebreeding and first 3 weeks of breeding											
50	100	1.6	3.2	0.94	4.1	3.4	150	5.3	2.6	2,350	24
60	100	1.7	2.8	1.00	4.4	3.6	157	5.5	2.9	2,820	26
70	100	1.8	2.6	1.06	4.7	3.8	164	5.7	3.2	3,290	27
80	100	1.9	2.4	1.12	4.9	4.0	171	5.9	3.6	3,760	28
90	100	2.0	2.2	1.18	5.1	4.2	177	6.1	3.9	4,230	30
Nonlactating - First 15 weeks gestation											
50	30	1.2	2.4	0.67	3.0	2.4	112	2.9	2.1	2,350	18
60	30	1.3	2.2	0.72	3.2	2.6	121	3.2	2.5	2,820	20
70	30	1.4	2.0	0.77	3.4	2.8	130	3.5	2.9	3,290	21
80	30	1.5	1.9	0.82	3.6	3.0	139	3.8	3.3	3,760	22
90	30	1.6	1.8	0.87	3.8	3.2	148	4.1	3.6	4,230	24
Las 4 weeks gestation (130-150% lambing rate expected) or last 4-6 weeks lactation suckling singles[d]											
50	180 (45)	1.6	3.2	0.94	4.1	3.4	175	5.9	4.8	4,250	24
60	180 (45)	1.7	2.8	1.00	4.4	3.6	184	6.0	5.2	5,100	26
70	180 (45)	1.8	2.6	1.06	4.7	3.8	193	6.2	5.6	5,950	27
80	180 (45)	1.9	2.4	1.12	4.9	4.0	202	6.3	6.1	6,800	28
90	180 (45)	2.0	2.2	1.18	5.1	4.2	212	6.4	6.5	7,650	30
Last 4 weeks gestation (180-225% lambing rate expected)											
50	225	1.7	3.4	1.10	4.8	4.0	196	6.2	3.4	4,250	26
60	225	1.8	3.0	1.17	5.1	4.2	205	6.9	4.0	5,100	27
70	225	1.9	2.7	1.24	5.4	4.4	214	7.6	4.5	5,950	28
80	225	2.0	2.5	1.30	5.7	4.7	223	8.3	5.1	6,800	30
90	225	2.1	2.3	1.37	6.0	5.0	232	8.9	5.7	7,650	32
First 6-8 weeks lactation suckling singles or last 4-6 weeks lactation suckling twins[d]											
50	-25 (90)	2.1	4.2	1.36	6.0	4.9	304	8.9	6.1	4,250	32
60	-25 (90)	2.3	3.8	1.50	6.6	5.4	319	9.1	6.6	5,100	34
70	-25 (90)	2.5	3.6	1.63	7.2	5.9	334	9.3	7.0	5,950	38
80	-25 (90)	2.6	3.2	1.69	7.4	6.1	344	9.5	7.4	6,800	39
90	-25 (90)	2.7	3.0	1.75	7.6	6.3	353	9.6	7.8	7,650	40
First 6-8 weeks lactation suckling twins											
50	-60	2.4	4.8	1.56	6.9	5.6	389	10.5	7.3	5,000	36
60	-60	2.6	4.3	1.69	7.4	6.1	405	10.7	7.7	6,000	39
70	-60	2.8	4.0	1.82	8.0	6.6	420	11.0	8.1	7,000	42
80	-60	3.0	3.8	1.95	8.6	7.0	435	11.2	8.6	8,000	45
90	-60	3.2	3.6	2.08	9.2	7.5	450	11.4	9.0	9,000	48
Ewe Lambs											
Nonlactating - First 15 weeks gestation											
40	160	1.4	3.5	0.83	3.6	3.0	156	5.5	3.0	1,880	21
50	135	1.5	3.0	0.88	3.9	3.2	159	5.2	3.1	2,350	22
60	135	1.6	2.7	0.94	4.1	3.4	161	5.5	3.4	2,820	24
70	125	1.7	2.4	1.00	4.4	3.6	164	5.5	3.7	3,290	26
Last 4 weeks gestation (100-120% lambing rate expected)											
40	180	1.5	3.8	0.94	4.1	3.4	187	6.4	3.1	3,400	22
50	160	1.6	3.2	1.00	4.4	3.6	189	6.3	3.4	4,250	24
60	160	1.7	2.8	1.07	4.7	3.9	192	6.6	3.8	5,100	26
70	150	1.8	2.6	1.14	5.0	4.1	194	6.8	4.2	5,950	27
Last 4 weeks gestation (130-175% lambing rate expected)											
40	225	1.5	3.8	0.99	4.4	3.6	202	7.4	3.5	3,400	22
50	225	1.6	3.2	1.06	4.7	3.8	204	7.8	3.9	4,250	24
60	225	1.7	2.8	1.12	4.9	4.0	207	8.1	4.3	5,100	26
70	215	1.8	2.6	1.14	5.0	4.1	210	8.2	4.7	5,950	27
First 6-8 weeks lactation suckling singles (wean by 8 weeks)											
40	-50	1.7	4.2	1.12	4.9	4.0	257	6.0	4.3	3,400	26
50	-50	2.1	4.2	1.39	6.1	5.0	282	6.5	4.7	4,250	32
60	-50	2.3	3.8	1.52	6.7	5.5	295	6.8	5.1	5,100	34
70	-50	2.5	3.6	1.65	7.3	6.0	301	7.1	5.6	5,450	38
First 6-8 weeks lactation suckling twins (wean by 8 weeks)											

40	-100	2.1	5.2	1.45	6.4	5.2	306	8.4	5.6	4,000	32
50	-100	2.3	4.6	1.59	7.0	5.7	321	8.7	6.0	5,000	34
60	-100	2.5	4.2	1.72	7.6	6.2	336	9.0	6.4	6,000	36
70	-100	2.7	3.9	1.85	8.1	6.6	351	9.3	6.9	7,000	40
Replacement Ewe Lambs [e]											
30	227	1.2	4.0	0.78	3.4	2.8	185	6.4	2.6	1,410	18
40	182	1.4	3.5	0.91	4.0	3.3	176	5.9	2.6	1,880	21
50	120	1.5	3.0	0.88	3.9	3.2	136	4.8	2.4	2,350	22
60	100	1.5	2.5	0.88	3.9	3.2	134	4.5	2.5	2,820	22
70	100	1.5	2.1	0.88	3.9	3.2	132	4.6	2.8	3,290	22
Replacement Ram Lambs [e]											
40	330	1.8	4.5	1.1	5.0	4.1	243	7.8	3.7	1,880	
60	320	2.4	4.0	1.5	6.7	5.5	263	8.4	4.2	2,820	
80	200	2.8	3.5	1.8	7.8	6.4	268	8.5	4.6	3,700	
100	250	3.0	3.0	1.9	8.4	6.9	264	8.2	4.8	4,700	
Lambs Finishing - 4 to 7 Months Old [f]											
30	295	1.3	4.3	0.94	4.1	3.4	191	6.6	3.2	1,410	20
40	275	1.6	4.0	1.22	5.4	4.4	185	6.6	3.3	1,880	24
50	205	1.6	3.2	1.23	5.4	4.4	100	5.6	3.0	2,350	24
Early Weaned Lambs - Moderate Growth Potential [f]											
10	200	0.5	5.0	0.40	1.8	1.4	127	4.0	1.9	470	10
20	250	1.0	5.0	0.80	3.5	2.9	167	5.4	2.5	940	20
30	300	1.3	4.3	1.00	4.4	3.6	191	6.7	3.2	1,410	20
40	345	1.5	3.8	1.16	5.1	4.2	202	7.7	3.9	1,880	22
50	300	1.5	3.0	1.16	5.1	4.2	181	7.0	3.8	2,350	22
Early Weaned Lambs - Rapid Growth Potential [f]											
10	250	0.6	6.0	0.48	2.1	1.7	157	4.9	2.2	470	12
20	300	1.2	6.0	0.92	4.0	3.3	205	6.5	2.9	940	24
30	325	1.4	4.7	1.10	4.8	4.0	216	7.2	3.4	1,410	21
40	400	1.5	3.8	1.14	5.0	4.1	234	8.6	4.3	1,880	22
50	425	1.7	3.4	1.29	5.7	4.7	240	9.4	4.8	2,350	25
60	350	1.7	2.8	1.29	5.7	4.7	240	8.2	4.5	2,820	25

[a]To convert dry matter to an as-fed basis, divide dry matter values by the percentage of dry matter in the particular feed; [b]One kilogram TDN = 4.4 Mcal DE ; ME = 82% of DE. Because of rounding errors, values in Table 1 and Table 2 may differ; [c]Values are applicable for ewes in moderate condition. Fat ewes should be fed according to the next lower weight category and thin ewes at the next higher weight category. Once desired or moderate weight condition is attained, use that weight category through all production stages; [d]Values in parentheses are for ewes suckling lambs the last 4-6 weeks of lactation; [e]Lambs intended for breeding; thus. maximum weight gains and finish are of secondary importance; [f]Maximum weight gains expected.

2. **Table 2. Nutrient Composition in Diets for Sheep (100% DM Basis)**[a] [TDN = total digestible nutrients; DE = digestible energy; ME = metabolizable energy]

		Energy[b]									
Body weight (kg)	Weight change/day (g)	TDN[c] (%)	DE (Mcal/kg)	ME (Mcal/kg)	Concentrate (%)	Forage protein (%)	Crude Ca (%)	P (%)	activity (%)	Vitamin A activity (IU/kg)	Vitamin E (IU/kg)
Ewes[d]											
Maintenance											
70	10	55	2.4	2.0	0	100	9.4	0.20	0.20	2,742	15
Flushing - 2 Weeks prebreeding and first 3 weeks of breeding											
70	100	59	2.6	2.1	15	85	9.1	0.32	0.18	1,828	15
Nonlactating - First 15 weeks gestation											
70	30	55	2.4	2.0	0	100	9.3	0.25	0.20	2,350	15
Las 4 weeks gestation (130-150% lambing rate expected) or last 4-6 weeks lactation suckling singles[e]											
70	180 (0.45)	59	2.6	2.1	15	85	10.7	0.35	0.23	3,306	15
Last 4 weeks gestation (180-225% lambing rate expected)											
70	225	65	2.9	2.3	35	65	11.3	0.40	0.24	3,132	15
First 6-8 weeks lactation suckling singles or last 4-6 weeks lactation suckling twins[e]											
70	-25 (90)	65	2.9	2.4	35	65	13.4	0.32	0.26	2,380	15
First 6-8 weeks lactation suckling twins											
70	-60	65	2.9	2.4	35	65	15.0	0.39	0.29	2,500	15
Ewe Lambs											
Nonlactating - First 15 weeks gestation											
55	135	59	2.6	2.1	15	85	10.6	0.35	0.22	1,668	15
Last 4 weeks gestation (100-120% lambing rate expected)											
55	160	63	2.8	2.3	30	70	11.8	0.39	0.22	2,833	15
Last 4 weeks gestation (130-175% lambing rate expected)											
55	225	66	2.9	2.4	40	60	12.8	0.48	0.25	2,833	15
First 6-8 weeks lactation suckling singles (wean by 8 weeks)											
55	-50	66	2.9	2.4	40	60	13.1	0.30	0.22	2,125	15
First 6-8 weeks lactation suckling twins (wean by 8 weeks)											
55	-100	69	3.0	2.5	50	50	13.7	0.37	0.26	2,292	15
Replacement Ewe Lambs[f]											
30	227	65	2.9	2.4	35	65	12.8	0.53	0.22	1,175	15
40	182	65	2.9	2.4	35	65	10.2	0.42	0.18	1,343	15
50-70	115	59	2.6	2.1	15	85	9.1	0.31	0.17	1,567	15
Replacement Ram Lambs[f]											
40	330	63	2.8	2.3	30	70	13.5	0.43	0.21	1,175	15
60	320	63	2.8	2.3	30	70	11.0	0.35	0.18	1,659	15
80-100	270	63	2.8	2.3	30	70	9.6	0.30	0.16	1,979	15
Lambs Finishing - 4 to 7 Months Old[g]											
30	295	72	3.2	2.5	60	40	14.7	0.51	0.24	1,085	15
40	275	76	3.3	2.7	75	25	11.6	0.42	0.21	1,175	15
50	205	77	3.4	2.8	80	20	10.0	0.35	0.19	1,469	15
Early Weaned Lambs - Moderate and Rapid Growth Potential[g]											
10	250	80	3.5	2.9	90	10	26.2	0.82	0.38	940	20
20	300	78	3.4	2.8	85	15	16.9	0.54	0.24	940	20
30	325	78	3.3	2.7	85	15	15.1	0.51	0.24	1,085	15
40-60	400	78	3.3	2.7	85	15	14.5	0.55	0.28	1,253	15

[a]Values in Table 2 are calculated from daily requirements in Table 1 divided by DM intake. The exception? Vitamin E daily requirement/head are calculated from vitamin E/kg diet x DM intake; [b]One kilogram TDN = 4.4 Mcal DE. ME = 82% of DE. Because of rounding errors, values in Table 1 and Table 2 may differ; [c]TDN calculated on following basis: 55 & 50% TDN on the DM and as-fed basis, respectively, for hay, and 83 and 75% TDN on the DM and as-fed basis for grain; [e]Values are for ewes in moderate condition. Fat ewes should be fed according to the next lower weight category and thin ewes at the next higher weight category. Once desired or moderate weight condition is attained, use that weight category through all production stages; [e]Values in parentheses are for ewes suckling lambs the last 4-6 weeks of lactation; [f]Lambs intended for breeding, thus maximum weight gain and finish are of secondary importance; [g]Maximum weight gains expected.

3. Table 3. Net Energy Requirements for Lambs of Small, Medium, and Large Mature Weight Genotypes[a] (kcal/d) [NEm = net energy for maintenance; NEg = net energy for gain; growthTDN = total digestible nutrients; DE = digestible energy; ME = metabolizable energy]

Body Weight (kg)[b]:	10	20	25	30	35	40	45	50
NEm Requirements[c]:	315	530	626	718	806	891	973	1053
NEg Requirements								
Mature Weight & Daily Gain (g)[b]								
Small mature weight lambs[d]								
100	178	300	354	406	456	504	551	596
150	267	450	532	610	684	756	826	894
200	357	600	708	812	912	1,008	1,102	1,192
250	446	750	886	1,016	1,140	1,261	1,377	1,490
300	535	900	1,064	1,219	1,368	1,513	1,652	1,788
Medium mature weight lambs[e]								
100	155	261	309	354	397	439	480	519
150	233	392	463	531	596	658	719	778
200	310	522	618	708	794	878	960	1,038
250	388	653	771	884	993	1,097	1,199	1,297
300	466	784	926	1,062	1,191	1,316	1,438	1,557
350	543	914	1,080	1,238	1,390	1,536	1,678	1,816
400	621	1,044	1,234	1,415	1,589	1,756	1,918	2,076
Large mature weight lambs[f]								
100	132	221	262	300	337	372	407	439
150	197	332	392	450	505	558	610	660
200	263	442	524	600	674	744	813	880
250	329	553	654	750	842	930	1,016	1,099
300	394	663	785	900	1,010	1,116	1,220	1,320
350	461	775	916	1,050	1,179	1,303	1,423	1,540
400	526	885	1,046	1,200	1,347	1,489	1,626	1,760
450	592	996	1,177	1,350	1,515	1,675	1,830	1,980

[a]Approximate mature ram weights of 95, 115, and 135 kg, respectively; [b]Weights and gains include fill; [c]NEm = 56 Kcal·$W^{0.75}$·d^{-1}; [d]NEg = 317 kcal·$W^{0.75}$·LWG, kg·d^{-1}; [e]NEg =276 kcal·$W^{0.75}$·LWG, kg·d^{-1}; [f]NEg = 234 kcal·$W^{0.75}$·LWG, kg·d^{-1}.

4. Table 4. NEpreg (NEy) Requirements (Kcal/day) of Ewes Carrying Different Numbers of Fetuses at Various Stages of Gestation[a,b]

Number of Fetuses Being Carried	Stage of Gestation (days)					
	100	%	120	%	140	%
1	70	100	145	100	260	100
2	125	178	265	183	440	169
3	170	243	345	238	570	219

[a]For gravid uterus (plus contents) and mammary gland development only; [b]% = As a percentage of a single fetus's requirement.

5. Crude Protein Requirements for Lambs of Small, Medium and Large Mature Weight Genotypes (g/d)[a,b]

Body Weight (kg):	10	20	25	30	35	40	45	50
Mature Weight & Daily Gain (g)								
Small mature weight lambs								
100	84	112	122	127	131	136	135	134
150	103	121	137	140	144	147	145	143
200	123	145	152	154	156	158	154	151
250	142	162	167	168	168	169	164	159
300	162	178	182	181	180	180	174	168
Medium mature weight lambs								
100	85	114	125	130	135	140	139	139
150	106	132	141	145	149	153	151	149
200	127	150	158	160	163	166	163	160
250	147	167	174	175	177	179	175	171
300	168	185	191	191	191	191	186	181
350	188	203	207	206	205	204	198	192
400	209	221	224	221	219	217	210	202
Large mature weight lambs								
100	94	128	134	139	145	144	150	156
150	115	147	152	156	160	159	164	169
200	136	166	170	173	176	174	178	182
250	157	186	188	190	192	189	192	195
300	179	205	206	207	208	204	206	208
350	200	224	224	224	224	219	220	221
400	221	243	242	241	240	234	234	234
450	242	262	260	256	256	249	248	248

[a]Approximate mature ram weights of 95, 115, and 135 kg, respectively; [b]Weights and gains include fill.

6. Table 6. Macromineral and Micromineral Requirements of Sheep (Dry Matter Basis)

Nutrient	Requirement	Maximum Tolerance[a]
Macromineral, %		
Sodium	0.09-0.18	
Chlorine	-	
Calcium	0.20-0.82	
Phosphorus	0.16-0.38	
Magnesium	0.12-0.18	
Potassium	0.50-0.80	
Sulfur	0.14-0.26	
Micromineral, mg/kg or ppm		
Iodine	0.10-0.80[b]	50
Iron	30-50	500
Copper	7-11[c]	25[d]
Molybdenum	0.5	10[d]
Cobalt	0.1-0.2	10
Manganese	20-40	1,000
Zinc	20-33	750
Selenium	0.1-0.2	2
Fluorine	-	60-150

[a]NRC (1980); [b]High level for pregnancy and lactation in diets not containing goitrogens; should be increased if diets contain goitrogens; [c]Requirement when dietary Mo concentrations are < 1 mg/kg DM; [d]Lower levels may be toxic under some circumstances.

7. Vitamin E Requirements of Growing-Finishing Lambs and Suggested Levels of Feed Fortification to Provide 100% of Requirements

Body Weight	α-Tocopheryl Acetate		Feed	To Concentrate		To 15% Protein Supplement	
(kg)	(mg/1amb/day)	(mg/kg diet)	(kg)	(mg/kg)	(mg/ton)	(mg/kg)	(mg/ton)
10	5.0	20	0.23	20	18,200	133	120,000
20	10.0	20	0.45	20	18,200	133	120,000
30	15.0	15	0.96	15	13,600	100	90,000
40	20.0	15	1.30	15	13,600	100	90,000
50	25.0	15	1.60	15	13,600	100	90,000

FISH, DOG, AND CAT NUTRITION AND FEEDING

- *References: NRC (1993), Hirakawa (1998) in Kellems & Church (1998), Corbin (2001. Feedstuffs 73:70-75), and Jurgens (2002).*

FISH DIET FORMULATION AND PROCESSING

1. **General**

A. A primary objective in diet formulation? To provide a balanced mixture of ingredients to support the maintenance, growth, reproduction, and health at an acceptable cost!
B. Also, must consider some factors that can facilitate the manufacturing process to produce a diet with the desired physical characteristics.
C. The diet should be palatable & not contain antinutritional factors in the amount or concentrations that can reduce the performance.
D. The NRC's dietary requirements:

1) Fish size, metabolic function, management, and environmental factors have slight to profound effects on dietary nutrients needed for optimum performance. Thus, the NRC requirement data should be used with some discretion.
2) The NRC estimates were mostly made with purified diets containing highly digestible ingredients (i.e., the data represent near 100% digestibility), thus important to make some allowances for, e.g., bioavailability of nutrients and processing & storage losses when formulating diets using natural ingredients.
3) Unknown energy & nutrient requirements for some species? Can use the requirements established for a related species with some caution?

2. **Formulating Fish Diets**

A. Protein:

1) Usually, the first nutrient considered and adjust energy to provide the optimum ratio.
2) Must be balanced for indispensable amino acids.

B. Carbohydrate? - The amount varies with fish species, depending on their ability to use it as an energy source and processing requirements.
C, Lipids? - Select the type & concentration to satisfy essential fatty acid (EFA) and energy requirements.
D. Vitamins? - Mostly supplied from a supplemental premix because of uncertainty over the content and bioavailability of vitamins in the feedstuffs.
E. Minerals? - The content in feedstuffs is a bit more consistent (vs. vitamins?), thus usually make mineral supplementation based on the composition of the major ingredients.
F. Overfortification of labile nutrients?

1) Necessary as a safety factor in processed fish diets.
2) Amino acids, several vitamins, and inorganic elements are relatively stable to heat, moisture, and oxidation under normal processing and storage conditions.
3) But, some vitamins are subject to some loss, thus should include more than the established requirements?

G. Least-cost formulation using linear programming methods? - Commonly used for fish diets & diets for other food animals, and necessary to have:

1) Nutrient requirements of the animal.
2) Bioavailability of nutrients and the energy content of ingredients:

   a) Important in making computerized substitutions among ingredients.
   b) Values are often quite variable among fish and also among feedstuffs.
   c) Some examples? (1) Cold-water fishes do not use carbohydrates as a source of energy as well as warm-water species, (2) digestibility of P is less for fish vs. livestock, especially for fish without gastric secretions, and (3) Lys in cottonseed meal is less digestible than the Lys in soybean meal.

3) Minimum and maximum restrictions on concentrations of various ingredients.

   a) Can be placed on certain ingredients because of their effects on production process and palatability, or their potential adverse effects on fish performance, flesh quality, or water quality.
   b) Examples?

      (1) Fishmeal and other animal protein sources - Beneficial in catfish diets for reasons not explained on the basis amino acids, thus may specify a minimum?
      (2) Cottonseed meal - Sometimes restricted because of free gossypol toxicity.
      (3) Carotenoid concentrations - Should be controlled because of the effect of xanthophylls on undesirable yellow pigmentation to light-fleshed fish.
      (4) Red pigmentation sources - Necessary for the diets of salmonids.

4) Cost of ingredients.

3. **Some Common Ingredients for Fish Diets**

A. Fishmeal - Prepared from good-quality, whole fish is one of the highest-quality protein sources commonly available.

1) It is also a rich source of energy, EFA, and minerals, and is highly digestible and palatable to most fishes.
2) Ones made from fish parts, such as waste from fish processing and canning plants:

a) Have less high-quality protein vs. ones made from whole fish.
b) High in ash, and can produce mineral imbalances, so . . .

B. Other animal protein sources?

1) By-products, such as meat and bone meal and poultry by-product meal, that contain about 45 to 55% CP. Quality is less vs. whole fish meal, and also the ash content is usually high because a larger proportion non-muscle tissues.
2) Flash or spray-dried blood meal - Rich in protein (80 to 86%) but low in Met and unbalanced in branched-chain amino acids.
3) Feather meal - High in CP (80%) but usually digestibility is low.

C. Soybean meal:

1) Universally available and has one of the best amino acid profile of all protein-rich plant feedstuffs.
2) For some fish, such as young salmon, soybean meal can be unpalatable, but others, such as channel catfish, readily consume diets containing up to 50% soybean meal.

D. Cottonseed and peanut meals:

1) Are concentrated sources of protein and have been used in fish feeds in the US, but limiting in Lys & Met.
2) Most cottonseed meals contain free gossypol, which is moderately toxic to monogastric animals and limits its use in fish feeds.

E. Others:

1) Lupin flour - Effectively replaces full-fat soybean flour as a protein source in feeds for rainbow trout.
2) Canola meal:

a) Has an amino acid profile comparable to soybean meal, but lower in CP and higher in fiber and tanins.
b) Has been used in experimental feeds for salmonids with success though.

F. Replacing fish meal or other animal by-product proteins with oilseed meals?

1) Must consider losses in energy, minerals, and lipids.
2) Examples? - Dehulled soybean meal contains 25% less ME for rainbow trout, 86% less available P for channel catfish, and 90% less (n-3) fatty acids than anchovy fish meal on an equal DM basis.

G. Carbohydrates - Primary nutritional contribution of grains.

1) Whole grains contain 62 to 72% starch, which is 60 to 70% digestible by warm-water fish, but less digestible by salmonids.
2) Starch in grains is important binding agent in steam-pelleted and extruded fish feeds.

H. Fats and oils:

1) Used as a source of energy to provide EFA, and to coat the outside of pellets to reduce abrasiveness and dustiness.
2) Marine fish oils are rich sources of essential (n-3) fatty acids, containing 10 to 25% of the highly unsaturated (n-3) fatty acids.

I. Ingredient quality?

1) Major ingredients - Should analyze for proximate composition & selected nutrients such as limiting amino acids (Lys and S-amino acids?) or EFA on a regular basis.
2) Animal by-products with high proportion of bones, feathers, or connective tissues should be subjected to in vitro enzyme assays to assess protein digestibility?
3) Should be tested for mycotoxins, pesticides, and other contaminants periodically?

4. **Feed Processing**

A. Should be processed into water-stable, particulate forms (granules, pellets) for efficient consumption by the fish and to minimize fouling of the water.
B. Compression pelleted or extruded feed is common, but also moist (or semimoist), microencapsulated, and micropulverized feeds are available.
C. Steam pelleting through compression:

1) Produces a dense pellet that sinks rapidly in water.
2) Involves the use of moisture, heat, and pressure to agglomerate ingredients into compact and larger particles.
3) Steam added to the ground feed mixture (mash) during pelleting assists in partially gelatinizing starch, which aids in the binding of the ingredients.
4) Must be firmly bonded to prevent rapid disintegration in water, which will reduce feed efficiency and water quality.

D. Extrusion:

1) The feed mixture in the form of a dough is forced through a small orifice at high pressure and temperature. Allows entrapment of water vapor by the feed particles, which, on drying, will float on water.
2) Usually the mixture of finely ground ingredients is conditioned with steam into a "mash" that may or may not be precooked before entering the extruder.
3) Contain more water than steam-pelleted particles, thus require external heat for drying. May end up with the loss of heat-sensitive vitamins such L-ascorbic acid.

4) Extruded feeds are firmly bound due to gelatinization of starch and denaturation of protein, which results in few fines and long water stability.
5) Extruded feeds are preferred by many producers, especially those feeding in large ponds, because they allow observation of the feeding process.

E. Granule diets for small fish

1) Prepared by pelleting the ingredient mixture and then reducing the size of the pellets by crumbling. Crumbled pellets are separated into various sizes by screening.
2) Fat is usually sprayed onto the surface of the particles after processing.
3) Considerable loss of water-soluble nutrients because leaching may occur with small-particle diets, which have large surface area?

F. Microencapsulation:

1) Coating of the diet with a thin layer of a compound to reduce disintegration, leaching, or bacterial degradation.
2) Materials should be water insoluble but digestible by enzymes in the digestive tract of the fish.
3) Microencapsulation and microbinding vary with the encapsulation material used & the substrate being coated. Nylon (N-N bonds) cross-linked proteins, Ca alginate, and oils have been used as encapsulation materials.

G. Moist or semimoist feeds

1) Prepared by adding moisture and a hydrocolloidal binding agent (e.g., carboxy-methyl-cellulose, gelatinized starch, or ground, wet animal tissue) with the dry ingredients, and forming the mixture into soft, moist pellets.
2) Advantages? - More palatable than dry diets for some species, no need for a steam-pelleting machine, and heating and drying are avoided.
3) Disadvantages? - Susceptible to microorganism or oxidation spoilage unless fed immediately or frozen. Fish parts should be pasteurized to destroy possible pathogens and thiaminase!
4) Not necessary to store some feeds frozen - May contain humectants (e.g., propylene glycol, which lower water activity below that will allow bacterial growth) and fungistats (e.g., propionic or sorbic acid).

5. **Other Dietary Components?**

A. Diets and ingredients contain materials other than nutrients that may affect metabolism positively or negatively. Naturally present or added for specific purposes.

B. Water:

1) Moist feeds (10-40%) have been used for Pacific salmon & Atlantic salmon - They prefer moist feeds under hatchery conditions.

2) In recent years, commercial semimoist (15 to 20%) diets that do not require refrigeration have been introduced:

    a) To reduce moisture loss during processing and storage & to improve texture. Use polyhydric alcohols - e.g., propylene glycol, glycerol, and sorbitol.
    b) Mold inhibitors are also required.

C. Fiber

1) Fish do not secrete cellulase, thus cellulose digestion does not play important role in their nutrition.
2) Some roles of fiber?

    a) Provide physical bulk to the feed, and cellulose & hemicellulose have been used as diluents & binders in fish diets.
    b) Some researchers reported that small amounts of supplemental cellulose increased growth and the efficiency of protein utilization.
    c) Diets with natural ingredients that contain 3-5% fiber? - No beneficial effect of adding fiber?

3) Most fish can tolerate up to 8% or so of dietary fiber, but higher concentrations can depress growth.
4) In most instances, the concern is excess dietary fiber, which can reduce nutrient intake and performance.
5) Try to use highly digestible ingredients & limit the fiber content to minimize an environmental impact?

D. Hormones

1) Various hormones have been evaluated in fish studies - e.g., Growth hormone, thyroid hormones, gonadotropin, prolactin, insulin, and various steroids.
2) Steroids:

    a) About 20 fish species have shown anabolic responses to steroids, but some warm-water species (e.g., channel catfish) have responded negatively.
    b) Prolonged steroid treatment for growth may cause detrimental side effects such as early gonadal development, skeletal deformity, increased susceptability to infections, and pathological changes in the liver.
    c) None has been approved by the FDA for growth enhancement.

3) Hormones have been used successfully to induce or synchronize ovulation & the stimulation of spermiation - e.g., Pituitary extracts & human chorionic gonadotropin.

4) Use of some sex steroids to reverse the sex of some species of salmonids, carp, and tilapias (e.g., feed ethynylestradiol, esterone, diethylstilbestrol, 17-β-estradiol, ethynyltestosterone, methyltestoterone, etc.) - Objectives?

   a) To produce monosex and sterile fish of the faster growing sex.
   b) Achieve better somatic growth.
   c) Prevent sexual maturation & the accompanying deterioration of flesh quality.

E. Antimicrobial agents

1) Only two antibiotics, sulfadimethoxine/ormetoprim & oxytetracycline, have been approved by the FDA for use in fish.
2) Stable under compression pellet processing & storage, but may lose some oxytetracycline with extrusion. Not much effect on sulfadimethoxine/ormetoprim.
3) Unlike with farm animals, antibiotics may not have beneficial effect on bacterial microflora of fish.
4) Chemotherapeutic compounds may be toxic or have adverse effects when administered for an extended period of time.

F. Antioxidants

1) Commonly used in fish feeds with a high concentration of polyenic fatty acids to prevent the oxidation of lipids. Ethoxyquin, BHT & BHA are most commonly used.
2) Breakdown products of lipid oxidation can react with the epsilon amino group of Lys & reduce its nutritional value.
3) Natural vitamin E has antioxidative activity, but synthetic form does not because it is in ester form in the diet, which has little antioxidative activity until hydrolized to alcohol form in the gut.

G. Pigments

A. Fish & brids use oxygenated carotenoids (xanthophylls) for pigmentation of skin, flesh, and plumage/feather. Fish cannot synthesize, thus rely on exogenous sources.
B. In salmonids, two oxycarotenoids, astaxanthin & canthaxanthin, are responsible for the red to orange coloring of the flesh, skin, and fins.

FISH FEEDING PRACTICES

1. **General**

A. Need to use different feeding strategies simply because of the difference in the size and species of fish and also the diverse environmental and management conditions.
B. Need to consider carefully some characteristics such as the particle size, texture, density, and palatability.

C. Feed allowance and frequency of feeding are important considerations for the rate & efficiency of growth.
D. Type of feed (floating or sinking) used and method of feeding would depend on the fish, the culture system, and the equipment and personnel available. And, these factors can be as important as meeting the nutrient needs per se.

2. **Feeding Larval Fish**

A. "Larval stage?" - Refers to the period of going through metamorphosis of external and physiological characters from hatch until the juvenile stage.
B. External traits & major organ functions of juveniles can be similar to those of adults.
C. Can be divided into three groups according to the alimentary tract morphology and the enzyme secretion:

   1) First group - e.g., Salmonids & channel catfish, which seems to have a functional stomach before changing from endogenous to external feed.
   2) Second group - e.g., Striped bass & many marine species with a very rudimentary digestive tract, which have no functional stomach or gastric glands & undergo complex metamorphosis of the digestive system.
   3) Third group - e.g., Carps, which develop a functional digestive tract but remain stomachless throughout life.

D. Larval metamorphosis & diets?

   1) Striped bass, which completes metamorphosis in 21 to 42 days, cannot use dry diets at day 5, when initial feeding begins, but they can at day 15.
   2) Common carp can be transferred to commercial dry diets at 15 to 30 mg, whereas larval whitefish must weigh 50 mg to be weaned to dry diets.
   3) Transition from live to dry diet must be a gradual process.

E. Utilization of prepared diets:

   1) Some fish may not be able to digest the protein from prepared diets at larval stages.
   2) Possible reasons?

      a) Low affinity of the proteolytic enzymes in the immature digestive tract, or lack/absence of particular enzymes?
      b) High feed consumption can increase the passage rate, thus low digestive efficiency. Larval fish may ingest 50 to 300% of their body wt/day vs. 2 to 10% for sub-adult fish fed to marketable size.
      c) Absence of hormones or their regulators, or factors in live feeds that can inhibit or stimulate hormone action in larvae.

F. Live feed

1) Better to feed food organisms in their natural diets, but rotifer (*Brachionus plicatilis*) and brine shrimp (*Anemia*) are the only zooplankters produced in mass quantities.
2) Some variations in the nutritional quality exist among sources of zooplankton from different geographical origins and culture conditions, especially the n−3 PUFA
3) Many fish are very sensitive to a deficiency of n-3 PUFA, thus may want to fortify live zooplankton with essential fatty acids?

   a) Feed the newly hatched zooplankton marine algae (*Chlorella* spp.) or yeast high in n-3 PUFA for a period of 24 hr.
   b) Expose zooplankton nauplii to a suspension of lipid rich in n-3 PUFA, such as fish oil, and an emulsifying compound for 3-12 hr before being offered.

G. Prepared larval fish diets

1) Must meet the nutritional needs, have to be appropriate size for ingestion, must have the desired physical properties with regard to buoyancy, texture, and color; and also may have to simulate the movement in many instances.
2) Nutritional components:

   a) Should be based on the juvenile fish requirements, but inadequate info on the differences in nutrient needs between larval fish and juveniles.
   b) But, obviously, larval fish have a higher metabolic rate, thus may benefit from a higher dietary concentration of nutrients and energy.

H. Feeding:

1) Optimum diet particle size? - Increases in proportion to fish size and should not exceed 20 percent of the mouth opening.
2) Frequent feeding is important in all larval fish, and can be offered 10 to 24 times a day or almost continuously and in excess.
3) Diets containing 70 to 80% good-quality fishmeal support good growth in starter feeds for salmonids and channel catfish.
4) Diets based on single-cell protein and freeze-dried animal tissues have been proved successful with the stomachless larvae of common carp, grass carp, and silver carp.

3. **Channel Catfish**

A. Channel catfish:

1) Have a relatively well-developed digestive system, and consume & utilize prepared diets well at the time the fish begin feeding.
2) When to initiate feeding? - When the yolk sac reserves have been depleted and the fish "swim-up" to the surface in search of feed.

B. "Swim-up" fish - Can be fed at hourly by automatic feeders at a rate of 25% of body wt per day, and reduce to 4 to 2 feedings of 5 to 10% of body wt as fish size increases.

C. A popular commercial practice?

1) Transfer from the hatchery to prepared nursery ponds, which have a good population of feed organisms & free of predators, within a few days after the beginning of feeding.
2) Feed diets in the pond twice a day at the rate of 10% & decreasing to 3% of body wt per day for the remainder of the growing season.
3) Initially, nursery pond diets should be 2- to 3-mm crumbles, and later, small pelleted or extruded particles of 3 to 5 mm diameter can be used.

D. Catfish production in the US:

1) Feed extruded diets in large ponds (5 to 10 ha in size):
   a) Extruded diets can float on the water surface & allow observation of the fish during feeding.
   b) Can feed closer to their maximum rate without overfeeding, and also disease and water quality problems can be detected more easily.
2) The use of pellets that sink can reduce feed costs by 10 to 20% vs. floating feeds, but need more management.
3) Using a combination (85% sinking & 15% floating) saves 10 to 15% in feed costs and still allows the management benefits of the floating feed.
4) To minimize wasted feed, most catfish farmers do not feed completely to satiation in large ponds.

Examples of natural ingredient reference diets (NRC, 1993)

	Guelph Salmonid[a]	Paciifc Salmon[b]	Channel Catfish[c]
Ingredient, %			
Fishmeal			
Herring	30	50	-
Menhaden	-	-	8
Soybean meal	13	-	50
Corn gluten meal	17	-	-
Corn	-	-	34.1
Wheat middlings	16.5	12.2	5
Dried whey	10	5	-
Blood meal	-	10	-
Condensed milk solubles	-	3	-
Poultry by-product meal	-	1.5	-
Wheat germ meal	-	5	-
Dicalcium phosphate	-	-	1
Fish oil			
Marine	11.5	9	-
Catfish	-	-	1.5
Vitamin mixture[d]	1	2.2	0.2
Trace mineral mixture[e]	1	0.1	0.2
Pellet binder	-	2.0	-
Composition			
CP (N x 6.25), %	38	50[g]	32
DE, kcal/g	4,100	4,200[g]	3,000

[a]Source: Cho, C. Y. 1990. Food Rev. Int. 6(3):333-357; [b]Source: Hardy, R. W. 1991. Pages 105-121 in Handbook of Nutrient Requirements of Finfish, R. P. Wilson, ed. CRC Press, Boca Raton; [c]Robinson, E. H. 1991. Miss. Agric. For. Exp. Sta. Bull. 979; [d]Vitamin mix should meet the vitamin requirements for the species with an allowances for processing and storage losses; [e]Mineral mix should provide the following quantities in mg/kg of diet for the following diets: Guelph salmonid - Cu = 6.25, Fe = 13.2, Mn = 21.5, I = 6, Zn = 52, & NaCI = 3,000; Abernathy Pacific salmon - Zn = 75, Mn = 20, Cu = 1.5, & I = 10; Channel catfish - Zn = 100, Fe = 30, Cu = 5, I = 5, Mn = 2.5, Se= 0.3, and Co = 0.05; [f]Estimated.

F. Others? (See the table on "Examples of natural ingredient reference diets")

1) Traditionally, fish are fed once daily, 6 or 7 days per wk, but fed twice daily when the water temperature is above 25°C, which increase both intake & growth by 20% or so.
2) Feeding 7 days per week allows for 17% more feed to be consumed and 19% more growth than in a 6-day regimen, according to some.

3) Should not be fed late at night or very early in the morning when dissolved oxygen (DO) in the pond water is low.
4) Generally, catfish do not eat consistently with the water temperature below 21°C.

   a) A recommended guide for winter feeding of catfish in ponds? Provide a daily rate of about 0.75% of their estimated wt when the water temperature at 1 m depth is equal to or greater than 13°C.
   b) Fingerling fish can be fed 1% of body wt three times per week or daily with extended periods of warm weather.
   c) Feed low-CP diets (25%) to market-size fish (> 0.25 kg) during winter.

4. **Tilapia**

A. Culture systems and husbandry methods used for producing tilapia (*Oreochromis* and *Tilapia* spp.) seem to be very diverse.
B. Usually, produced in ponds with "low-cost" diets because tilapia are efficient feeders of natural aquatic feed organisms:

   1) Thus, perhaps not necessary to balance nutrients in diets when natural feeds are important sources of nutrients?
   2) But, need nutritionally complete feeds when the fish are stocked at high densities in tanks, raceways, net pens, and ponds, and natural feed is absent or insignificant.

C. Nutrient requirements/feeding?

   1) Nutritional needs seem to be similar to other warm-water fish, and commercial diets for channel catfish and common carp have been used successfully. (See the table on "Examples of natural ingredient reference diets" for channel catfish that can be fed to Tilapia.)
   2) Prefer smaller pellets vs. channel catfish & salmonids of comparable size - 3 to 5 mm in diameter for the most common marketable size of 0.5 kg.
   3) Respond to more frequent feeding vs. channel catfish and salmonids. (See the table on "Daily feeding allowances & frequencies.")

Example of daily feeding allowances & frequencies for Tilapias at 28°C

Size	Feed, % BW	Times fed/day
2 d - 1 g	30-10	8
1-5 g	10-6	6
5-20 g	6-4	4
20-100 g	4-3	3-4
> 100 g	3	3

Sources: Kubaryk, 1980. Ph.D. Dissertation. Auburn Univ., Auburtn University, AL; Jauncey & Ross, 1982. A Guide to Tilapia Feeds and Feeding. Univ. of Sterling, Sterling, U.K.

5. **Striped Bass and Hybrid Bass**

A. Striped bass & striped bass x white bass hybrids - Becoming an important aquaculture fish in the US.
B. Because of the condition of inland water for spawning, must obtain larvae & juveniles from hatcheries.
C. Larvae:

1) Usually start on small brine shrimp nauplii or rotifers at day 4 to 5 posthatch, and nauphi in the rearing container is maintained at 10 to 100 nauphi per mL.
2) May start feeding dry larval diets with appropriate size on day 5 to 8 and gradually replace all of the live feed by days 14 to 28.
3) Release the larvae into prepared nursery ponds with heavy zooplankton populations as early as 5 days after the larvae begin to feed.

D. Are voracious feeders, and respond to multiple daily feeding & can grow rapidly.
E. Respond to diets high in CP (36 to 45%) & fishmeal, but not much info on their preferences for energy sources.
F. Young fish need dietary eicosapentaenoic or docosahenaenoic acid for normal growth.
G. Commercial trout and salmon diets may be used successfully in rearing from juveniles to marketable size. (See the table on "Examples of natural ingredient reference diets" for salmon that can be fed to bass.)

6. **Rainbow Trout**

A. Start feeding as soon as fish deplete their yolk sac and begin to swim up:

1) Should be capable of consuming dry, prepared diets.
2) Feed at least once every hour during the normal light hours & can overfeed slightly to ensure adaptation, as long as left-over feed is removed regularly.
3) Water temperature should be kept above 6°C for swim-up fry.

B. Feeds/feeding:

1) Should use appropriately sized granules or pellets, and may have to screen to remove particles that are too small for the fish, and to prevent fouling of the water.
2) Optimum size? - 0.5 to 1.5 mm granules for 1 to 10 g, 2 to 3 mm granules for 20 to 40 g, 3 to 4 mm pellets for 50 to 100 g, and 5 to 7 mm pellets for fish over 200 g.
3) Overfeeding - Can reduces feed efficiency & increase the nutrient discharge, thus close observation is necessary or use an appropriate feeding guide!?
4) Daily feed allowances? - Varies with the size, strain, water temperature, feeding frequency, and energy concentration of the diet.
5) Feeding can be done by hand, usually twice daily, or by mechanical devices at predetermined amounts with appropriate feeding frequencies.

7. **Pacific Salmon**

° Terminology? Parr = a young salmon during its first two years of life; Smolt = a young salmon at the stage intermediate between the parr and the grilse; Grilse = a young Atlantic salmon on its first return from the sea to fresh or brackish waters.

A. In the US, common to rear the fish to smolt stage in freshwater hatcheries & then release for migration to the Pacific Ocean & return to near shore areas after reaching adulthood.
B. Some are grown from postjuvenile to marketable size in net pens on the Pacific coast of North America, in South America (Chile), South Australia, and Japan.
C. Feeds/feeding: (See the table on "Examples of natural ingredient reference diets")

1) Start with a meal diet (< 0.6 mm), and as the size increases, use crumbles (0.8-2.0 mm), then to pellets (> 2.0 mm).
2) Should feed frequently, and automatic feeders with hourly feeding are often used.
3) Starter diets should contain at least 40% CP with whole fish meal being one-half of the diet.
4) Many hatcheries feed moist pellets to enhance intake, but dry compressed (pelleted) or extruded diets have replaced moist diets in many because of the reduced cost & elimination of the need for frozen storage.
5) Extruded feeds that float or sink slowly are often fed in net pens:

a) Porous, low-density feeds can absorb more oil vs. compressed pellets.
b) Give the fish more time to consume the feed before it sinks through the net.
c) Give the feeder a better opportunity to observe feed consumption.
d) But, would be expensive vs. compressed pellets!

6) Semimoist diets (18 to 22% moisture), which do not require frozen storage, are also used, and may be more palatable than dry diets to young salmon?
7) Must contain carotenoid pigments to give the flesh a pink-red color:

a) May have to include sources of astaxanthin and canthaxanthin (. . . crustacean meals or oils, dried Phoffia yeast, and certain algae contain astaxanthin).
b) 40 to 50 mg of carotenoid per kg of diet fed for about 6 mo is needed to obtain satisfactory flesh color.

8) Hand feeding twice daily- Common in growing from postjuvenile to food-size:

a) Can provide "contact" with fish & also more growth vs. once-daily feeding.
b) Automatic feeders can reduce labor costs & also can feed more often throughout the day, but should watch for a possibility of wasting feed, underfeeding, etc.

8. **Atlantic Salmon**

A. Atlantic salmon farming is relatively new enterprise & involves two phases:

1) Juvenile freshwater stage - The fish grows from fry to smoltified postjuvenile, which lasts approximately 1.5 years.
2) Saltwater phase - May last for 2 years with the targeted market size of 4 to 6 kg.

B Atlantic salmon fry can use prepared, dry diets as their first feed:

1) Begin with a finely ground (< 0.6 mm) mash diet, change to crumbles, and then change to small compressed pellets during the freshwater stage.
2) Usually, starter diets contain more than 50% high-quality fish meal and 10-12% marine fish oil.

C. Relatively little information is available on the nutrient requirements, but functional commercial diets have been formulated from the data for rainbow trout and Pacific salmon, and also from feeding trials with natural ingredient diets.

D. Both moist and dry grower diets are being used. (See the table on "Examples of natural ingredient reference diets")

1) Moist diets - Contain dry ingredients supplemented with raw fish parts or fish ensilage, which are highly palatable but generally more expensive.
2) Dry, compressed, or extruded diets - Can be used, and slowly sinking extruded diets have become popular because of some reasons mentioned before for other fish.
3) Protein sources - Used fish meal as a primary source in the past, but as much as 20% soybean meal can be used successfully.
4) Over 20% lipid (as fish oil) is commonly used in commercial grower diets that contain 40 to 45% CP - More lipids than other species & can result in high body fat, and this practice is being questioned.
5) Approximately 50 mg of carotenoid, as astaxanthin or canthaxanthin, is added per kg of diet and fed for 1 yr for satisfactory flesh pigmentation.

E. Feeding:

1) Atlantic salmon may have a smaller stomach than rainbow trout, thus may have to feed more often.
2) Recommendation? "5- to 10-min" feeding intervals for fry and "30-min" intervals for parr.
3) Automatic feeders are often used in hatcheries, and fish in net pens are usually hand fed at least twice daily.

NUTRITION OF DOGS AND CATS IN GENERAL

1. Introduction

A. Archeological records indicate that the special relationship between humans & dogs is at least 12,000 yr old, and perhaps the first domesticated canid appeared before the agricultural phase.

B. Both domestic dogs & cats are members of the order *Carnivora*, and possess anatomical features that have supported their feeding behavior through evolution:

1) Canine teeth allow them to successfully catch & consume prey.
2) The carnassids, flat molars, facilitate the reduction of food particle size to ease the swallowing of prey.
3) Although both are classified in the same order, considerable distinction between the domestic dog and cat because the divergence of order occurred early in the evolutionary pathway.

C. The tremendous breed variation seen in today's dogs may have been, perhaps, the result of 12,000 years of selective breeding, but unlike dogs, few anatomical changes have occurred in the cat during its domestication.

2. U.S. Pet Food Industry

A. In the US, there are estimated 67 million dogs and 65 million cats?

B. The US pet food industry? A $11.8 billion enterprise (. . . & $28 billion business on the worldwide basis) and continues to grow 4-6% annually.

C. Manufactures the equivalent of 870 railroad boxcar loads of pet food every working day (each boxcar load = 40 tons of pet food).

D. Importance for US agriculture?

1) To produce 8.8 million tons of dry pet foods each year, use 3.6 million tons of corn, 1.07 million tons of soybeans (to make soybean meal), and 1.5 million tons of poultry, swine, and beef byproducts.
2) Others? - Corn gluten meal, wheat and wheat byproducts, brewers dry yeast, sorghum and corn oil.

E. Each year from 1997 to 1999, introduced 58-400 new pet food products within the US.

F. Reasons for the increase in consumer expenditures? Attributable to changing demographics and lifestyle trends?

1) More anthropomorphic considerations for their pets.
2) More elaborate and specialized pet food products with advanced nutritional information & packaging.
3) Give "end-of-the-day" treats to their pets following a day away at work?

G. The pet food industry:

1) Tends to be more defined than the human food industry and relies heavily on nutritional databases based on the Food & Drug Administration and the Association of American Feed Control Officials (AAFCO) with input by USDA & the Pel Food Institute.
2) AAFCO's Dog & Cat Food Nutrient Profile:

a) Based on extensive research and data generated and confirmed by extensive testing by universities and the pet food industry.
b) Unlike NRC guidelines, not minimum requirements but are "working successful guidelines!"

H. Designer foods? - "Gourmet foods" are now available for dogs and cats with human food grade, and they are increasing in popularity, the number of products, and tonnage!

NUTRIENT REQUIREMENTS OF DOGS AND CATS

1. **General**

A. The nutrient needs of today's dogs and cats can be satisfied in a variety of ways through the use of commercially available diets.

1) No need for pet owners to become a nutrition specialist to provide good nutrition to their pet.
2) Can choose from hundreds of brands of pet food to achieve optimum nutrient intake, economically & conveniently.
3) Nutritional information is relatively abundant from manufacturers of pet foods in both published literatures and advertising.

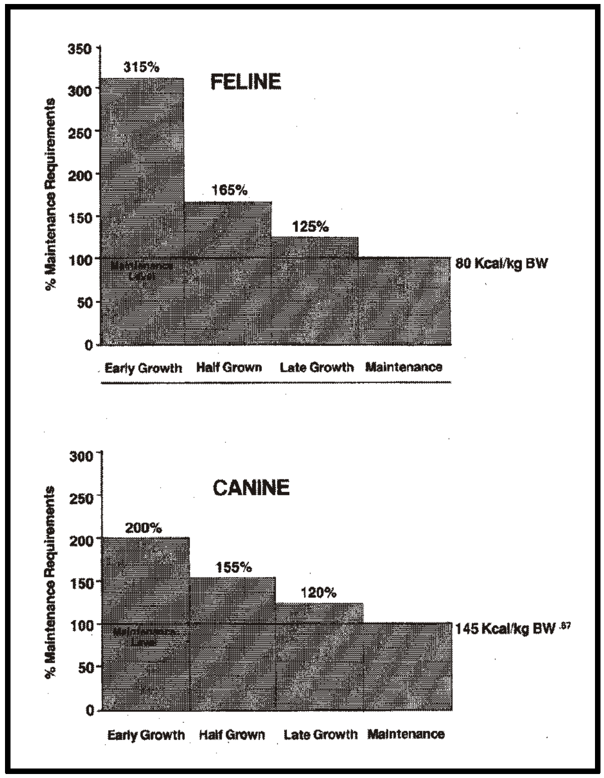
B. Estimation of the requirements can be complicated by the wide variation in size, performance, physical exertion, reproduction, age, environmental and psychological stress, etc.

1) A paucity of information exists on definitive nutrient requirements related to breeds, age, and sex.
2) Even with some suggested requirements, a substantial variation exists, which is not really surprising considering those factors plus breed diversity, especially in canine species.
3) The requirements cannot be defined simply as being at a single level, rather should be given as a range!?
4) Optimum nutrition often requires nutrients above the minimum requirements, and the final determination must be based on pet's response to a particular feeding regimen.

2. **Water**

   A. Often overlooked, but is of utmost importance, and dehydration is a primary concern in growing puppies and kittens because of their high body water content.
   B. Can be provided by the moisture content of food, metabolic water, and drinking water:

      1) Water content of commercial diets can range form 10 to 78%, thus the consumption of water would vary accordingly.
      2) In general, a dog gets about 25% of the requirements from drinking water, but a cat get only 10% from drinking water.

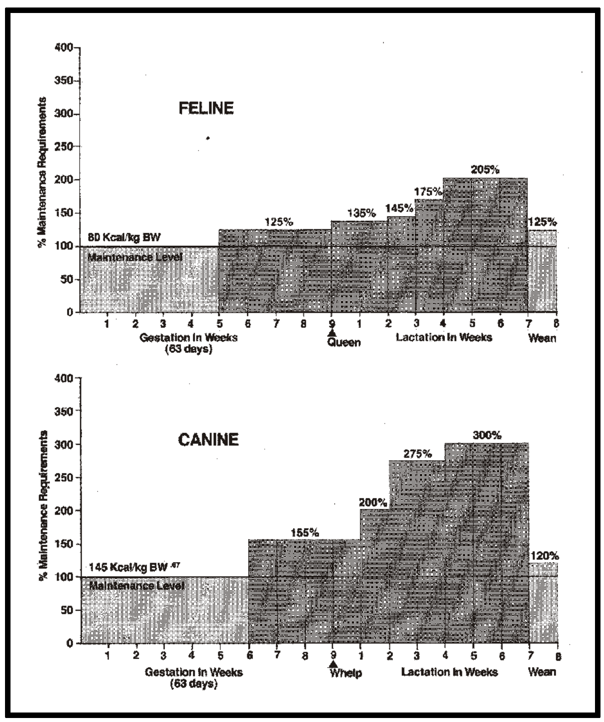


3. **Energy**

   A. See figures on "Feline & canine ME requirements for growth (first figure)" & "Feline & canine ME requirements for production (second figure)" (Hirakawa, 1998).
   B. Energy needs of dogs and cats:

      1) Affected by the animal's metabolic efficiency, environmental factors, physical exercise & activity level, age, and the stage of production.
      2) The energy needs per unit of body weight decreases as the size of the animal increases, just like any other warm-blooded animals.

   C. Animals fed a balanced diet tend to eat to satisfy their energy need, thus diets can be compared in terms of a nutrient per unit of energy.



4. **Carbohydrates**

A. Grain starches provide an important and economical source of dietary energy in most pet foods.
B. Limited information on this area, but a dog can utilize up to 65 to 70% dietary carbohydrates, whereas a cat can utilize only about 35 to 40%. Because the cat has active hexokinase but does not have glucokinase? Dogs have both!
C. Fiber:

1) Inclusion of small amounts is necessary for the normal function of the GI tract by providing the bulk, maintaining normal passage rate & intestinal motility, and maintaining the structural integrity of gastrointestinal mucosa.
2) Common sources? - Wheat middlings, citrus, beet pulp, soy hulls, peanut hulls, etc. Also, grains & plant protein sources can contribute fibers.
3) Fermentation of fiber (i.e., VFA) may contribute as energy source for the cells lining the intestine.
4) Certain types of fiber (e.g., fructooligosaccharides) may be beneficial in the treatment of some gastrointestinal diseases?
5) Just like other nonruminant species, too much fiber can have some adverse effects!

5. **Lipids**

A. In pet foods, fat serves as a concentrated form of energy, a carrier for fat-soluble vitamins, a source of essential fatty acids, and an enhancer of diet palatability.
B. The optimum content? - Depends on other nutrients, e.g., as low as 5-10% in low-CP or inferior-quality protein, but can increase concomitantly with the increase in the CP and(or) protein quality.
C. Dogs and cats need linoleic acid, and cats also need arachidonic acid because they don't have appropriate enzymes to convert linoleic to arachidonic acid.
D. Common sources? - Tallow, lard, poultry fat, and many vegetable oils. Animal sources, especially fish oil, are appropriate source of arachidonic acid, but not plant sources.
E. Omega-3 & omega-6? - A proper proportion of these two may have beneficial effects on some disorders, such as treatment of allergic skin disorders in dogs, according to some studies.

6. **Protein**

A. Ideally, an intact protein source would supply all 10 indispensable amino acids in adequate amount, but there are considerable variations in the protein quality among various sources.
B. Also, relatively little is known about the quantitative amino acid requirements for canine and feline, and factors affecting the requirements.

1) Some studies led to the quantitative assessment of amino acid requirements, and the resulting minimum requirements were incorporated into the NRC guidelines.
2) Because those were the minimums established with purified diets, the AAFCO Nutrient Profiles added some safety margins.

C. Protein sources?

1) Plant protein sources, such as soybean meal and corn gluten meal, and animal protein sources, such as poultry, meat and respective by-products, are common ingredients in pet foods.
2) Although cereals are a major source of energy in cereal-based products, they also supply a substantial portion of protein:

   a) Often, those are deficient in some indispensable amino acids.
   b) Thus, fresh meats, meat and poultry meals, and various meat by-products are often added to alleviate the deficiency.

D. As in other nonruminant species, the indispensable amino acid requirements are affected by the age, sex, and breed/genetic potential of the animal - some e.g.?

1) Young puppies may not be affected by sex, but Lys requirement is higher for the immature male beagle vs. the immature female.
2) Labradors may have higher S-amino acid needs than beagles, and also S-amino acid needs of pointer puppies are different from beagles or labradors.

E. Cats, a strict carnivore, is unique in its protein/amino acid needs:

1) Have substantially higher requirements than the dog because of the high activity of the amino acid catabolic enzymes in the liver.
2) May not be a practical importance, but cats are very sensitive to a deficiency of Arg, which (i.e., devoid of Arg) can lead to hyperammonemia in less than hour.
3) Cats also have a higher S-amino acid needs relative to other mammals because of the needs for the cat's thick hair coat, which is high in cysteine. Perhaps, the reason for its high protein requirement!?
4) The amino acid, taurine, is uniquely important for cats.

   a) Synthesized form Met & Cys in the liver & other tissues, and the amount synthesized is sufficient in dogs but not in cats.
   b) Present in bile as taurocholic acid and in high concentrations in the retina & olfactory bulb.
   c) Unlike the dog, conjugates cholic acid exclusively with taurine & is unable to alternate between taurine & glycine conjugations in the production of bile:

      (1) Can lead to a reduction in conjugated bile acids & central retinal degeneration can develop.
      (2) Typically, reduced visual acuity, without total loss of vision, has been seen in older kittens & adult cats.
      (3) Also, may be associated with cardiomyopathy & poor reproductive performance.

d) Thus, the cat has a continual dietary need for taurine, which is only present in animal protein sources.

7. **Vitamins and Minerals**

A. Vitamins

1) A quality-stable fat source should be used to ensure fat-soluble vitamin absorption - Many add an antioxidant.
2) Water-soluble vitamins are carefully selected & added in excess of minimum needs to compensate for losses associated with heat processing and extended shelf life.
3) Conversion of β-carotene to vitamin A in cats:

a) Cannot convert because of a deficiency of the intestinal enzyme, β-carotene-15-15'-dioxigenase, thus they need dietary source of preformed vitamin A.
b) Also, cats may be susceptible to vitamin A toxicity because of no regulation at the intestinal mucosa. Readily absorb vitamin A?

4) Niacin - Cats have a unique dietary need for niacin because of they cannot synthesize it from Trp.

B. Minerals

1) A paucity of information on quantitative and qualitative mineral requiremnts for dogs and cats.
2) Tn ensure dietary adequacy, pet foods are fortified with essential minerals.
3) Ca:P - The proper ratio is about 1.2:1 (1:1 for cats & 1.2 to 1.4:1 for dogs?), and common sources of Ca are bone meal, skim milk, and alfalfa leaf meal, whereas bone meal & meat scraps can supply P. Vitamin D is needed for the utilization of Ca & P.
4) Many dog owners feel that growing puppies need additional Ca to prevent skeletal problems, but supplementing previously adequate diet with Ca may have no beneficial effect & actually it may have some adverse effects!

COMMERCIAL PET FOODS AND TABLE SCRAPS

1. **Dry Pet Foods**

A. The most common type of pet food in the U.S.:

1) Has been a trend toward increased sale of dry dog food & decreased sale of canned dog food in recent years.
2) A trend toward increased sale of both canned and dry cat foods.

B. Dry foods:

1) Commonly contain whole or dehulled cereal grains, cereal byproducts, soybean products, animal products, milk products, fat and oils and mineral and vitamin supplements.
2) Cereals are heat-treated to dextrinize starches and improve their digestibility.
3) Enough fats are added to increase the energy density, and adequate amounts of vitamins & minerals are carefully blended throughout the meat and cereal mixture.
4) Most mixtures contain about 6 to 10% moisture and the average energy value is 1,500 to 1,600 kcal/lb or 300 to 400 kca1/8 oz. cup.

C. Three main types of dry foods:

1) Dry meals:

a) May be pelleted or pelleted and then crumbled to a uniform particle size.
b) May be fat-coated, which increases their energy density and enhances the palatability.

2) Kibbles:

a) Ground together cereal grains & dried meat scraps along with dairy products, vitamins and minerals into a flour, blended with water & formed into a dough.
b) May be baked on a large sheet and then crumbled or "kibbled" into uniform-sized fragments.

3) Expanded dry foods:

a) Mixing raw grains, meat meal, vegetables, dairy products, vitamins, and minerals with steam inside a blending pressure cooker, which allows the ingredients to be cooked while being whipped into a homogeneous mixture.
b) A mixture would be pushed through a die and expanded with steam and air into small porous nuggets, which are hardened by passing through heated air streams.
c) Then, the hardened nugget is usually passed through a spray chamber & coated with a liquid fat, carbohydrate or milk product to provides additional energy or palatability.

2. **Semimoist Foods**

A. Represent a very diverse group of products & very convenient to feed, but have fallen in popularity in recent years. Increase in the variety of semimoist "treats & snacks" though!
B. The moisture content is about 23 to 40%, and generally contain a mixture of soybean meal, corn syrup, fresh meat or meat by-products, animal fat, vitamins, and minerals together with preservatives and humectants.

1) Phosphoric, hydrochloric, and malic acids are commonly used acids to lower the pH to retard bacterial growth and spoilage.
2) Sugars, corn syrup, and salts elevate the soluble solids in the product and bind the water so it is unavailable to bacteria and fungi.
3) Propylene glycol is hygroscopic and binds moisture in the product to keep the food pliable and prevent drying, but has been banned by the FDA to use as a humectant because of potential risk to cats.

C. Commonly packaged with cellophane or foil in portion controlled servings, and can be stored unrefrigerated because of the preservatives and humectants - Often shaped and colored to resemble meat chunks or hamburger patties.

3. **Canned Foods**

A. Extremely popular, especially for cats - The canned cat food market has grown dramatically in recent years.
B. Fresh, wet ingredients are sealed into containers (generally cans) to prevent any recontamination and then subjected to a heat-sterilization process to destroy any microorganisms of spoilage already in the food.
C. Types of canned foods:

1) Ration-type canned foods - Ground fresh meat and meat byproducts along with fat, water, and cereal ingredients are blended to make a complete balanced diet.
2) Gourmet or meat-type canned foods:

a) Look like containing a substantial amount of meat but actually contain a variety of animal byproducts and textured vegetable protein, which is composed of extruded soy flour mixed with red or brown coloring.
b) The high protein content requires the animal to use protein as its major energy source.
c) Because of their high protein and fat content and high palatability, excellent to feed when food intake is decreased because of anorexia from any cause & when protein requirements are increased (. . . such as for extensive wound healing & protein losing nephropathy or enteropathy).
d) The canned gourmet cat foods:

(1) Extremely palatable, and a good diet to try to induce voluntary food intake in either the anorectic dog or cat.
(2) Composed primarily of animal tissues such as shrimp, tuna, kidney, liver, and chicken and numerous combinations.
(3) Because of high palatability, cats frequently become addicted to a specific ingredient?

4. **Table Scraps**

   A. Frequently quite palatable to dogs but generally not nutritionally balanced.
   B. Most table scraps are fats and carbohydrates, yielding lots of energy and little else. The dog may obtain a sizeable portion of its daily energy need from the useless scraps & lose appetite for the commercial food.
   C. Spicy food should not be given to any animal.

FEEDING OF DOGS AND CATS

1. **Feeding Methods & Some Tips**

   A. Three methods of feeding dogs and cats:

      1) Free-choice, ad libitum, or self-feeding. Allowed to eat as much as it wants and whenever it chooses because foods are made available all the time.
      2) Time restricted meal-feeding - Offered more food than it will consume within a specified period of time, generally 5 to 30 minutes.
      3) Food restricted meal-feeding - Offered a specific but less amount of food than it would eat if the amount fed were not restricted.
      ☛ Meal-feeding are repeated at a specific frequency such as once or twice a day.

   B. Some people use only one, while others use a combination of methods - e.g., Provide a dry or soft-moist food free-choice & meal-feed a canned food or specific food(s) such as meat, table scraps etc.
   C. The method can be determined by the type of food used:

      1) Dry foods - Can be self-fed successfully to most dogs and cats, but some will overeat & become obese or have some digestive disturbances.

         a) The dry food's abrasive action on the teeth help keep them scaled and clean.
         b) Gum exercise is also provided by the chewing of the dry food.
         c) Not eating enough? - Some problem such as sore gums or lips or bad teeth?

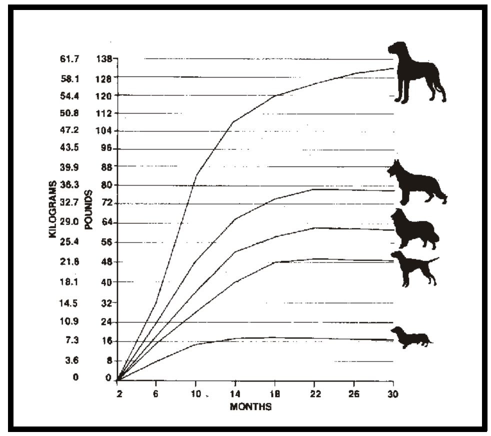
      2) Canned foods, fresh foods, and moistened dry foods:

         a) Should be opened or prepared fresh daily and not exposed to the air for more than 10 to 12 hr during summer because of possible spoilage!
         b) An alternative? - Set a regular feeding time so that the owner can check on the animal's appetite each day, and uneaten food should not be in front of them for more than 30 minutes, especially during warm weather.

   D. Avoid between-meal snacks and table scraps because of possible unbalanced nutrition, obesity, digestive disturbances, and development of a finicky eater or food beggar. Should not constitute more than 25% of the animal's ration.

E. Poultry bones, chopped bones, or small bones may lodge in the animal's mouth or gastrointestinal tract, whereas large bones may result in broken teeth.
F. Although most adult dogs eat rapidly and voraciously, many dogs are inhibited-type eaters & prefer to be left alone while eating.
G. Most cats like to eat alone and without distractions or worry of competition - If feeding more than one, should have separate bowls and their bowls should be separated.
H. Regardless of the method of feeding used for cats, best to feed a ration type of cat food and to feed on a regular schedule.

2. **How Much to Feed?**



A. The amount of food to be given to the dog or cat?

◦ See the figure on "Canine breed growth rates (Hirakawa, 1998)" - Growth curves would certainly affect how to feed the pet!

1) Determined by trial and error, energy need, and a rule of thumb?
2) Most household pets consume about ⅓ to ½ oz of dry matter food/lb of body weight when they are inactive/at maintenance.
3) Puppies may consume about three times this amount during the fast growing period.
4) Hardworking and lactating dogs will consume up to three times the maintenance.
4) When canned diets are fed, about three times as much by weight is needed as when dry foods are fed.

B. Some variations/adjustments?

1) The amount consumed by individual dogs vary, and two related dogs of the same strain may require different levels of food intake to maintain their body condition.
2) Heavy exercise increases the nutritional requirements, and a good dog may lose up to 20 lb during the hunting season.
3) Cold weather will increase the requirement of food.
4) The size of the animal must be considered - A small dog will require more food per lb than will a large dog.
5) Nervousness is another factor - Purebred breeds have a tendency to be more nervous and need more food, but they are always thin and often have a diarrhea problem.
6) Spayed and castrated animals need one third to one half as much food than they needed originally because of less natural exercise.

3. **Feeding During Pregnancy and Lactation**

A. The primary goal? - Obviously to provide a nutritionally balanced diet!

B. Diets for dogs?

1) Can be fed a canine reproduction or growth diet throughout pregnancy but is needed especially during the last 3 to 4 wk of pregnancy & during lactation.
2) The diet on DM basis should be at least 80% digestible & contain at least 25% CP, 17% fat, 1,750 kcalME/lb, less than 5% fiber, 1-1.8% Ca, and 0.8-1.6% P.

C. Diets for cats?

1) Can be fed a feline reproduction and growth diet throughout pregnancy but is needed especially during the last 3 wk of pregnancy and during lactation.
2) The diet on DM basis should be at least 80% digestible & contain at least 35% CP, 17% fat, 1,800 kcalME/lb, 1-1.8% Ca, and 0.8-1.6% P.

D. Some tips?

1) Should not be given any supplements (e.g., meat, milk, Ca, P, or vitamins) or fed anything other than a good quality diet meeting the specifications.
2) Ones with optimum body wt at breeding should be fed the same amount needed for maintenance during the first 5 to 6 wk of pregnancy.
3) After 5 to 6 wk, the amount fed should be gradually increased so that the dam is getting 15 to 25% more energy by parturition time. (Free-choice or twice a day?)
5) During the lactation phase:

   a) Feed at least three times a day or free-choice to maintain optimum body wt.
   b) Feed 1.5, 2, and 3 times the maintenance during the 1st, 2nd, and 3rd wk of lactation to weaning, respectively.
   c) Encourage the young to begin eating solid food at 3 wk of age to assist the dam in maintaining her optimum body wt during peak lactation (3rd through 6th wk).

4. **Feeding and Raising Young Dogs and Cats**

A. Orphan puppies and kittens

1) Environment - Need a separate quarter for each young dog or cat, and the temperature for the 1st 7 days should be 85° to 90°F, 80°F for the next 2 to 3 wk, and 75°F by the 4th wk. Bedding should be cleaned daily to prevent skin rash.
2) Milk replacer - Need a diet formulated to satisfy the nutritional needs of the young, and various modifications of homemade & commercially prepared formulas simulating the dam's milk have been used with good success.
3) Methods of feeding?

   a) General:

(1) Keep all equipment scrupulously clean.
(2) Do not prepare more than needed to feed for a 48-hour period, and divide the formula into portions & store in refrigerator.
(3) Warm the formula to about 100°F or near body temperature before feeding.

b) Nipple bottle feeding - Nipple bottles made especially for feeding orphan puppies or kittens are preferred.
c) Tube feeding - The easiest, cleanest, fastest, safest, and most preferred way to feed the orphan puppy or kitten.
d) Supplemental feeding:

(1) Try to encourage the young to eat some solid food.
(2) May want to mix water with the solid food to make a thick mushy gruel.
(3) Smear some of the gruel on the animal's lips.
(4) Once they are eating from a bowl, gradually decrease the amount of water mixed with the food until only the solid food is fed three times a day.

B. Weanling puppies and kittens

1) Feed the weanlings a diet 3 to 4 times daily.
2) Wean at 4 to 7 wk of age (5½ to 6 wk is the average) and allow 7-10 days for the weaning process.
3) Often, the dam will start to wean on her own due to the irritation caused by the presence of animals' teeth and toenails.
4) Take the dam from the young in the daytime for the first few days, putting her back with the young at night - Gradually take her away for longer periods so she will finally wean them permanently.

C. Older puppies and kittens

1) Feed three times & twice a day for the fist 3 mo & 6 mo, respectively.
2) Dogs and cats that are 8 mo to 1 year and older may be fed once daily - May feed them twice a day if they aren't fed too much at a time.

5. Feeding and Caring for Aging Dogs and Cats

A. Geriatric nutrition?

1) Difficulty in providing a geriatric diet? - Cannot use a general definition for the geriatric animal.
2) Little scientific info available on the nutrition of geriatric dogs and cats, but according to one report, geriatric dogs may be just as capable in digesting and metabolizing nutrients vs. young dogs.

3) Contrary to popular belief, older animals do not have different dietary needs vs. younger animals.

B. Reduce protein?

1) Some pet foods are formulated to contain less protein based on the idea that the dietary protein may contribute to the onset of or progression of kidney insufficiency.
2) Recent research show that increased dietary protein did not increase their risk for developing renal disease.
3) Older animals may even have a higher protein needs vs. young animals, and dietary protein should not be restricted below amounts provided for adult maintenance.

C. Some considerations?

1) Early detection of nutritional disturbances and proper nutritional management thereafter may slow or prevent the progression of organ failures and possibly slow the aging process.
2) Good oral hygiene is important in ensuring adequate food intake and utilization.
3) The amount fed should satisfy hunger but should not result in unnecessary abdominal distension and discomfort. Feed small meals at least twice a day (on a regular schedule) of a palatable & highly digestible diet.
4) A diet for a normal aged dog? On a DM basis, at least 80% digestible & contains at least 14 to 21% CP, 10% fat, 1,700 kcal ME/lb, less than 4% fiber, 0.5 to 0.8% Ca, 0.4 to 0.7% P, and 0.2 to 0.4% Na, and be of good quality.
5) A diet for a normal aged cat? On a DM basis, at least 80% digestible & contains at least 25 to 35% CP, 15% fat, 1,700 kcal ME/lb, less than 4% fiber, 0.5 to 0.8% Ca, 0.4 to 0.7% P, 0.2 to 0.4% sodium, less than 0.10% Mg, and be of good quality.
6) Older dogs/cats may have a reduced appetite & digestive/absorption ability. If so, should be fed palatable high-energy diets at frequent intervals.
7) Important for the aged dog or cat to have adequate physical activity to maintain muscle tone, enhance circulation, and improve waste elimination.

6. **Nutritional Problems**

A. Obesity

1) Obesity is currently the most common nutritional problem in digs/cats in the US.

a) Dogs and cats are considered obese when they are 10-15% above their optimum body weight.
b) More common in female than male dogs up to 12 yr of age and is about twice as high in neutered dogs of both sexes.
c) Beagles, cocker spaniels, collies, dachshunds, and Labradors have the highest incidence of obesity.

d) Obesity in cats is equally common in both sexes with higher incidence in older neutered cats.

2) Can result in chronic health problems & reduced longevity because of locomotion problems/bone & joint disease, diabetes mellitus, cardiovascular disease, hypertension, heat intolerance, altered resistance, and many others.
3) Causes? Factors such as endocrine imbalances and abnormal responsive taste that interfere with internal body signals are rare, thus perhaps, overfeeding for whatever the reason and insufficient exercise might be the primary causes!?
4) Method for weight reduction?

a) Should be considered for all dogs & cats that are more than 15% above their optimum weight to decrease health problems, reduce future health care costs, improve appearance, and increase the animal's enjoyment and length of life.
b) Goals - First reduce body fat stores and attain normal body weight & then maintain the weight for the remainder of the pet's life!
c) Exercise - Quite helpful, not only in increasing energy expenditures but also reduces appetite & food intake.
d) Methods for weight reduction program for the obese animal include:

(1) Decrease the regular commercial diet by 50% of that needed for the maintenance of the initial (obese) body weight.
(2) Feed the regular commercial diet at 60% for dogs and 66% for cats of that needed for the maintenance of optimum body weight
(3) Feed a nutritionally complete and balanced high-fiber, low-energy diet.
(4) Feed at least three times a day with the amount fed restricted to feeding times.
(5) Keep palatable water available at all times.
☛ Exclude all table scraps, snacks, sweets, etc., and also avoid total fasting or starvation for quick weight reduction.

B. Nutritional problems in the cat eating commercial dog foods

1) Develop malnutrition in the adult cat when all the basic nutritional needs are not being met, and a common cause may be a continuous ingestion of commercially prepared, cereal-based dog foods?
2) The cat's nutritional needs are quite different from those of the dog as mentioned before:

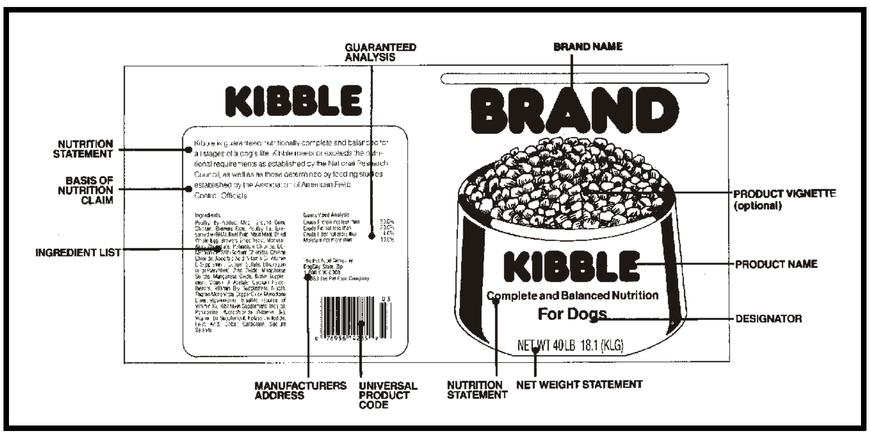
a) The cat has a much higher protein requirement than the dog.
b) Little dietary arginine is needed by the mature dog but the cat will die within hours after consuming an arginine-free diet.
c) Cats require taurine in the diet - Inadequate taurine results in central retinal degeneration and blindness.

d) Cats cannot convert linoleic acid to arachidonic acid, thus must consume preformed arachidonic acid. If not, develop a dry lusterless hair coat or, if severe deprivation is present, emaciation and spots of moist dermatitis develop.
e) Cats cannot convert beta carotene in plants to vitamin A, thus must consume preformed vitamin A.
f) Cats cannot convert the amino acid Trp to the B vitamin, niacin, and, therefore, require more niacin in the diet.

3) Primary treatment is to feed a nutritionally balanced commercially prepared or homemade diet formulated for cats.
4) Cats in general should not be fed any single food item or cat food consisting of a single food item, such as some of the gourmet cat foods, at more than 25% of the cat's total food intake.

PET FOOD LABELS

1. **General**



A. A pet food label contain a tremendous amount of useful information, and can be used to distinguish a quality product from inferior products if interpreted correctly.
B. The information required on the label is prepared and approved by the joint federal and state AAFCO, and requires:

1) The product name,
2) The net weight,
3) An ingredient list,
4) A guaranteed analysis,
5) The name and address of the manufacturer, packer, or distributor,
6) Designation of "Dog Food" or "Cat Food," and
7) A statement describing the purpose of the product and the method used to determine its adequacy.

2. **Nutritional Statements**

A. Provide ingredient lists & guaranteed analyses, but lack specific info on the content and availability of many nutrients.

1) Possible to have "two labels" to have identical info, yet the nutritional value could be totally different!
2) Differences in processing methods and selection of quality raw materials can have an impact on the quality, thus one product can be superior while another can be totally unsatisfactory.

B. Product literature as consumer education tool - Can be provided by some manufacturers but certainly not by all!
C. Perhaps, the reputation of the pet food manufacturer and information concerning animal nutrition testing of a product may assist in product selection.
D. The claim of nutritional adequacy:

1) With the exception of teats & snacks, all pet foods that are interstate commerce must contain a statement & validation of nutritional adequacy.
2) With the "complete and balanced nutrition" claim, manufacturers must indicate the method used to substantiate the claim.

3. **Nutritional Adequacy**

A. According to AAFCO regulations, manufacturers can validate the nutritional adequacy in one of the two ways.
B. First one is to perform "AAFCO sanctioned feeding trials" on food:

1) Most thorough & reliable method.
2) Terms included such as "feeding tests," "AAFCO feeding test protocols," or "AAFCO feeding studies" in a label claim indicate that the product has been tested.

C. Second one is to "formulate the diet to meet the AAFCO Nutrient Profiles for Dog and Cat Foods:"

1) Allows the manufacturers to substantiate the claim by merely calculating the nutrient content of the formulation using standard tables of ingredients without laboratory analyses or feeding trial.
2) Although some manufacturers using this method may still conduct some own feeding trial, but consumers wouldn't know that from the label.

3. **Physical Evaluation of Pet Food**

A. Evaluation of the package or container:

1) Dry & semimoist foods - Should be provided in tightly sealed multilayer packages.
2) An inner liner aids in prevention of moisture migration, fat wicking, and infestation, and also keeping product aroma in to maintain palatability.
3) Canned foods with dented or swollen - May indicate bacteria fermentation, thus should not be fed?

B. Product appearance should meet the standard:

1) Consider consistency of product color, size & shape, as well as pleasant aroma.
2) Presence of foreign materials (including ingredient-related such as hair, feathers, etc.) - Indication of inadequate quality assurance program?

4. **Palatability Evaluation**

A. Simply because, if not consumed, even the most nutritious food is of no benefit, pet foods are routinely tested for acceptability - Usually by offering an animal two products, one of which is a control of known acceptability.
B. Product odor, taste, texture, shape, and moisture content affect the palatability.
C. Highly palatable foods may not be always the most nutritious though!

1) For instance, palatability for cat foods can be enhanced by adding palatable ingredients such as garlic & cheese powder or phosphoric acid, but they may not have any nutritional value.
2) In fact, a highly palatable food may lead to eating more than its energy needs, thus resulting in obesity!

NUTRIENT REQUIREMENT TABLE FOR FISH, AND DOG & CAT FOOD PROFILE TABLES

[Based on NRC (1993) & AAFCO (1994/2001, Cited by Hirakawa (1998), Corbin (2001), and Jurgens (2002)]

1. **Table 1. Nutrient Requirements for Channel Catfish, Rainbow Trout, Pacific Salmon, Common Carp, and Tilapia (As-Fed Basis)**[a] (NRC, 1993)

Species:	Channel Catfish	Rainbow Trout	Pacific Salmon	Common Carp	Tilapia
Energy[b] (kcal DE/kg diet)	3,000	3,600	3,600	3,200	3,000
Crude Protein (digestible), %	32 (28)	38 (34)	38 (34)	35 (30.5)	32 (28)
Amino acid, %					
Arginine	1.20	1.50	2.04	1.31	1.18
Histidine	0.42	0.70	0.61	0.64	0.48
Isoleucine	0.73	0.90	0.75	0.76	0.87
Leucine	0.98	1.40	1.33	1.00	0.95
Lysine	1.43	1.80	1.70	1.74	1.43
Methionine + cystine	0.64	1.00	1.36	0.94	0.90
Phenylalanine + tyrosine	1.40	1.80	1.73	1.98	1.55
Threonine	0.56	0.80	0.75	1.19	1.05
Tryptophane	0.14	0.20	0.17	0.24	0.28
Valine	0.84	1.20	1.09	1.10	0.78
n-3 fatty acids, %	0.5-1.0	1.0	1.0-2.0	1.0	-
n-6 fatty acids, %	-	1.0	-	1.0	0.5-1.0
Macrominerals, %					
Calcium	R	1.0E	NT	NT	R
Chlorine	R	0.9E	NT	NT	NT
Magnesium	0.04	0.05	NT	0.05	0.06
Phosphorus	0.45	0.60	0.60	0.60	0.50
Potassium	R	0.7	0.8	NT	NT
Sodium	R	0.6E	NT	NT	NT
Microminerals, mg.kg					
Copper	5	3	NT	3	R
Iodine	1.1E	1.1	0.6-1.1	NT	NT
Iron	39	60	NT	150	NT
Manganese	2.4	13.0	R	13.0	R
Zinc	20	30	R	30	20
Selenium	0.25	0.30	R	NT	NT
Fat-soluble vitamins					
Vitamin A, IU/kg	1,000-2,000	2,500	2,500	4,000	NT
Vitamin D, IU/kg	500	2,400	NT	NT	NT
Vitamin E, IU/kg	50	50	50	100	50
Vitamin K, mg/kg	R	R	R	NT	NT
Water-soluble vitamins, mg/kg					
Riboflavin	9	4	7	7	6
Pantothenic acid	15	20	20	30	10
Niacin	14	10	R	28	NT
Vitamin B_{12}	R	0.01E	R	NR	NR
Choline	400	1,000	800	500	NT
Biotin	R	0.15	R	1	NT
Folate	1.5	1.0	2.0	NR	NT
Thiamin	1	1	R	0.5	NT
Vitamin B_6	3	3	6	6	NT
Myoinositol	NR	300	300	440	NT
Vitamin C	20-50	50	50	R	50

☞ NOTE: These requirements have been determined with highly purified ingredients in which the nutrients are highly digestible, therefore the values presented represent near 100 percent bioavailability. [a]R, required in diet but quantity not determined; NR, no dietary requirement demonstrated under expertmental conditions; NT, not tested; and E, estimated. [b]Typical energy concentrations in commercial diets.

2. Table 2. Association of American Feed Control Officials (AAFCO) Dog Food Nutrient Profiles (Dry Matter Basis)[a] [Hirakawa (1998), Corbin (2001), and Jurgens (2002)]

Nutrient	Unit	Growth & Reproduction Minimum	Adult Maintenance Minimum	Maximum
Crude Protein	%	22.0	18.0	
Arginine	%	0.62	0.51	
Histidine	%	0.22	0.18	
Isoleucine	%	0.45	0.37	
Leucine	%	0.72	0.59	
Lysine	%	0.77	0.63	
Methionine-cystine	%	0.53	0.43	
Phenylalanine-tyrosine	%	0.89	0.73	
Threonine	%	0.58	0.48	
Tryptophan	%	0.20	0.16	
Valine	%	0.48	0.39	
Crude Fat[b]	%	8.0	5.0	
Linoleic acid	%	1.0	1.0	
Minerals				
Calcium	%	1.0	0.6	2.5
Phosphorus	%	0.8	0.5	1.6
Ca:P ratio		1.1	1:1	2:1
Potassium	%	0.6	0.6	
Sodium	%	0.3	0.06	
Chloride	%	0.45	0.09	
Magnesium	%	0.04	0.04	0.3
Iron[c]	mg/kg	80	80	3,000
Copper[d]	mg/kg	7.3	7.3	250
Manganese	mg/kg	5.0	5.0	
Zinc	mg/kg	120	120	1,000
Iodine	mg/kg	1.5	1.5	50
Selenium	mg/kg	0.11	0.11	2
Vitamins & Other				
Vitamin A	IU/kg	5,000	5,000	250,000
Vitamin D	IU/kg	500	500	5000
Vitamin E	IU/kg	50	50	1000
Thiamine[e]	mg/kg	1.0	1.0	
Riboflavin	mg/kg	2.2	2.2	
Pantothenic acid	mg/kg	10	10	
Niacin	mg/kg	11.4	11.4	
Pyridoxine	mg/kg	1.0	1.0	
Folic acid	mg/kg	0.18	0.18	
Vitamin B_{12}	mg/kg	0.022	0.022	
Choline	mg/kg	1200	1200	

[a]Presumes an energy density of 3,500 kcal ME/kg, as determined in accordance with Regulation PF9. Rations greater than 4,000 kcal ME/kg should be corrected for energy density. Diets less than 3,500 kcal ME/kg should not be corrected for energy. Diets of low-energy density should not be considered adequate for growth or reproductive needs based on comparison to the Profiles alone. [b]Although a true requirement for crude fat per se has not been established, the minimum level was based on recognition of crude fat as a source of essential fatty acids, as a carrier of fat-soluble vitamins, to enhance palatability, and to supply an adequate caloric density. [c]Because of very poor bioavailability, iron from carbonate or oxide sources that are added to the diet should not be considered in determining the minimum nutrient level. [d]Because of very poor bioavailability, copper from oxide sources that are added to the diet should not be considered in determining the minimum nutrient level. [e]Because processing may destroy up to 90% of the thiamine in the diet, allowances in formulation should be made to ensure the minimum nutrient level is met after processing.

3. **Table 3. AAFCO Cat Food Nutrient Profiles (Dry Matter Basis)**[a] [Hirakawa (1998), Corbin (2001), and Jurgens (2002)]

Nutrient	Unit	Growth & Reproduction, Minimum	Adult Maintenance, Minimum	Maximum
Crude Protein	%	30.0	26.0	
Arginine	%	1.25	1.04	
Histidine	%	0.31	0.31	
Isoleucine	%	0.52	0.52	
Leucine	%	1.25	1.25	
Lysine	%	1.20	0.83	
Methionine-cystine	%	1.10	1.10	
Methionine	%	0.62	0.62	1.5
Phenylalanine-tyrosine	%	0.88	0.88	
Phenylalanine	%	0.42	0.42	
Threonine	%	0.73	0.73	
Trytophan	%	0.25	0.16	
Valine	%	0.62	0.62	
Crude Fat[b]	%	9.0	9.0	
Linoleic acid	%	0.5	0.5	
Arachidonic acid	%	0.02	0.02	
Minerals				
Calcium	%	1.0	0.6	
Phosphorus	%	0.8	0.5	
Potassium	%	0.6	0.6	
Sodium	%	0.2	0.2	
Chloride	%	0.3	0.3	
Magnesium[c]	%	0.08	0.04	
Iron[d]	mg/kg	80	80	
Copper (extruded)	mg/kg	15	5	
Copper (canned)	mg/kg	5	5	
Manganese	mg/kg	7.5	7.5	
Zinc	mg/kg	75	75	2000
Iodine	mg/kg	0.35	0.35	
Selenium	mg/kg	0.1	0.1	
Vitamins & Others				
Vitamin A	IU/kg	9,000	5,000	750,000
Vitamin D	IU/kg	750	500	10,000
Vitamin E	IU/kg	30	30	
Vitamin K	mg/kg	0.1	0.1	
Thiamine	mg/kg	5.0	5.0	
Riboflavin	mg/kg	4.0	4.0	
Pantothenic acid	mg/kg	5.0	5.0	
Niacin	mg/kg	60	60	
Pyridoxine	mg/kg	4.0	4.0	
Folic acid	mg/kg	0.8	0.8	
Biotin	mg/kg	0.07	0.07	
Vitamin B_{12}	mg/kg	0.02	0.02	
Choline	mg/kg	2,400	2,400	
Taurine (extruded)	%	0.10	0.10	
Taurine (canned)	%	0.20	0.20	

[a]Presumes an energy density of 4,000 kcal ME/kg as determined in accordance with Regulation PF9. Rations greater than 4,500 kcal ME/kg should be corrected for energy density; diets ess than 4500 kcal ME/kg should not be corrected for energy. Diets of low-energy density should not be considered adequate for growth or reproductive needs based on comparison to the Profiles alone. [b]Although a true requirement for crude fat per se has not been established, the minimum level was based on recognition of crude fat as a source of essential fatty acids, as a carrier of fat-soluble vitamins, to enhance palatability, and to supply an adequate caloric density. [c]If the mean urine pH of cats fed ad libitum is not below 6.4, the risk of struvite urolithiasis increases as the magnesium content of the diet increases. [d]Because of very poor bioavailability, iron from carbonate or oxide sources are added to the diet should not be considered in determining the minimum nutrient level.

DIET FORMULATION & COMMON FEED INGREDIENTS

AS-FED, DRY MATTER, OR AIR-DRY

1. **Expressing the Nutrient & Energy Content**

   A. Dry matter (DM) basis - The amount contained in only the DM portion of the feed ingredient/diet, i.e., without water. [Because feeds contain varying amounts of DM, perhaps, simpler and more accurate if both the composition and nutrient requirements are expressed on a DM basis!?]

   B. As-fed basis - The amount contained in the feed ingredient/diet as it would be fed to the animal; including water.

   C. Air-dry basis:

      1) Usually, assumed to be approximately 90% DM.
      2) Most feeds will equilibrate to about 90% DM after a prolonged, aerobic storage.
      3) Air-dry and as-fed basis may be the same for many common feeds.

   D. Percent dry matter?

      1) Determined by drying a sample to remove all the moisture, and the weight of the remaining is expressed as a percent of the original weight.
      2) Example - "1.0 g of corn is dried and 0.90 g of corn remained after drying," then:

$$\frac{0.90}{1.00} \times 100 = 90\% \text{ DM}$$

2. **As-Fed Basis Converted to DM Basis**

   A. Can be converted by:

$$\frac{\text{Nutrient \% on as-fed basis}}{\text{\% DM in the feed expressed as decimal fraction}} = \text{Nutrient \% on DM basis}$$

or

$$\frac{\text{\% Nutrient (as-fed basis)}}{\text{\% Feed DM}} = \frac{\text{\% Nutrient (DM basis)}}{\text{100\% DM}}$$

   B. Example? - "Alfalfa silage analyzed to contain 7% CP on an as-fed basis and contained 40% DM. What would be the CP content on DM basis?"

   $7 \div 0.40 = 17.5$, thus 17.5% CP on DM basis, or

$$\frac{7}{40} = \frac{X}{100} \Rightarrow 40\,X = 700 \Rightarrow X = \frac{700}{40} = 17.5\% \text{ CP on DM basis}$$

3. **DM Basis Converted to As-Fed Basis**

A. Can be converted by:

Nutrient % on DM basis x % DM in the feed expressed as decimal fraction = Nutrient % on as-fed basis

or

$$\frac{\text{\% Nutrient (as-fed basis)}}{\text{\% Feed DM}} = \frac{\text{\% Nutrient (DM basis)}}{\text{100\% DM}}$$

B. Example? - "Alfalfa silage analyzed contain 10% crude fiber on a DM basis. If the linseed meal contains 91% DM, what would be the % crude fiber expressed on an as-fed basis?"

10.0 x 0.91 = 9.1, thus 9.1% on as-fed basis, or

$$\frac{X}{91} = \frac{10}{100} \Rightarrow 100\ X = 910 \Rightarrow X = \frac{910}{100} = 9.1\%\ \text{Crude fiber on as-fed basis}$$

4. **Converted to Air-Dry Basis**

A. DM basis to air-dry basis (90% DM):

Nutrient % on DM basis x 0.90 = Nutrient % on air-dry basis

B. As-fed basis to air-dry basis (90% DM):

$$\frac{90}{\text{\% Feed DM}} \text{ x Nutrient \% on as-fed basis} = \text{Nutrient \% on air-dry basis}$$

5. **Amount in DM and as-fed?**

A. Amount in DM = Amount in as-fed * DM content (decimal)
B. Amount in DM = X (amount in as-fed) * DM content (decimal)
C. Amount in as-fed? $X = \frac{\text{Amount in DM}}{\text{DM content (decimal)}}$

6. **Rule of thumb for conversions?**

A. When converting from "as-fed to DM?"

1) The nutrient content will increase.
2) The weight will decrease

B. When converting from "DM to as-fed?"

1) The nutrient content will decrease.
2) The weight will increase.

SIMPLE DIET FORMULATION TECHNIQUES

1. **Formulating a Diet with Two Ingredients**

☛ Can be used for two mixtures rather than two ingredients!

A. Algebraic diet formulation (using an equation with one unknown, X)

1) Example - "Formulate a 14% crude protein (CP) diet using corn (8.8% CP) and a protein supplement (38% CP), and also check the results for accuracy."
2) Procedure & check - See boxes.

Algebraic equation with one un known, X:

If % supplement = X
% corn = 100 - X

0.088 (100 - X) + 0.38X = 0.14 (100)
[lb CP from corn] [lb CP from supplement] [lb CP in 100 lb of diet]

8.8 - 0.088X + 0.38X = 14
0.38X - 0.088X = 14 - 8.8
0.292X = 5.2
X = 17.81 [lb supplement]
100 - X = 82.19 [lb corn]

0.088 (82.19) + 0.38 (17.81) = ?
7.233 + 6.768 = 14.00

B. Algebraic diet formulation [using equations with two unknowns, X & Y; See Kellems & Church (1998) or Jurgens (2002)]

1) Use the same example - "Formulate a 14% CP diet using corn (8.8% CP) and a protein supplement (38% CP), and check the results for accuracy."
2) Procedure (Formulate 100 lb of a diet containing 14% CP) & check - See boxes.

Algebraic equation with two unknowns, X & Y:

X = lb corn in the diet
Y = lb supplement in the diet

Equation 1: X + Y = 100.0 lb diet
Equation 2: 0.088X + 0.38Y = 14.0 lb CP (14% of 100 lb)

☞ To solve this problem, need to develop a third equation to subtract from Equation 2 to cancel either X or Y - Develop Equation 3 by multiplying Equation 1 by a factor of 0.088, thus:

Equation 2: 0.088X + 0.38Y = 14.0
Equation 3: -0.088X + -0.088Y = -8.8 (Subtract)

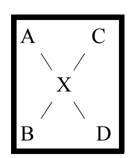
0 + 0.292Y = 5.2

$$Y = \frac{5.2}{0.292} = 17.81 \text{ (lb supplement)}$$

X = 100 - 17.81 = 82.19 (lb corn)

82.19 lb corn	x 8.8% CP	= 7.23 lb CP
17.81 lb supplement	x 38.0% CP	= 6.77 lb CP
100.00 lb diet		14.00 lb CP

C. Pearson square - A simple procedure originally devised to blend milk products to a known fat percentage, and can be used for diet formulation too. [See Kellems & Church (1998) or Jurgens (2002)]



1) Use the same example - "Formulate a 14% CP diet using corn (8.8% CP) and a protein supplement (38% CP), and check the results."
2) How?

   a) The desired solution is placed in the center ("X").
   b) Feed sources "A" & "B" are then added.
   c) To solve, the difference between X & A goes in the D position, and the difference between B & X goes in the C position . . . without regard to sign.
   d) The answer is expressed as parts as illustrated in the example (formulate 100 lb of a diet containing 14% CP):

Pearson square:

Corn	8.8% CP	\ /	24.0 parts corn
		14%	
Supplement	38% CP	/ \	5.2 parts supplement
			29.2 total parts

$$\frac{24.0 \text{ parts corn}}{29.2 \text{ total parts}} \times 100 = 82.19\% \text{ corn}$$

$$\frac{5.2 \text{ parts supplement}}{29.2 \text{ total parts}} \times 100 = 17.81\% \text{ supplement}$$

3) Check - See the box.

82.19 lb corn	x 8.8% CP	= 7.23 lb CP
17.81 lb supplement	x 38.0% CP	= 6.77 lb CP
100.00 lb diet		14.00 lb CP

2. **Including a Fixed Ingredient(s)**

A. Algebraic diet formulation (equation with one unknown, X)

1) Example - "Formulate a 12% CP diet using corn (8.8% CP) and a protein supplement (35% CP), with 3% rye (11.9% CP) and 7.5% milo (11.0% CP)."
2) Known quantities? 3% Rye + 7.5% milo = 10.5%, thus remaining 89.5% to be balanced!
3) Procedure & check? - See the box.

Algebraic equation with one un known, X:

If % supplement = X
% corn = 89.5 - X

0.119 (3) + 0.11 (7.5) + 0.088 (89.5 - X) + 0.35X = 0.12 (100)

☞ From left, lb CP from rye, lb CP from milo, lb CP from corn, lb CP from supplement, and lb CP in 100 lb of diet.

0.357 + 0.825 + 7.876 - 0.088X + 0.35X = 12
0.35X - 0.088X = 12 - 7.876 - 0.825 -0.357
0.262X = 2.942
X = 11.229 [lb supplement]
89.5 - X = 78.271 [lb corn]

Check?

0.119 (3) + 0.11 (7.5) + 0.088 (78.271) + 0.35 (11.229) = ?
0.357 + 0.825 + 6.888 + 3.930 = 12

B. Algebraic diet formulation (using equations with two unknowns, X & Y)

1) The same example - "Formulate a 12% CP diet using corn (8.8% CP) and a protein supplement (35% CP), with 3% rye (11.9% CP) and 7.5% milo (11.0% CP)."

2) Known quantities & fixed amount of CP?

   a) 3% Rye + 7.5% milo = 10.5%, thus remaining 89.5% to be balanced.
   b) 0.119 (3) + 0.11 (7.5) = 0.357 + 0.825 = 1.182, or 1.182 lb of CP per 100 lb of diet (or 1.182%) is fixed. Thus, the remaining protein (10.818 lb/100 lb feed) must be balanced with corn and supplement.

Algebraic equation with two unknowns, X & Y:

X = lb corn in the diet
Y = lb supplement in the diet

Equation 1:	X	+	Y	=	89.5	lb diet
Equation 2:	0.088X	+	0.35Y	=	10.818	lb CP
Equation 3:	-0.088X	+	-0.088Y	=	-7.876	(Subtract)
	0		0.262Y	=	2.942	

$$Y = \frac{2.942}{0.262} = 11.229 \text{ (lb supplement)}$$

X = 89.5 - 11.229 = 78.271 (lb corn)

Check?

0.119 (3) + 0.11 (7.5) + 0.088 (78.271) + 0.35 (11.229) = ?
0.357 + 0.825 + 6.888 + 3.930 = 12

3) Procedure & check? - See the box

C. Pearson square

1) The same example - "Formulate a 12% CP diet using corn (8.8% CP) and a protein supplement (35% CP), with 3% rye (11.9% CP) and 7.5% milo (11.0% CP)."
2) Known quantities & fixed amount of CP?

   a) 3% Rye + 7.5% milo = 10.5%, thus remaining 89.5% to be balanced.
   b) 0.119 (3) + 0.11 (7.5) = 0.357 + 0.825 = 1.182, or 1.182 lb of CP per 100 lb of diet (or 1.182%) is fixed. Thus, the remaining protein (10.818 lb/100 lb of feed or 10.818%) must be balanced with corn and supplement.
   c) Need to determine the % CP necessary in corn-supplement combination to provide 10.818 lb/100 lb of feed . . . 10.818/89.5 x 100 = 12.087%.

3) Procedure & check? - See the box

Pearson square:

Corn	8.8% CP		22.913 parts corn
		12.087%	
Supplement	35% CP		3.287 parts supplement
			26.2 total parts

$$\frac{22.913 \text{ parts corn}}{26.2 \text{ total parts}} \times 100 = 87.454\% \text{ corn}$$

$$\frac{3.287 \text{ parts supplement}}{26.2 \text{ total parts}} \times 100 = 12.546\% \text{ supplement}$$

89.5 x 87.454% = 78.271 lb corn
89.5 x 12.546% = 11.229 lb supplement

Check?

3.00 lb rye	x 11.9% CP =	0.357 lb CP
7.50 lb milo	x 11.0% CP =	0.825 lb CP
78.271 lb corn	x 8.8% CP =	6.888 lb CP
11.229 lb supplement	x 35.0% CP =	3.930 lb CP
100.00 lb diet		12.000 lb CP

3. **Applications?**

A. As you would expect, these same/similar approaches can be applied to balance diets for other nutrients, and this simple or basic concept can be used to formulate more complex diets with many ingredients . . . with some modifications, that is!
B. To formulate actual diets, need to balance for other major nutrients, such as Ca & P, and also need to provide some additional "space/room" for additional ingredients, e.g., salt, vitamin and(or) trace mineral premix(es), antibiotics, etc.
C. Also, similar approaches can be used to formulate vitamin or mineral premixes.

A COMPLETE DIET, SUPPLEMENT, AND BASE MIX

- To formulate actual/practical diets in most instances, need to balance for other major/important nutrients such as Ca & P!
- Also, may need to formulate a supplement or base mix [& also a vitamin and(or) mineral premixes?] that will be fed along with major energy and(or) protein sources
- A simple approach used to formulate a diet with only two ingredients can be used to (after some modifications, that is!) accomplish the task!

1. **Formulating a Complete Diet**

◦ *Will use a grower-finisher pig diet as an example, but the same/similar approach can be used for a diet for other species!*

A. ***Please formulate a grower-finisher diet:***

Containing: **14%** CP,
0.50% Ca, and
0.40% P

		CP, %	Ca, %	P, %
Using:	Corn	8.8	0.03	0.27
	Soybean meal (**SBM**)	50.9	0.26	0.62
	5% Alfalfa meal	17.0	1.33	0.24
	Dicalcium phosphate (**Dical**)	-	23.35	18.21
	Limestone (**Lime**)	-	35.8	-

With: **0.5%** salt, **0.1%** trace mineral (**TM**) premix, and **1.0%** vitamin (**Vit**) premix premix.

☛ Assume that salt, TM & Vit premixes do not contain protein, Ca, or P.

B. ***Step 1 - Balance for protein:***

SBM = x & Corn = 93.4 - x   (100% - 5% alfalfa - 1.6% salt, TM premix & Vit premix = 93.4)

0 (1.6) + 0.17 (5) + 0.088 (93.4 - x) + 0.509x = 0.14 (100) [From left, CP from salt-TM-Vit, alfalfa, corn, and SBM!]

0 + 0.85 + 8.219 - 0.088x + 0.509x = 14
0.509x - 0.088x = 14-8.219 - 0.85
0.421x = 4.931
x = 11.712 (SBM)
93.4 - 11.712 = 81.688 (Corn)

Check: 0 (1.6) + 0.17 (5) + 0.088 (81.688) + 0.509 (11.712) = 0 + 0.85 + 7.188544 + 5.961408 = **14.0**

C. *Step 2 - Balance for P:*

- This is done before balancing for Ca because all the supplemental P must come from one of the minerals, which may also provide part of the Ca need.
- For this example, Dical contains both P & Ca.

Dical = x & Corn = 81.688 - x (Use corn to make an adjustment.)

0.0024 (5) + 0.0027 (81.688 - x) + 0.0062 (11.712) + 0.1821x = 0.004 (100) [From left, P from alfalfa, corn, SBM, and Dical.]

0.012 + 0.2206 - 0.0027x + 0.0726 + 0.1821x = 0.004 (100)
0.1821x - 0.0027x = 0.40 - 0.012 - 0.2206 - 0.0726
0.1794x = 0.0948
x = 0.5284 (Dical)
81.688 - 0.5284 = 81.1596 or 81.160 (Corn)

Check: 0.0024 (5) + 0.0027 (81.1596) + 0.0062 (11.712) + 0.1821 (0.5284) = 0.012 + 0.2191309 + 0.0726 + 0.0962216 = **0.40**

D. *Step 3 - Balance for Ca:*

Lime = x & Corn = 81.160 - x

0.0133 (5) + 0.0003 (81.160 - x) + 0.0026 (11.712) + 0.2335 (0.5284) + 0.358x = 0.005 (100)
[From left, Ca from alfalfa, corn, SBM, Dical, and Lime.]

0.0665 + 0.0243 + 0.0003x + 0.0304 + 0.1234 + 0.358x = 0.50
0.358x - 0.0003x = 0.50 - 0.1234 - 0.0304 - 0.0243 - 0.0665
0.3577x = 0.2553
x = 0.7139 (Lime)
1.160 - 0.7139 = 80.4461 (Corn)

Check: 0.0133 (5) + 0.0003 (80.4461) + 0.0026 (11.712) + 0.2335 (0.5284) + 0.358 (0.7139) = 0.0665 + 0.0241338 + 0.0304512 + 0.1233814 + 0.2555762 = **0.50**

E. *Step 4 - Balance for protein again with adjustments made for fixed quantities to account for Dical & Lime:*

SBM = x & Corn = 92.16 - x [93.4 - 0.5284 (Dical) - 0.7139 (Lime) = 92.16]

0 (2.84) + 0.17 (5) + 0.088 (92.16 - x) + 0.509x = 0.14 (100) [From left, CP from salt-TM-Vit-Dical-Lime portion, alfalfa, corn, and SBM.]

0 + 0.85 + 8.1101 - 0.088x + 0.509x = 14
0.509x - 0.088x = 14 - 8.1101 - 0.85
0.421x = 5.0399
x = 11.97 (SBM)
92.16 - 11.97 = 80.19 (Corn)

Check: 0 (2.84) + 0.17 (5) + 0.088 (80.19) + 0.509 (11.97) = 0 + 0.85 + 7.05672 + 6.09273 = **14.00**

2. Formulating a Supplement or Base Mix

- Again, will use a grower-finisher pig diet as an example, but the same/similar approach can be used for a supplement/base mix for other species!

A. What do you mean by a "supplement, a base mix, or a premix?" (Provided some definitions used for pig diets, but other folks may define differently, so . . . ?)

1) "Supplement"

a) Contain protein, minerals, and vitamins.
b) Mix with grain(s) to produce complete diets.

2) "Base mix"

a) Contains minerals and vitamins.
b) Mix with grain(s) and protein supplement(s) to produce complete diets.

3) "Premix"

a) Mineral or vitamin mix.
b) Mix with grain(s), protein supplement(s), and mineral or vitamin premix to produce complete diets.

B. General procedures for formulating supplements & base mixes:

1) A supplement to be mixed or fed with the grain portion of a diet - Steps:

a) Formulate a complete diet.
b) Determine the amount of supplement needed: "Total - Grain Portion = Supplement."
c) Express ingredients as a percent of the supplement, rather than the diet.
d) Write the specification for the supplement.

2) A base mix to be fed with the grain and protein portion of the diet - Steps:

   a) Formulate a complete diet.
   b) Determine the amount of base mix needed: "Total - (Grain + Protein Portion) = Base Mix."
   c) Express ingredients as a percent of the base mix rather than the diet.
   d) Write specifications for the base mix.

3) A supplement to be fed with the known amount of grain and the supplement:

   a) Determine the contribution of the known amount of grain toward the animal's requirement.
   b) Write the specifications for the supplement.
   c) Formulate the supplement.

	CP, %	Ca, %	P, %
Corn	8.8	0.03	0.27
SBM	50.9	0.26	0.62
Dical	-	23.35	18.21
Lime	-	35.8	-

C. An example - "Formulate a **supplement (500 lb)** to be fed with **1,500 lb of corn/ton** of complete diet."

- Use SBM, Dical, Lime, salt, Vit premix, TM premix, and corn as a carrier, and Pigs need **14% CP**, **0.5% Ca**, **0.4% P**, **0.5% salt**, **0.1% TM premix** & **1.0% Vit premix**.

1) Determine the "**specifications**" for the supplement

   a) ***Complete diet is:***

   1,500/2,000 = 75% Corn & 500/2,000 = 25% Supplement

   b) ***% CP in supplement:***

   $0.088\ (75) + x\ (25) = 0.14\ (100)$
   $6.6 + 25x = 14$
   $25x = 7.4$
   $x = 0.296$ [Thus, 0.296 x 100 = 29.6% (% CP in supplement)]

   ☛ ***Please note that, unlike before, "x" for CP & others to determine specifications represents the "content" of particular nutrient in a feed ingredient . . . Not the "amount/lb (or %)" of a feedstuff!***

   c) ***% Ca in supplement:***

   $0.0003\ (75) + x\ (25) = 0.005\ (100)$
   $0.0225 + 25x = 0.5$
   $25x = 0.4775$
   $x = 0.0191$ [Thus, 0.0191 x 100 = 1.91% (% Ca in supplement)]

d) ***% P in supplement:***

$$0.0027\ (75) + x\ (25) = 0.004\ (100)$$
$$0.2025 + 25x = 0.4$$
$$25x = 0.1975$$
$$x = 0.0079$$ [Thus, 0.0079 x 100 = 0.79% (% P in supplement)]

e) ***% salt in supplement:***

$$0\ (75) + x\ (25) = 0.005\ (100)$$
$$5x = 0.5$$
$$x = 0.02$$ [Thus, 0.02 x 100 = 2% (% salt in supplement)]

f) ***% TM in supplement:***

$$0\ (75) + x\ (25) = 0.001\ (100)$$
$$25x = 0.1$$
$$x = 0.004$$ [Thus, 0.004 x 100 = 0.4% (% TM premix in supplement)]

g) ***% Vit in supplement:***

$$0\ (75) + x\ (25) = 0.01\ (100)$$
$$25x = 1.0$$
$$x = 0.04$$ [Thus, 0.04 x 100 = 4% (% Vit premix in supplement)]

Supplement Specifications, %	
CP	29.6
Ca	1.9
P	0.8
Salt	2.0
TM premix	0.4
Vit premix	4.0

2) Supplement Specifications - Please see the box.
3) Formulate a supplement:

a) ***Step 1 - Balance for CP:***

100 - [2 (salt) + 0.4 (TM) + 4.0 (Vit)] = 93.6 SBM = x & Corn = 93.6 - x

$$0.088\ (93.6 - x) + 0.509x = 0.296\ (100)$$
$$8.24 - 0.088x + 0.509x = 29.6$$
$$0.421x = 21.36$$
$$x = 50.74\ \text{(SBM)}$$
$$93.6 - 50.74 = 42.86\ \text{(Corn)}$$

b) ***Step 2 - Balance for P:*** Dical = x & Corn = 42.86 - x

$$0.0027\ (42.86 - x) + 0.0062\ (50.74) + 0.1821x = 0.008\ (100)$$
$$0.1157 - 0.0027x + 0.3146 + 0.1821x = 0.8$$
$$0.1794x = 0.3697$$
$$x = 2.06\ \text{(Dical)}$$

c) ***Step 3 - Balance for Ca:*** Lime = x & Corn = 40.80 - x (42.86 - 2.06 = 40.80)

$$0.0003\ (40.80 - x) + 0.0026\ (50.74) + 0.2335\ (2.06) + 0.358x = 0.019\ (100)$$

$$0.0122 - 0.0003x + 0.1319 + 0.481 + 0.358x = 1.9$$
$$0.3577x = 1.2749$$
$$x = 3.56 \text{ (Lime)}$$

d) ***Step 4 - Re-balance for CP:***

SBM = x & Corn = 87.98 - x [93.6 - 2.06 (Dical) - 3.56 (Lime) = 87.98]

$$0.088\ (87.98 - x) + 0.509\ x = 0.296\ (100)$$
$$7.74 - 0.088x + 0.509\ x = 29.6$$
$$0.421x = 21.86$$
$$x = 51.92 \text{ (SBM)}$$
$$87.98 - 51.92 = 36.06 \text{ (Corn)}$$

SBM	51.92
Corn	36.06
Vit premix	4.00
Lime	3.56
Dical	2.06
Salt	2.00
TM premix	0.40

e) ***Supplement (%)? - Please see the box:***

3. **Formulating a Base Mix or a Premix?**

A. Assume we have a diet with the following composition (per ton or 2,000 lb):

Corn	1553
SBM	353
Lime	11
Dical	51
Salt	10
TM premix	2
Vit premix	20

B. Formulate base mix to be fed with the corn & SBM:

2,000 - (1553 + 353) = 94 lb (Should be the base mix)

Lime	11/94 x 100 =	11.70%
Dical	51/94 x 100 =	54.26%
Salt	10/94 x 100 =	10.64%
TM premix	2/94 x 100 =	2.12%
Vit premix	20/94 x 100 =	21.28%
		100.00%

C. Formulating a TM or Vit premix?

1) Determine each TM or vitamin requirement.
2) The requirement must be satisfied with the amount or proportion of TM premix or Vit premix included in the base mix (or supplement or diet) - i.e., Should be included at "X" percent of the base mix, supplement, or diet!
3) Each source of TM or vitamin may not be 100% pure, thus may need to provide some "space/room" to make some adjustment, thus use a carrier(s).
4) Express each source of TM or vitamin needed in % or unit/certain weight.

FEED INGREDIENTS IN GENERAL

- *References: See Thacker and Kirkwood (1990), Seerley (1991) in Miller et al. (1991), Kellems and Church (1998), Chiba (2001) in Lewis & Southern (2001), Chiba (2005) in Pond & Bell (2005), Jurgens (2002), and others for detailed info on major feed ingredients & others.*

1. Classification of Feedstuffs/Ingredients & Some Examples

A. General:

1) Feedstuffs - Can be defined as any component of a diet that serves some useful function (Kellems & Church, 1998).
2) Most feedstuffs provide one or more of nutrients such as protein, lipids, carbohydrates, minerals, or vitamins.
3) Some feedstuffs are included to modify the diet's characteristics rather than simply providing energy or nutrient - e.g., to emulsify fat, provide bulk, reduce oxidation, provide flavor, color, etc.
4) Feedstuffs are given an "**International Feed Number (IFN)**," which indicates how a feedstuff has been categorized.
5) The International Feed Identification System classifies feedstuffs into eight general categories with the first digit of the IFN indicates the "Major Category:"

    - 1. Roughages - Dry forages and roughages, 2. Pasture, range plants and forages fed fresh, 3. Silages & hayleges, 4. Energy feeds, 5. Protein supplements, 6. Mineral supplements, 7. Vitamin supplements, and 8. Additives.

B. [1] Roughages or Dry forages and roughages

1) All forages and roughages cut & cured, and other products with more than 18% crude fiber or containing more than 35% cell wall (dry basis). Usually low in net energy per unit weight because of the high cell-wall content.
2) Carbonaceous roughages (low protein) - Straws, Stalks, Weathered grass, etc.
3) Proteinaceous roughages - Legume hays, grass/legume hays, etc.

C. [2] Pasture, range plants and forages fed fresh

1) All forage feeds either not cut (including feeds cured on the stem) or cut and fed fresh - Grazed parts (growing & dormant), greenchop, food crop residues, etc.
2) Carbonaceous (low protein) - Fresh Grama grass, fresh Wheatgrass, etc.
3) Proteinaceous (high protein) - Fresh & early vegetative Wheatgrass, etc.

D. [3] Silages & haylages

1) Includes only ensiled forages, but not ensiled fish, grain, roots, and tubers.
2) Carbonaceous (low protein) - Corn silages, grass silage, etc.
3) Proteinaceous - Alfalfa silage, clover silage, etc..

E. [4] Energy feeds

1) Ones with less than 20% CP and less than 18% crude fiber or less than 35% cell wall on a dry basis - e.g., grain, mill byproducts, fruit, nuts, roots, tubers, etc.
2) Carbonaceous concentrates (low protein) - Cereal grains (corn, oats, barley, rye and wheat), sorghums (kafir, milo and hybrids), milling by-products of cereal grains, beet and citrus pulp, molasses of various types, seed and mill screenings, animal, marine, and vegetable lipids, fresh or ensiled root & tubers, etc.

F. [5] Protein supplements

1) Products that contain 20% or more of protein (dry basis) from animal origin (including ensiled products), as well as oilseed meals.
2) Supplements of vegetable origin - Soybean meal, flaxseed meal (linseed meal), cottonseed meal, peanut meal, corn gluten meal, sorghum gluten meal, brewer's dried grains, sesame meal, etc.
3) Supplements of animal origin:

a) Animal tissues - Tankage, tankage with bone, meat scraps, meat and bone scraps, blood meal, meat meal, etc.
b) Fish products - Fish meal, dried fish solubles, condensed fish solubles, etc.
c) Milk products - Dried skim milk, dried whole milk, dried butter milk, condensed butter milk, dried whey, etc.

4) Also, include single-cell sources (bacteria, yeast, and algae), non-protein N (urea, ammonia, biuret, etc.), etc.

G. [6] Mineral supplements - Steamed bone meal, calcium carbonate, limestone, etc.
H. [7] Vitamin supplements - Ensiled yeast, carotene, fish, salmon, oil, wheat germ oil, etc.
I. [8] Additives - Antibiotics, antioxidants, probiotics, coloring material, flavors, hormones, enzymes, emulsifying agents, buffers, etc.

2. Roughages in General

A. Earth's surface? (Kellems and Church, 1998)

1) Approximately one-third of the earth's surface is land (34 billion acres), and out of this total land, 3 to 4% is utilized for urban and industrial purposes, 10% is being farmed, 28 to 30% is forest lands, some of which can be used by animals, approximately 15% is non-productive, i.e., deserts to land covered by ice in the Arctic and Antarctic regions, and the remaining 40% is comprised of rangeland

(more suitable vs. cultivation) such as grassland, savannas, scrublands, tundra, alpinr communities, coastal marshes, and wet meadows.

2) "*Thus, it is obvious that production of materials useful for humans (food, fiber clothing, etc.) can only be achieved from a large portion of the world's land by grazing animals, both domestic and wild*."

B. Forages, roughages, and herbages?

1) “Forage” - Defined as the total plant material available to be consumed by an animal.
2) “Roughage” - A terms often used to describe those dietary components that are characterized by being high in fiber (cellulose).
3) “Herbage” - Often used by ones involved in management of wildlife, and is plant materials that does not include the seeds or roots and can be utilized by as food by herbivorous animals.
4) The terms “forages and roughages” are often used interchangeably to describe plant materials that are high in structural carbohydrates, which contain high amounts of cellulose and hemicellulose.

C. General characteristics:

1) Low in energy and containing more than 18% crude fiber, and variable in protein content.
2) Higher in Ca and trace mineral elements than most concentrates.
3) Legumes are higher in protein and B vitamins than some concentrates.
4) Better source of fat-soluble vitamins than most concentrates.
5) Usually, palatable to ruminant species.
6) Limited use in swine diets, and also beef finishing rations & some high-energy lactating rations.
7) Required by lactating dairy cows to help maintain a normal milk fat content.
8) More variable in nutritive contents and acceptability than concentrates because of variations in maturity, harvesting (i.e., stages?), and storing procedures.

3. **High-Energy Feedstuffs in General**

A. High-energy feedstuffs - Fed or added to a diet/ration primarily to increase energy intake or dietary energy density, but many of them also provide amino acids, minerals and vitamins!
B. Include various cereal grains and many of their milling by-products, roots and tubers, liquid feeds, such as molasses, fats and oils, and others.
C. Available energy (digestible, metabolizable, or net) per unit of dry matter is much higher than roughages.
D. Depending on the type of diet and the class of animal, may make up a substantial portion of the animal's total diet.
E. General characteristics:

1) Low in fiber, and high in energy.
2) Low in protein vs. oil seed meals & some mill feeds, and protein quality is variable and generally low.
3) Low in Ca, but fair in P (good vs. forages).
4) Low in vitamin D, vitamin A (excluding yellow corn), riboflavin, vitamin B_{12}, and pantothenic acid, and fair in vitamin E.
5) High in thiamin and also high in niacin but mostly in a bound, unavailable form.

4. **Protein Supplements in General**

A. Protein is a critical nutrient, i.e., the one likely to be low or deficient, especially for young, rapidly growing animals and, e.g., high-producing dairy cattle.
B. Protein supplements? - Those having 20% or more crude protein on a dry matter basis.
C. Optimum use is a must simply because protein supplements are usually much more expensive than energy sources, and wasteful usage can increase the production cost.
D. For nonruminant species and young suckling ruminant species, a diet must supply the indispensable amino acids (thus, protein quality is important) and adequate N to synthesize dispensable amino acids.
E. For ruminant species:

1) Dietary need is a combination of needs to nourish microorganisms and the needs for adequate supply of digestible, indispensable amino acids in the gut.
2) Protein quality is important for high-producing ruminants because of the increased needs for rumen udegradable protein. Microbial protein may not be adequate for high-producing animals.

F. Protein supplements? Animal, plant, marine, and microbial sources are available, but today, the major protein sources used for animal production are oilseed meals. Some animals protein source are also being used though!
G. Oilseed meals in general:

1) Soybean is clearly the prominent oilseed produced in the world, and soybean meal accounted for 64.1% of the world production of protein meals in 1997 to 1998.
2) Moderate heating is generally required to inactivate anti-nutritional factors present in oilseed meals. But, overheating can reduce amino acid availability!
3) Generally high in crude protein content, except some with hulls. The CP content is usually standardized before marketing by dilution with hulls or other materials.
4) Generally low in Ca, but high in P content. The biological availability of minerals in plant sources, such as oilseeds, are generally low, especially true for P.

H. Animal protein sources in general:

1) Good sources of lysine and other amino acids, and the amino acid pattern is often very similar to the dietary needs of animals.

2) Compared with plant proteins, very good sources of vitamins and minerals, such as the B vitamins (especially vitamin B_{12}) and Ca and P.
3) More variable in the nutrient content, and are subjected to high drying temperatures for dehydration and sterilization. Obviously, proper heating is necessary to produce a quality product.
4) Some clarifications on meat meal, meat and bone meal, meat meal tankage, and meat and bone meal tankage:

    a) The only difference between meal and tankage is that the meal does not contain blood.
    b) Meat meal is distinguished from meat and bone meal based on the P content - If the product contains more than 4.4% P, it is considered as meat and bone meal.
    c) Meat meal tankage and meat and bone meal tankage can be differentiated similarly on the basis of P content.
    d) For all these, Ca should not be more than 2.2 times the actual P content.

5. **Mineral Supplements in General**

A. Minerals are the inorganic components and make up only a relatively small portion of the animal diet, but vital to the animal.
B. All the required minerals are needed in an animal's diet and(or) water supply, but the need for supplementation vary widely among species. Classified as either macrominerals or microminerals (or trace minerals/elements!?).
C. Macrominerals:

1) Include salt (NaCl), Ca, P, Mg, & sometimes K & S.
2) Ca? - Little difference in availability among Ca sources. Most are utilized well by different animals.
3) P sources differ wide in availability, especially when fed to noruminant species simply because ½ to ⅔ of plant P is bound to phytic acid, which is poorly utilized by nonruminants.
4) Salt - Often iodized and(or) added small amounts of other trace elements (e.g., Co, Mn, Fe, Zn, and Cu). Either as a block (free-choice) or a loose form.

D. Micro or trace minerals/elements:

1) Include Cu, Fe, I, Mn, Se, Zn, and also Co. (Others? - Cr, F, Ni, Si, etc.)
2) Differences exist in biological availability depending on the form. Some forms may not be available to animals at all.
3) Chelation? Chelating with other molecules (e.g., some amino acids) may improve the stability and absorption/utilization of some trace elements.

6. **Vitamin Supplements in General**

A. Almost all feedstuffs contain some vitamins, but their concentrations vary widely.
B. In plants, vitamin concentration can be affected by harvesting, processing, and storage conditions, as well as plant species and part.
C. In animals, the liver and kidney are generally good sources of most of the vitamins.
D. Yeasts and other microorganisms are excellent source, especially, B vitamins.
E. Limiting vitamins in natural diets (mostly for nonruminants), thus the need for supplementation!?

 1) Mostly for nonruminants - Vitamins A, D, E, riboflavin, pantothenic acid, niacin, choline, and vitamin B_{12}, depending on the species & class. Also, biotin (in pigs & poultry) and vitamin K (with reduced microbial synthesis) in some instances?!
 2) For ruminants - Vitamin A & also β-carotene, and vitamin D & E for dairy cows? Also, thiamin & niacin in some instances!?

F. Vitamins can be purchased individually or as a mixture.
G. Fat-soluble vitamins need a antioxidant to retain their potency.
H. Some/most(?) water-soluble vitamins are subject to destruction by heat, moisture, light, trace elements, etc.

BRIEF DESCRIPTION OF SOME COMMON FEED INGREDIENTS

- *See: Kellems and Church (1998), Chiba (2001), and Jurgens (2002).*
- Abbreviations: CP = crude protein; TDN = total digestible nutrients; SBM = soybean meal; DM = dry matter.

Alfalfa - Perennial plant varying in height from 18 in. to 3 ft. Grown extensively throughout the Midwest and western US. Hay is high in the feeding value and excellent for general purposes - 15 to 15% CP, > 50% TDN, high in Ca (1.3 to 1.5%), and fair in P. "Dehydrated meals" - Dried products produced after cutting & grinding. Contains 15 to 23% CP, but ones with 17 & 20% CP are common.

Animal fat - Obtained from the tissues of mammals and(or) poultry in the commercial rendering or extraction. Usually treated with an antioxidant to prevent rancidity. Used to increase the energy, decrease dustiness, improve texture & palatability, facilitate pelleting, and reduce machinery wear.

Bakery, waste, dehydrated - Blended, dried and ground meal consists of stale bakery products and certain other bakery wastes. Similar to corn in the nutrient composition, but much higher in fat (12 to 16%) and also salt. Because of the high salt content, should be limited to about 20% of total for cattle & pig diets.

Barley, grain - Majority is grown in North Central & Far Western states. Contains 70 to 75% TDN & 11 to 12% CP, and 88 to 90% feeding value of corn for cattle and sheep & 80% for pigs. Limit in pig and poultry diets because of the fiber content (5 to 6%), but can be used as the only grain in all concentrate diets with cattle.

Beet pulp, dehy - The residue from sugar beet processing. Contains 65 to 70% TDN & 8 to 10%CP. 18 to 19% in the fiber content, and a good laxative in sow diets. Generally, should not replace > 15 to 20% of grain.

Bermudagrass, common & coastal- "Common" - Long-lived perennial spreading by runners, rootstocks or both, and by seeds. Stems are very leafy. Requires warm weather during the growing season and will bear intense heat without injury. Not resistant to cold & not stand shading well. Most commonly used for pasture rather than for hay. Contains 6 to 15% CP (DM). "Coastal" - A hybrid superior to common Bermudagrass, but does not produce viable seed. More growth, cold resistant, and resistant to leaf diseases and root-knot nematode. Most extensively produced hay crop in the Deep South. With adequately fertilization & cutting at the proper stage, can make a high quality hay. Contains 7 to 18% CP (DM).

Blood, meal - Coagulated packing house blood that has been dried into a meal. Drying methods include drum, ring, and flash/spray. High in CP (80%+), but may be low in digestibility and quality because of the heat damage during the drying process, and also unpalatable. Contains highly undegradable protein for ruminants.

Blood, plasma - Plasma fraction of blood yields a fine, light tan powder containing 78% CP (spray-dried plasma). High in Lys, Trp, Thr, but low in Met & Ile. Highly digestible & contains an amino acid profile that closely matches the young pig's needs, and may have a positive effect on the immune system of the young pig.

Bluegrass, Kentucky - Long-lived, perennial sod grass with rhizomes & grows 6 to 30 in. tall. Often the earliest growing grass in the spring. Very sensitive to heat and summer drought. Highly palatable and nutritious to all species of livestock. Able to withstand continued heavy grazing. Undesirable as a hay grass because of its low growth, low yield, and maturity before other grasses are ready to cut. Contains 12 to 17% CP (DM).

Brewer's grain, dehydrated - The dried extracted residue of barley malt alone or in mixture with other cereal grain or grain products resulting from the manufacturing of wort. Contains 25 to 27% CP and 14 to 16% crude fiber. Commonly fed to dairy cattle up to about ⅓ of the grain mix. Often included in horse rations but seldom fed to swine or poultry because of the high fiber content.

Brewer's yeast, dehydrated - Dried yeast product (nonfermentative) with a minimum of 35% CP (DM). Contains protein of high quality and high in many B vitamins.

Bromegrass, smooth - Erect, leafy, long-lived, drought-resistant perennial. 2 to 4 ft tall with many underground rootstocks. Used for pasture, hay, silage, and erosion control. Produces abundant herbage in the spring and late summer. Best growth in the second and third year. Quite palatable for all classes of animals. Contains 4 to over 20% CP (DM) depending on maturity and fertilization.

Buckwheat, grain - Originated in Asia & minor crop in the US. A summer annual with rather coarse, branched stems and large, broadly arrow-shaped leaves. Seeds are pointed, broad at the base, and triangular to nearly round in cross section. Japanese buckwheat is most widely grown in the US. Whole buckwheat being used for poultry scratch feed mixtures. The middlings from milling make good livestock feed as they are high in protein.

Canarygrass, Reed - Coarse, vigorous, long-lived perennial 2 to 6 ft tall with leafy, short stems, tending to grow in dense bunches of 2 or 3 ft in diameter. Prefers a moist, cool site and thrives on land too wet for most other grasses. One of the most heat & drought tolerant cool-season grasses. Used mostly as pasture, but increasing hay and silage usage. Has a long growing season and recovers quickly from grazing or mowing. Contains 9 to 13% CP (DM).

Canola, meal - The remaining portion of seeds after removing most of the hull and oil. Contains 35 to 40% CP, 13 to 14% fiber. Lower in palatability, energy and Lys vs SBM. Unprocessed rapeseed contains erucic acid and the enzyme myrosinase - Thyrotoxic or goitrogenic activity. Canola - Cultivars of rapeseed with much lower erucic acid and glucosinolate content. To be called canola, oil must contain less than 5% erucic acid, while the meal must contain less than 3 mg/g of glucosinolates. For young pigs and poultry, 5% of the total diet, whereas 12% for older pigs and poultry. Not palatable to ruminants, but can use up to 10% of the ruminant diet.

Casein, dehydrated - The solid residue obtained by acid or rennin coagulation of defatted milk & dried.

Citrus pulp, dehydrated - Dried residue of citrus family, producing a coarse, flaky product. High in fiber (13%) and low in CP (6 to7%) & P (0.12%). Ca content may be> 2% because of the use of certain Ca compounds for processing. Fed mainly to dairy cattle but may be fed to beef cattle. Generally, < 20 to 25 of the ration.

Ladino clover - A giant, rapid-growing, white clover. Leaves, stems and flower heads grow from two to three times large vs common white clover. Thrives in a temperate climate and favors moist fertile soils. Primarily a grazing crop, but does not withstand close or continuous grazing. Difficult to mow and cure. Hay yields usually quite low. A similar feeding value, but has a higher "carrying" capacity compared to common white clover.

Red clover - Perennial plant normally growing taller than alfalfa but does not have as extensive root development nor productive life. Best suited to regions with abundant rainfall. An important crop in the north central and northeastern regions of the US. Used primarily for hay, and it has a similar nutrient composition to alfalfa except for slightly lower CP (12 to 22%)

Coconut, meal - Also known as Copra meal. Widely grown/distributed in many tropical areas of the world. Residual oil content falls between 9 and 16%, but some may contain > 20%. Its oil composed predominantly of short- and medium-chained fatty acids. Contains about 21%CP and 10% fiber. Deficient in Lys & Met, and generally a poor source of amino acids for nonruminants.

Corn, cobs, ground - A potential feed source where ear corn is harvested. Low in CP (2 to 3%), but useful as an energy source.

Corn, distiller's grain, dehydrated - Obtained by the processing of the residue remaining after removal of the alcohol and some water from a yeast-fermented mash. Made from the dried coarse grain fraction. Contains 25 to 27% CP and 9 to 11% fiber.

Corn, distiller's grain with/solubles -Obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of the grain by condensing & drying at least ¾ of the solids of the resultant whole stillage. Contains 25 to 27% CP.

Corn, distiller's solubles - Obtained after removing ethyl alcohol by distillation from the yeast fermentation of the grain by condensing the thin stillage fraction and drying. Contains 25 to 27% CP & 4% crude fiber.

Corn, gluten feed - Dried residue remaining after removal of the larger portion of the starch, gluten and germ. Contains corn bran, and 20 to 25% CP.

Corn, gluten meal - Dried residue remaining after removal of larger part of starch, germ and bran, and contains 40 to 60% CP.

Corn, grain - Most popular and widely used grain in Midwest. High in energy (80% TDN), thiamin, niacin (bound form for pigs & poultry though!), fair in P & low in Ca, CP (8 to 9%), vitamin D, riboflavin and pantothenic acid. Fed in various forms - air-dried (88 to 90% DM), high-moisture(20 to 34%), and whole ear, i.e., corn-and-cobmeal.

Corn, hominy feed - A mixture of corn bran, corn germ and part of the starchy portion of the grain. Must contain not less than 4% crude fat. Contains 10 to 11% CP. Generally about equal to corn in the feeding value.

Corn, silage - Most popular silage in the US in areas where corn grows well. Excellent for most classes of livestock. Moderate to high energy content, but low in CP (7 to 9%).

Cottonseed, hulls - By-product of oil extraction process. Consists primary of the outer covering of the cottonseed. Contains 4 to 5% CP (DM).

Cottonseed, ground - Feeding whole cottonseed to lactating dairy cattle has become popular in recent years. May increase milk production/milk fat.

Cottonseed, meal, mechanical & solvent extracted - Grown primary in southern US. Removing kernels from hulls & crushed, and then oil is removed via mechanical or solvent extraction. Contains 36 to 41% CP & 61 to 70% TDN. Protein quality is low. Contains gossypol (0.03 to 0.20%), which is toxic to noruminants, especially young pigs & chicks (& also calves), and symptoms are similar to pneumonia, except fluid fluids accumulates in abdominal cavity. Many factors (species, age, dietary components, etc.) affect the toxicity. Should not make up more than 25 to 30% of protein supplement.

Feather meal, hydrolyzed - Pressure-treated, clean undecomposed feather from poultry. Contains 85% CP, and 75% of the CP should be guaranteed digestible. Primarily used in swine and poultry feeds. Low in histidine, lysine, methionine & tryptophan. High bypass protein for ruminant species.

Fescue, Tall - A deeply rooted and strongly tuffed perennial bunchgrass with stems 3 to 4 ft tall. Adapted to moist, deep soils, tolerates moderately high soil salinity, able to survive prolonged winter flooding, but not tolerant of extended drought. Used for pasture and hay, but more widely for pasture, especially winter grazing. Contains 10 to 15% CP (DM). ["Summer toxicosis" due to the formation of a plant endophyte fungus and high plant content of the alkaloid perloline - Reduce palatability and digestibility and cause an increase in body temperature and roughened hair coat of the cattle. Cattle prefer to stand in the shade or in water. Lessened or eliminated by planting a variety of tall fescue, which is resistant to endophyte.]

Fish meal - Consists of whole fish or fish cuttings (by-products) with or without the extraction of part of the oil, dried and ground into a meal. Several types depending on the type of fish used. CP ranges from 35% to 70% depending on type of product (whole fish or cuttings). Excellent protein quality and source of B vitamins. High in the content of Ca and P.

Fish solubles - Evaporated product of the aqueous portion the oil removal process. If dehydrated, contains about 60% CP. If condensed (50% DM), contains about 30% CP. Excellent protein quality and source of B vitamins. Fish protein sources are used primarily in diets for pigs and poultry

Meat meal & Meat and bone meal - By-products of the meat packing industry & also from rendering plants. Consists of unusable animal tissues cooked in steam jacketed kettles. Blood meal is normally not added, and usually does not contain gut, tendon and connective tissue to the extent of tankage. Contains 45 to 55% CP. If more than 4.4% P, must be labeled "meat and bone meal. Mostly used for pigs and poultry.

Milk, skim, dehy - Rsidue obtained by drying defatted milk. Contains less than 8% moisture and about 33% CP.

Millet, grain - Grown primary in Asia & Africa, and there are several different types. "Proso," resembling some sorghums, is sometimes grown in the US. Others include foxtail, pearl, finger millet, etc. Intermediate in feeding value between oats & corn.

Molasses, sugar beet or sugarcane - By-product of the sugar production. Commonly fed in the liquid form (70 to 80% DM). Readily available source of energy, and quite palatable. Often used as a pellet binder and to reduce dustiness. Form the basis for most liquid protein supplement containing urea. Should not use more than 10% of the replacement value of corn in livestock diets. Most commonly fed to ruminants or horses at 3 to 7% of the diet.

Oats, grain - Widely grown, but most common in Midwestern and North Central states. Contains 65 to 70% TDN and 12% CP. Quite palatable and 85% feeding value of corn for most species. Limit in beef finishing ration and pig & poultry diets because of high fiber (11%) & low energy. Excellent grain for horses to provide bulk.

Oats, groats - Kernels produced from cleaned and dried oats with the hull removed. Contain 16 to 17% CP and only about 3% crude fiber. Approximately equal to corn in feeding value, but too expensive for general livestock feeding. May be used in special diets such as early weaning diets for pigs.

Oats, hulls - By-product of oat groats. Consists primarily of the outer covering of the oat. Contain 5 to 6% CP and 26 to 28% crude fiber.

Oats, straw - What remains after harvesting the grain. Used commonly for bedding than for feeding because of low feeding value (2 to 5% CP).

Orchardgrass - Long-lived perennial that forms dense circular bunches. Commonly grows in clumps 2 to 4 ft tall. Shade tolerant, moderately heat and cold resistant and establishes a stand rapidly. Starts growth early in the spring, and new, immature growth is highly palatable. Grows and matures rapidly & palatability and nutritive value decline as matures. Generally recognized as superior to smooth bromegrass as a deterrent to bloat when used in mixtures with alfalfa. Contains 8 to 18% CP (DM).

Pea, seeds - A number of different species usually grown for humans, but may become available for animal feeding. Contain 20 to 28% CP. Deficient in S-amino acids & Trp?

Peanut meal, mechanical or solvent extracted - Consists of fat-extracted kernels ground, with some ground peanut hulls added. Contents vary, but 40 to 48% CP & 6 to 13% fiber. Poor amino acid balance & limiting in Lys & Met. May contain certain aflatoxins. For pigs and poultry, can replace 5 to 10% of the diet or 30 to 50% of SBM. For ruminants, equal to SBM in feeding value.

Poultry byproduct meal - Made from ground, dry-rendered or wet-rendered parts of the carcass, i.e., heads, feet, undeveloped eggs & intestines, but no feathers. Must not contain more than 16% ash. Contains 55 to 65% CP.

Rice, bran - Consists primarily of the seed coat and germ removed from polished rice production. Contains 13 to 15% CP & 12% crude fiber. Comparable to wheat bran in the feeding value, even though lower in CP. Some fed to dairy cattle or used as a carrier in feed additive premixes.

Rice, grain/groats - Not normally used as a feed grain, but occasionally, rough rice (unmilled) may become available for animals. Contains about 8% CP, 9% fiber, and 1.7% ether extract.

Rice, hulls - By-product from polished rice production, and consists primary of the outer covering of the rice. Contains 3 to 4% CP (DM).

Rye, grain - Least palatable of the grains, and may be contaminated with ergot (black fungus - reduces palatability, causes abortion & reduces blood supply to extremities, resulting in necrosis). Contains 75% TDN & 12% CP. Tend to cause digestive disturbances if ground too fine & should not make up more than ⅓ of the diet.

Ryegrass, Perennial - Short-lived, rapid-growing, leafy perennial that ordinarily attains a height of 1 to 2 ft. On poor soils, the grass lives only 2 yr, and when seeded in hay mixtures, perennial ryegrass will disappear after the first year. Serves as a temporary covering. Contains 6 to 13% CP (DM).

Safflower, meal, solvent extracted, with and without hulls - Produced by extracting oil from dehulled safflower seeds. Generally, less palatable vs other oil meals. CP & fiber contents are 23 & 30%, respectively, for undecorticated meal, and 42 & 15%, respectively, for dcorticated meal. Lys is the first limiting amino acid, & also limiting in S-amino acids. Not more than 30% of SBM for pig diets. Similar value for ruminants?

Sesame, meal, mechanically extracted - By-product of extracting oil from the sesame seed. On the average, contains 42% CP & 6.5% fiber for dehulled meal. Low in Lys, but a good source of in Met, Cys, Trp, Ca, P, Mg & others. Can be used in limited amounts in nonruminant diets.

Sorghum, grain - Quite drought resistant and grown in those areas inadequate in rainfall for corn production. Somewhat lower in energy than corn (75 to 78% TDN) and 95 to 98% feeding value of corn for poultry and pigs and 85 to 90% for cattle and sheep. Higher but more variable in CP (8 to 12%) than corn. Must be processed for maximum digestibility.

Soybean, hulls - Consist primary the outer covering of the soybeans. Contain digestible fiber even for nonruminant species. Urea solution absorbed soy hulls seems to be a satisfactory means of feeding dairy cows.

Soybean, meal, solvent extracted & without hulls - The residue of soy oil extraction, and the most widely used oilseed meal in the US. Must be heated to destroy anti-nutritional factors, and standardized to 44 (with hulls) to 48-50% (without hulls) by dilution with hulls. Most common & most complete amino acid source used to supplement or balance the amino acid deficiencies in grains. Properly processed SBM = standard protein source!?

Soybean, protein concentrate - Produced from dehulled and oil-extracted soybeans and leached with water to remove most of the water-soluble nonprotein constituents. Contains about 70% CP.

Soybean, seeds, heat processed - Properly processed soybeans can be used in place of SBM in pig diets. Contain 37 to 38% CP, 17 to 18% fat, and 84 to 92%TDN. Improve feed efficiency because of the fat content.

Sunflower, meal without hulls - Produced from oil extracted, dehulled sunflower seeds. Wide range in CP (32 to 45%?) and fiber (11 to 24%) depending on the oil extraction method and the amount of hulls removed. Rich source of B-complex vitamins. Limiting in Lys and energy vs SBM. Replace 30 to 50 of SBM in pig and poultry diets? Similar to other protein sources for most ruminant species.

Timothy - Perennial bunchgrass, 2 to 3½ ft tall, with a swollen or bulblike base but without rhizomes. Primarily a hay plant and does not stand heavy grazing. When grown in mixtures with clover or alfalfa, the first growth frequently is harvested for hay and the later after growth pastured. Especially popular as a hay for horses and should be cut no later than the early bloom stage for maximum nutrient value. Contains 8 to 12% CP (DM).

Triticale, grain - Hybrid derived from a cross of wheat and rye. Lower test weight and yield than either wheat or rye. Contains 78% TDN and 15% CP. Unpalatable and may contain ergot similar to rye.

Urea - Not a protein supplement, but a source of N (42 to 45% N) for protein synthesis by rumen bacteria (1lb of urea = 2.62 to 2.81 lb protein, or 262 to 281% CP). Works well in mixtures with plant proteins to lower protein cost (1 lb of urea & 6 lb of corn to replace 7 lb of SBM). General rules - No more than: a) ⅓ of N in ration, b) 1% of diet or 3% of concentrate mix, c) 10 to 15% of a typical protein supplement, and d) 5% of a supplement to be used with low-quality forages.

Wheat, bran - Coarse outer coating of the kernel containing 15 to 17% CP and 9 to 11 % CF. Included in swine farrowing diets or in diets of horses or cattle used for show because of its bulky and mild laxative properties. Generally limited to 10% to 15% of the diet.

Wheat, grain - Widely grown in US, but too expensive for livestock? Contains 80% TDN and 12 to 14% CP, and 105% feeding value vs corn in limited amount to pigs and cattle (not > 50%).

Wheat, middlings - Consists of the fine particles of wheat bran, wheat shorts, wheat germ, wheat flour and some of the offal from the tail of the mill. Contain 16 to 18% CP and must contain not more than 9.5% crude fiber. Most commonly used in pig diets because the fine particle size of middlings makes them unpalatable to ruminants.

Wheat, red dog - Consists of mill tailings together with some fine particles of bran, germ and flour. More floury particles than any other millfeed, and appearance is much like greyish flour flecked with small brown bran particles.

Wheat, shorts Consists of the same components as wheat middlings, but should not contain more than 7% crude fiber.

Whey, dehydrated - Whey is a fluid obtained by separating the coagulum from milk, cream, or skim milk in the manufacturing of cheese. Contains less than 10% DM and 1% CP. Dried product contains at least 11% CP and 61% lactose.

Yeast, Torula, dehydrated - Dried yeast (*Torulopsis* spp.) containing a minimum of 40% CP. Protein is of high quality and rich in most B vitamins.

FEED ADDITIVES

☛ *For additional info, please see Kellems and Church (1998) and(or) Jurgens (2002).*

1. Common Additives

A. Antibiotics - Compounds synthesized by living organisms that can inhibit the growth of other microorganisms. Two types (mostly derived from bacteria and molds):

1) Broad spectrum - Effective against both Gram positive and negative bacteria; e.g., Aureomycin (chlortetracycline) & Terramycin (oxytetracycline).
2) Narrow spectrum - Effective against Gram positive or negative (e.g., Tylosin & Penicillin).
3) Some examples:

Bacitracin methylene disalicylate	Chicken, swine, turkey
Bacitracin, zinc	Cattle, chicken, swine, turkey
Bambermycins	Chicken, swine, turkey, cattle
Chlortetracycline	Cattle, chicken, horse, sheep, swine, turkey
Laidlomycin	Cattle
Lasalocid	Cattle, sheep
Lincomycin	Chicken
Oxytetracycline	Cattle, chicken, sheep, swine, turkey
Penicillin	Chicken, swine, turkey
Tylosin	Chicken, swine
Virginiamycin	Chicken, swine, cattle

B. Chemotherapeutics (or chemobiotics):

1) Bacteriostatic/bactericidal compounds - Unlike antibiotics, produced chemically.
2) e.g., Sulfa compounds for swine, copper sulfate for chickens & swine, arsanilic acid for poultry & swine, carbadox for swine, and roxarsone for poultry.

C. Combinations - A combination of antibiotic(s) and chemobiotic(s) such as CSP 250, ASP 250 & Tylan Sulfa-G.

D. Probiotics - Bacteria, yeasts or a combination (e.g., live yeast cultures, lactobacillus sp., sarsaponin, etc.), which may competitively inhibit the development of undesirable microorganisms and(or) favor the development of desirable microorganisms.

E. Anthelmintics or dewormers - Examples include:

Dichlorvos (Atgard)	Swine
Fenbendazole (Safe-Guard)	Swine, cattle
Hygromycin B (Hygromix)	Chicken, swine
Ivermectin (lvomec)	Swine
Levamisole hydrochloride (Tramisol)	Cattle, swine
Morantel tartrate (Rumatel)	Cattle
Pyrantel tartrate (Banminth)	Swine

F. Coccidiostats - Prevent and treat coccidiosis (infectious diseases caused by protozoan parasites that attack the epithelial tissues of animals . . . rarely, man), and examples include:

Amprolium	Cattle, chicken, turkey
Clopidol	Chicken, turkey
Decoquinate	Cattle, chicken
Halofuginone hydrombromide	Chicken, turkey
Lasalocid	Chicken, sheep, turkey
Monensin	Chicken, cattle, turkey
Nicarbazin	Chicken
Narasin	Chicken
Robenidine hydrochloride	Chicken
Salinomycin	Chicken
Sulfadimethoxine and ormetoprim 5:3	Chicken, turkey
Zoalene	Chicken, turkey

G. Others?

1) Buffers and neutralizers - e.g., Sodium or potassium bicarbonate, Ca or Mg carbonate, Mg oxide, and sodium bentonite.
2) Antioxidants - e.g., Butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), ethoxyquin, and vitamin E.
3) Chemical preservatives - e.g., Ascorbic acid, Ca sorbate, citric acid, phosphoric acid, propionic acid, Na propionate, propylene glycol, etc.
4) Pellet-binding agents - e.g., Bentonite, ball clay, lignin sulfonate, molasses, etc.

2. Antibiotics & Growth Promoting Activity

A. Responses (e.g., in pigs):

1) Age: (Summary of 937 studies with 20,472 pigs; Peo, 1986. Proc. NE Whole Hog Days)

Item	Control	Antibiotics	% ↑
Starter (15-57 lb):			
ADG, lb	0.86	1.01	16
Feed:gain	2.32	2.16	7
Grower (37-108 lb):			
ADG, lb	1.30	1.45	11
Feed:gain	2.91	2.78	5
Grower-finisher (44-189):			
ADG, lb	1.50	1.56	4
Feed:gain	3.37	3.30	2

2) Experiment station vs. commercial production unit: (Data based on 12,000 pigs; Peo, 1986. Proc. NE Whole Hog Days)

Item	Exp.	ADG (% ↑)	F:G (% ↑)
Exp. Station	128	16.9	7.0
Commercial Prod. Unit	32	28.4	14.5
Average		*19.2*	*8.5*

3) Antibiotics & reproductive performance: (Cromwell, 1986. Univ. of Kentucky)

Item	Antibiotics (1963-1972)	No antibiotics (1972-1984)
Conception rate, %	91.4	82.6
No. pig born	10.8	10.2
No. pigs weaned	8.8	7.5
Survival rate, %	89.7	80.9
Incidence of MMA, %	< 10	66

B. Mode of action?

1) Metabolic effect:

a) Directly affect the rate or pattern of metabolic processes.
b) Bacteriostatic or bactericidal effects. (Metabolism is likely to be affected by systemic infections.)

2) Nutrient-sparing effect - May stimulate the growth of desirable microorganisms that synthesize vitamins and(or) amino acids.
3) Disease-control effect - Can suppress organisms that cause clinical or subclinical manifestation of diseases.

C. Drug resistance:

1) Resistance?

a) For every 10-mil bacteria, usually one is resistant to a particular antibiotic.
b) With continuous use of the same antibiotic, the majority of bacteria will be inhibited or killed, but the "resistant" bacteria will multiply rapidly.
☛ Equally applicable to domestic species, humans, etc.!

2) Two types of resistance:

a) "Mutational" - Being passed on to daughter cells only.

b) "Transferable" - Has a R factor or resistance factor, which can be transferred to other bacteria of the same or different types.

3) Questions/problems?

a) Are antibiotics still effective in animals? - Similar responses to antibiotics, ∴ still effective (Table)!

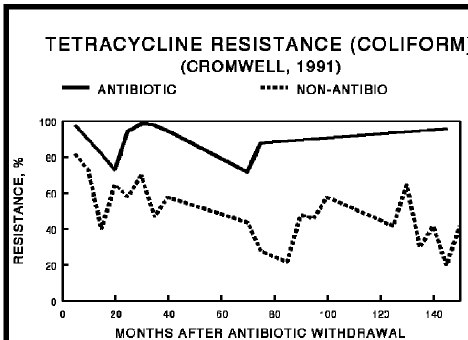
b) Can R factors from normal bacteria be transferred to pathogenic bacteria such as salmonella? Can be, but very rarely, and disease-causing capability is ↓ considerably when they are transferred!

c) Can the resistant pathogen be passed on to humans? (If so, antibiotics are no longer effective in treating humans, and drugs of the greatest concern are penicillin and tetracycline!) - Resistant bacteria are unable to establish themselves in the GI tract of human volunteers, so . . .

Percentage improvement by using antibiotics: (Cromwell, 1986. Univ. of Kentucky)

	1950-77	1978-85
ADG	16.1	15.0
Feed:gain	6.9	6.5

4) Resistant fecal coliforms in pigs - See a figure [Cromwell, 1991. In: Miller et al. (Ed.). Swine Nutrition. Butterworth-Heinemann, Boston]



☛ **The Bottom Line?**

a) Antibiotics are still effective!

b) Not likely to transfer the resistance from animals to humans! (But, theoretically possible! Thus, continues to be a subject of concern!)

c) Discontinuing their use may have little impact on antibacterial resistance!

3. **Additives and Residues**

☛ Many feed additives must be withdrawn from feeds to ensure residue-free carcasses, and withdrawal periods before slaughter vary among additives.

☛ The main concern is "sulfa residues!"

A. Reasons for concern (sulfa):

1) Some people are hypersensitive to sulfa. Can develop allergic reactions, and some people show reactions to undetectable levels (. . . fortunately, very small percentage of population)!

2) Sulfamethazine may cause cancer in the thyroid of rodents, which was reported by a group of researchers in 1988 . . . but:

a) Their findings have been refuted by many toxicologists during the FDA hearing.
b) The amount of sulfonamide consumed through meat/pork is unlikely to cause problem. Example - The total from consumption of one pork chop containing 0.1 ppm/day for 80 years equals one daily dose of human sulfonamide medication that has no adverse effect on human thyroid!

B. Tolerance level: (FDA)

1) "0.1 ppm" in muscle, liver or kidney - Established based on a long-term toxicology study, and it provides at least a 2,000-fold safety margin for humans!
2) Incidence of violations in pork liver (Tables).

Incidence of violations in pork liver:
(Cromwell, 1986. Univ. of Kentucky)

Year	% viol.	Year	% viol.
1970's	>15	1981	6.0
1977	13.2	1982	4.3
1978	9.7	1983	8.0
1979	6.3	1984	5.9
1980	4.5	1985	5.4

& More recent data on "Sulfa-on-Site (SOS)" surveillance of market pigs: [Large Anim. Vet. 50(4):10 (1995)]

1988 - 0.28%	1991 - 0.20%
1989 - 0.44%	1992 - 0.21%
1990 - 0.26%	1993 - 0.10%

C. Prevention check list:

1) Always read and follow directions, i.e., use proper dosage and follow withdrawal times & keep records! Don't rely on the memory!
2) Use part of other ingredients as a carrier for uniform mixing, and mix diets in proper sequence & flush the mixer - e.g., medicated feed → non-medicated feed for non-marketable animals → withdrawal feed.
3) Use only a granulated, not a powdered form!
4) Restrict its use to starter diets.
5) Clean everything regularly - Mixing equipment and rooms, transporting equipment (feed and pigs), holding bins, etc.
6) Avoid the use of feeders for both medicated and non-medicated feed. Just one mouthful can result in a tissue concentration that can violate!
7) Do not mix pigs receiving diets with sulfa with market hogs.
8) After sulfa withdrawal, move pigs to clean pens, and clean pens thoroughly 3 to 4 consecutive days.

ANALYSIS OF FEED INGREDIENTS AND DIETS

- *Reference: Kellems and Church (1998) & Jurgens (2002).*
- Also, see appropriate sections for additional information on the analysis of feedstuffs and(or) diets.

1. Analysis for the Composition of Nutrients

A. Feed ingredients/diets can be analyzed for nutrients using some direct analytical methods.
B. Three general analytical methods:

1) Chemical procedures - Gravimetric procedures, titration, calorimetry, chromatography, etc.
2) Biological procedures - Use animals (e.g., chick or rat) to assess the value . . . more tedious & expensive.
3) Microbiological procedures - Similar to biological procedures but use isolated bacteria or other microorganisms.

2. **Samples for Analysis?**

A. The most important factor in evaluating feeds? Obtaining a "representative sample" is as important as the accuracy of the analysis in obtaining reliable results!
B. Sampling - Recommendations for obtaining representative samples?

1) Grains or mixed feeds

a) Sacked feeds - Take two samples (a handful) each from 5 to 7 different sacks.
b) Bulk feeds or grain in bins - Take 12 to 15 samples from a given lot (. . . samples should be as widely separated as possible).
c) Samples should be mixed in a clean container, and take a 1- to 2-lb random subsample.

2) Hay

a) Should us a drill-type core sampler for maximum reliability.
b) Take 12 to 15 separated samples from each lot. One/per bale if baled.
c) If a core sampler is not available, take at least ten "grab" samples.
d) Mix core or grab samples (. . . cut to 1- to 2-in lengths) in a clean container (stems & leaves should not be separated) and take a random subsample.

3) Haylage or silage

a) Upright silos - Can be collected during the feeding period while the unloader is in operation, and collect the sample in the cart/similar feeding unit if hand feeding.
b) Pit or bunker silos - Take 4 to 5 grab samples from the freshly opened ones.
c) Do not collect spoiled sample unless mixing thoroughly so that animals would not separate it.
d) Approximately 1 to 2 lb should be collected each day for 2 to 4 days.
e) Samples should be frozen immediately after collection to prevent bacterial fermentation and moisture loss.
f) Mixed thoroughly in a clean container and take a random subsample.

4) Harvest sampling

a) Many times, more convenient and reliable to obtain samples during harvest.

b) Sampling procedures would be the same.

2. **Proximate Analysis**

A. Different fractions that result from the proximate analysis include: water, ash, crude protein, ether extract, crude fiber, and nitrogen-free extract (NFE).
B. Most widely used chemical scheme for describing feedstuffs, even though the information may not be useful in terms of nutrition for animals, or, even, misleading sometimes.
C. Proximate analysis

1) Dry matter:

a) Heat samples to a constant weight at a temperature above the boiling point of water (100-105°C) - Loss in weight = loss in water (100 - H_2O = % DM).
b) Source of error? - Loss of materials via volatilization & some liquids may be oxidized?

2) Ash (minerals):

a) Burn samples by placing a weighed amount in a muffle furnace for 2 hr at 600°C. Ash is considered as the remaining dry inorganic residues.
b) High temperature may alter forms of some minerals, and may even volatilize some, such as chlorine, zinc, selenium, and iodine.

3) Crude protein (Kjeldahl process):

a) Digest samples in concentrated sulfuric acid until all organic matter is destroyed. The N exits in the form of ammonium sulfate.
b) Neutralize digesta with sodium hydroxide and distilled, driving the ammonia over into standard acid, and titrated.
c) The procedure determines the amount of N in the sample, and total N x 6.25 = crude protein (. . . proteins contain an average of 16% N).
d) Does not distinguish one form of N from another, thus cannot tell true protein/ amino acids vs. other non-protein N.

4) Ether extract (fat):

a) Extract samples with ether for a period of 4 hr or more. Removes the fat, thus the loss of weight after drying/evaporation of ether = fat.
b) Includes any ether-soluble compounds, including some non-nutritive compounds such as chlorophyll, volatile oils, resins, pigments, and plant waxes (which are of little value to animals) as "fat."

5) Carbohydrates (CHO):

a) Not determined by the analysis as such. CH_2O = CF + NFE.
b) Crude fiber (CF):

(1) After removal of water & ether extract, the sample is boiled in weak acid (0.255 N H_2SO_4) and then in weak alkali (0.312 N NaOH). Removes the proteins, sugars, and starches, which are discarded.
(2) Cellulose, lignin, and mineral matters are left in the residue. Dried and weighed, then burped in a muffle furnace at 600°C, and the loss in the weight is reported as crude fiber.
(3) Consists mainly of hemicellulose, cellulose, and some insoluble lignin.

c) Nitrogen-free extract (NFE):

(1) Estimated by the difference, not by the actual analysis.
(2) Add % water, ash, protein, fiber, and fat, and subtracted from 100.
(3) Made up primarily of readily available CH_2O, such as sugars and starches, but may contain some hemicellulose and lignin, particularly in forages.

3. **Method of Forage Evaluation**

A. Proximate analysis:

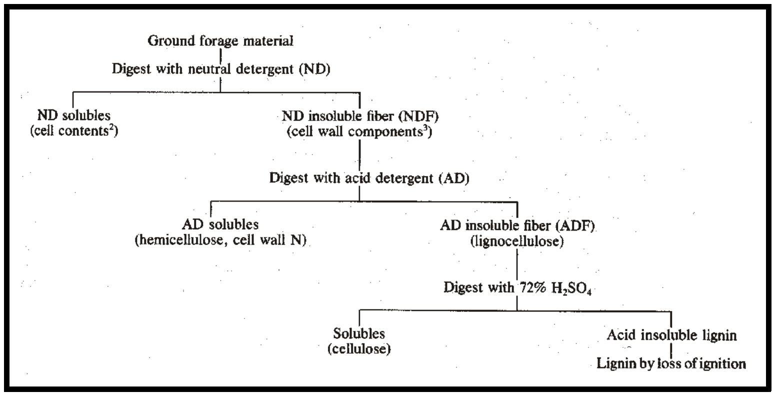
1) Served for many years and continues to serve a useful purpose in predicting the nutritive value of feeds.
2) But, there are some definite limitations of the system, especially with the crude fiber and NFE fractions:

a) The material that was dissolved by the solvents (NFE) was assumed to be digestible, and the residue (crude fiber) was assumed to be indigestible.
b) But, some studies showed that, in some cases, crude fiber was more digestible than the NFE fraction.

3) Thus, predicting the nutritive value from the proximate analysis may not be reliable, especially for those with more fibrous components.
4) Over the years, numerous methods/procedures that may provide a more definitive separation of the carbohydrate portion than does the proximate analysis have been evaluated.

B To develop a chemical procedure that fractionates forages into relatively digestible and indigestible portions, Van Soest (1967. JAS 26:119) proposed the extraction scheme - See the figure (Jurgens, 2002):

1) Cell contents - Sugar, starch, soluble carbohydrates, pectin, NPN, lipids, miscellaneous vitamins, etc.



2) Cell wall components - Cellulose, hemicellulose, lignin, silica, heat-damaged protein.
3) Nutritional value for animals?

   a) Soluble in neutral detergent - Completely digested by the ruminant.
   b) Fraction insoluble in neutral detergent - Low but variable availability depending upon the species of plant and its stage of maturity.
   c) A similar statement can be made for the acid detergent fiber and cellulose.
   d) Lignin is indigestible.

4. **Near Infrared Reflectance Spectroscopy**

A. Development of near infrared reflectance spectroscopy (NIRS) technology? - Very useful in assessing the forage quality.
B. A rapid and reproducible determination of the chemical composition of samples with little or no sample preparation.
C. Distinguish one another based on the fact that each of the major chemical components of a sample has near infrared absorption properties.
D. In the near infrared range, absorption occurs primarily as a result of vibrations of light-weight atoms that have strong molecular bonds.
E. The vibration frequency is low and will not be detected in the near infrared range when there are weak chemical bonds, or heavy atoms:

   1) Thus, NIR is primarily limited to chemical bonds containing hydrogen attached to atoms such as nitrogen, carbon, or oxygen.
   2) Consequently, the detection of minerals is poor unless the mineral exists in association with some organic constituent.

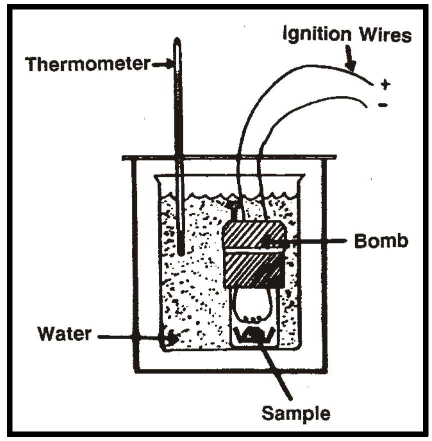
G. Advantages over the more traditional wet-lab procedures? - Speed (typical time ranging from 30 sec. to 3 min.), simplicity of sample preparation (only grinding?), no portion of the sample is consumed by the procedure, and ability to analyze multiple components in one operation.
H. Disadvantages? - Require a high-precision instrument, dependence on calibration procedures, and inability to measure minor constituents.

5. **Determination of Vitamins**

A. Because of the diversity of compounds, no routine analysis for vitamins, even though methods are available for assaying individual vitamins.
B. Biological assays are used for some, whereas the chemical analysis is used for others.

6. **Determination of Gross Energy**

A. Use the bomb calorimeter (see the figure: Jurgens, 2002) to determine the gross energy of a sample (solid, liquid, or gas):



1) Determine the energy value by burning it in an atmosphere of oxygen.
2) Liberated heat increases the temperature of water surrounding the container (which contains the sample) when the sample is burned.
3) The increased temperature provides the basis for calculating the energy value.

B The energy value is expressed in units called calories where 1 calorie = the amount of heat required to raise the temperature of 1 g of water from 14.5 to 15.5°C.

PROCESSING OF FEED INGREDIENTS AND(OR) DIETS

• *May want to see Kellems and Church (1998), which include a section on "Feed Preparation and Processing."*

1. **Processing in General**

A. Purposes? To alter the physical form or particle size, prevent spoilage, improve palatability, increase surface area, obtain a uniform mixture of various ingredients, avoid sorting by animals, increase digestibility by subjecting to pre-digestion (e.g., heat processing), etc.
B. Feed processing may involve mechanical, chemical, and(or) thermal methods, and also microbial fermentation may be involved.
C. As the level of production and feeding increases: (Kellems & Church, 1998)

1) Feed preparation/processing method may become more important.
2) Heavily fed animals become more selective and tend to sort out less palatable ingredients, or refuse and(or) waste feed.

2. **Common Processing Methods for Grains**

A. Cold processing:

1) Grinding - Hammer mills

a) The most common method, and perhaps the cheapest and most simple?
b) The size can be controlled by changing a screen size.
c) For nonruminants? - Fine (1/8- to 3/16-in screen or smaller), medium (¼- to ⅜-in screen) or coarse, with medium being the best? Depending the grain though!
d) For ruminants? - Perhaps, prefer coarsely ground grains because they don't like finely ground meals, especially, dusty meals.

2) Rolling/cracking - Produce smaller particles by compressing it between two corrugated rolls (less dusty feed vs. a hammer mill), and the physical texture is acceptable to many species.
3) Soaking, reconstitution, and high-moisture grain

a) Soaking for 12 to 24 hr can soften the grain (swells during the process) and make a palatable product. But, no advantage in performance? Also, some problems (storage space, souring/fermentation, etc.) have discouraged a large-scale use.
b) Reconstitution - Similar to soaking, and add water to dry grain to increase the moisture content to 25 to 30% and store the wet grain in an oxygen-limiting silo for 14 to 21 d prior to feeding. Improve performance in beef cattle, but the storage might be the major problem?
c) Harvest grain at high-moisture content (20 to 35%) and store in silo (or under plastic) to preserve the grain. A proper storage or chemical treatment (e.g., 1 to 1.5% of organic acid/mixture) is must to avoid heat & mold if weather is not cold.

B. Hot processing methods

1) Steam-rolling and steam-flaking

a) Steam-rolling - Grains are subjected to steam for a short period (3 to 5 min - just enough to soften the seed, but no modification of the starch granule) before rolling. Improve animal performance.
b) Steam-flaking - Similar to steam-rolling, but the grain is subjected to high-moisture steam for a longer time 15 to 30 min (. . . rupture of starch granules). Similar animal performance vs. steam-rolled grains?

2) Pelleting

a) By grinding feed and then forcing it through a thick, spinning die with the use of rollers, which compress the feed into holes in the pellet die.
b) Can be made in different diameters, length, and hardness, and all domestic animals generally like the physical nature of pellets.

3) Extruding

a) By passing the feed through a machine with a spiral screw that forces the feed through a tapered head.
b) Feed is ground, heated, and extended, producing a ribbonlike product.
c) Being used to process whole soybean seeds or other oil seeds. Heating is enough to destroy anti-nutritional factors in soybean & others.

4) Popping, micronizing, and roasting

a) Popping - Dry heat causing a sudden expansion that ruptures the endosperm of the grain. Usually rolled before feeding to reduce its bulkiness.
b) Micronizing - Essentially the same as popping, except heat is provided in the form of infrared energy.
c) Roasting - By passing the grain through a flame, resulting in heating and some expansion of the grain.

☛ Cost of equipment & also maintenance difficulties . . . !?

C. Effect of Processing on Performance (e.g., in pigs)

1) Ground cereal grains & pig performance: [Modified the data compiled by Lawrence, 1985. In: Cole & Haresign (Ed.) Recent Developments in Pig Nutrition]

Grain	Whole grain	Coarse ground	Medium ground	Fine ground	Rolled
Barley:					
Weight gain, kg/d	0.52	0.64	0.65	0.66	0.66
Feed:gain	3.98	3.19	3.17	3.14	3.10
Oats:					
Weight gain, kg/d		0.48	0.57	0.73	
Feed:gain		4.60	4.10	3.60	
Maize:					
Weight gain, kg/d	0.56		0.63		
Feed (DM):gain	2.94		2.63		
Sorghum:					
Weight gain, kg/d	0.81		0.85		
Feed:gain	4.01		3.72		

2) Effects of steam-flaking on starch digestion (%): (Osman et al., 1970. J. Nutr. 100:1133)

Processing	Barley	Milo
Untreated	22.7	16.0
Steamed, not flaked	18.4	11.7
Poorly flaked	26.5	14.4
Intermediately flaked	36.8	31.3
Flat flaked	51.2	41.0

3) Effects of popping & micronizing: (Adapted from Aumaitre, 1976. Journées Rech. Porcine Fr. 211 & Lawrence, 1973a,b. Anim. Prod. 16:99 & 16:109)

Item	Corn	Barley	Wheat
Dry matter, %			
Control	86	78	
Popped	88	79	
Dry matter, %			
Ground	86.9	79.7	
Micronized	86.5	80.9	
Gain to 90 kg, kg/d			
Ground	0.76	0.73	0.75
Micronized	0.83	0.77	0.78
Efficiency, kg DM/kg gain			
Ground	2.17	2.36	2.17
Micronized	2.04	2.25	2.23

4) Effects of pelleting: (% improvement or the No. of papers reported a positive response)

Reference/ criterion	% improvement or No. of papers
Vanschoubroek et al., 1971. (Nutr. Abstr. Rev. 41:1):	
Growth rate	+ 6.6%
Efficiency	+ 7.9%
Feed intake	- 2.1%
Braude, 1972. [57 published papers; In: Cole (Ed.) Pig Production]:	
Improved growth rate	38 papers
Improved efficiency	48 papers

3. Common Processing Methods for Roughage

A. Bailing - Still one of the most common methods of handling roughage, and large bales are becoming more common.
B. Chopping or grinding - Provide more uniform product & can reduce feed refusal and wastage. But, additional expense of grinding and loss of dust may be substantial?!
C. Pelleting - Usually consumed readily by ruminants, horses, and rabbits, and improve animal performance more with "low-quality" roughage. Some must be ground first, and the cost of processing is a bigger item vs. other methods.
D. Cubing - Hay is forced through dies that produce a square product (about 3 cm in size) of varying lengths & hardness. Often used for dairy cattle.
E. Dried/dehydrated, e.g., alfalfa - A substantial amount of alfalfa meal is produced. The cost is relatively high, thus used in limited amounts in pig or poultry diets as a source of carotene, vitamins, etc.

F. Effect of processing on performance?

1) Effect of processing of alfalfa hay on performance of growing-finishing cattle:

Item Gain, kg/d	DM, kg/d	Feed:gain	
Alfalfa hay (Webb & Cmarik, 1957. Univ. of IL Rep. 15-40-329)			
Baled	0.29	4.31	15.1
Chopped	0.28	4.22	15.1
Pelleted	0.78	6.49	8.3
Alfalfa hay (25 Kercher et al., 1971. Proc. W. Sec. ASAS 22:33)			
Baled	0.67	6.14	9.1
Cubed	0.86	6.65	7.8
Haylage	0.77	6.79	8.9

2) Effect of processing on feedlot performance of lambs

Item	Gain, g/d	Feed, kg/d	Feed:gain
Alfalfa (Weir et al., 1959. JAS 18:805)			
Chopped	136	1.41	10.31
Pelleted	177	1.68	9.43
Chopped + 30% barley	141	1.27	9.16
Pelleted + 30% barley	163	1.45	8.97
Alfalfa hay:Corn (50:50) (Fontenot & Hopkins, 1965. JAS 24:62)			
Long hay			
Ground corn	141	1.30	9.18
Pelleted corn	145	1.25	8.54
Ground hay			
Ground corn	145	1.34	9.38
Pelleted corn	154	1.20	7.79
Pelleted hay			
Ground corn	177	1.42	8.02
Pelleted corn	177	1.37	7.83
Pelleted complete ration	186	1.43	7.88
Pelleted complete, then ground	168	1.39	8.36

COMPOSITION OF COMMON FEED INGREDIENTS

- *References: Mostly based on Jurgens (2002), but others based on NRC publications (1994, 1998, 2000). For details/additional info, please see Jurgens (2002) or NRC (1994, 1998, 2000) using International Feed Name or Number (IFN) as a guide.*
- Abbreviations for Feed Ingredient Name/Description: **dehy** = dehydrated; **w/** = with; **DG** = distiller's grains; **mech ext** = mechanically extracted; **sol ext** = solvent extracted; **by-pro** = by-product; **rend** = rendered; **wo/** = without; **prot conc** = protein concentrate; **heat proc** = heat processed.
- Dash ("-") indicates no available data.

☛ **Each ingredient has 2 sets of values:** ***Top = On an "as-fed" basis!***
Second = On a "DM" or 100% DM basis!

1. **Table 1. General Nutrients** {DM = dry matter; CP = crude protein; RUP = ruminal undegradable protein [NRC, 2000 or 2001 (with forage = 25% DM intake); Ones in parentheses - Based on Kellems & Church (1998) & values for unknown IFN]; ADF = acid detergent fiber; NDF = neutral detergent fiber}

Ingredient name/ description & IFN	DM, %	CP %	RUP %	Cellulose, %	Crude fiber, %	Ether extract, %	Ash, %	ADF, %	NDF, %
1. Alfalfa, fresh	26.0	5.3		-	6.0	1.0	2.5	-	-
2-00-196	100.0	20.5	-	-	23.0	3.8	9.5	-	-
2. Alfalfa, hay	91.0	17.0		23.1	25.5	3.3	7.8	33.6	42.0
1-00-063	100.0	18.7	(28)	25.4	28.0	3.6	8.5	36.9	46.0
3. Alfalfa, dehy 17% CP	91.8	17.4		-	24.0	2.8	9.8	31.5	41.0
1-00-023	100.0	18.9	59	-	26.2	3.0	10.6	34.3	45.0
4. Alfalfa, dehy 20% CP	91.6	20.3		-	20.8	3.3	10.2	27.0	38.0
1-00-024	100.0	22.1	-	-	22.7	3.6	11.2	29.4	42.0
5. Bakery, waste, dehy	91.2	10.1		-	1.3	10.9	3.7	1.6	16.0
4-00-466	100.0	11.1	18	-	1.4	11.9	4.0	1.8	18.0
6. Barley, grain	88.6	11.5		5.2	4.9	1.8	2.4	7.7	17.0
4-00-549	100.0	13.0	27	5.9	5.6	2.0	2.7	8.7	19.0
7. Barley, straw	91.4	4.0		34.1	37.9	1.7	6.7	42.2	73.0
1-00-498	100.0	4.4	25	37.3	41.5	1.9	7.3	46.2	80.0
8. Beet pulp, dehy	91.0	8.9		18.3	18.2	0.5	4.9	25.0	49.0
4-00-669	100.0	9.8	45	20.1	20.0	0.6	5.3	27.5	54.0
9. Bermudagrass, fresh	28.9	4.2		8.1	7.7	0.6	3.3	9.1	-
2-00-712	100.0	14.6	-	28.0	26.6	2.0	11.4	31.4	-
10. Bermudagrass, hay	91.2	9.4		29.4	28.5	2.0	7.9	35.7	69.0
1-00-703	100.0	10.3	-	32.3	31.3	2.1	8.7	39.1	76.0
11. Blood, meal, spray dried	92.6	87.7		-	1.0	0.7	2.3	-	-
5-00-381	100.0	94.7	(82)	-	1.1	0.8	2.5	-	-
12. Blood, plasma	91.0	78.0		-	-	2.0	-	-	-
(NRC, 1998)									
13. Bluegrass, fresh	30.8	5.4		-	7.8	1.1	2.9	9.0	17.0
2-00-777	100.0	17.4	-	-	25.2	3.5	9.4	29.0	55.0
14. Bluegrass, hay	88.9	9.3		26.1	26.7	2.6	6.0	-	-
1-00-776	100.0	10.5	-	29.4	30.0	2.9	6.7	-	-
15. Brewer's grain, dehy	92.2	27.1		12.0	13.2	6.5	3.7	21.1	42.0
5-02-141	100.0	29.5	50	13.0	14.3	7.1	4.0	22.9	46.0
16. Brewer's yeast, dehy	93.1	43.4		-	3.2	1.0	6.7	3.7	-
7-05-527	100.0	46.6	-	-	3.5	1.1	7.2	4.0	-
17. Brome, fresh	27.0	4.1		-	7.5	0.8	-	9.5	16
2-00-963	100.0	15.2	-	-	28.0	3.0	-	35.2	58.0
18. Brome, hay	89.6	12.4		-	29.0	2.6	7.1	33.4	58.0
1-00-947	100.0	13.9	(44)	-	32.4	2.9	8.0	37.3	65.0
19. Buckwheat, grain	88.4	11.3		-	10.8	2.3	2.1	11.6	-
4-00-994	100.0	12.8	-	-	12.2	2.6	2.4	13.1	-
20. Canary grass, fresh	22.8	3.9		4.9	5.6	0.9	2.3	6.5	-
2-01-113	100.0	17.0	19	21.6	24.4	4.1	10.2	28.3	-
21. Canary grass, hay	89.3	9.1		-	30.2	2.7	7.3	32.7	-
1-01-104	100.0	10.2	22	-	33.9	3.0	8.1	36.6	-
22. Canola, meal	91.2	36.9		-	11.9	1.7	6.8	-	-
5-03-871	100.0	40.5	28	-	13.1	1.9	7.5	-	-
23. Casein, dehy	91.6	85.6		-	0.2	0.5	2.2	0.0	0.0
5-01-162	100.0	93.5	(19)	-	0.2	0.5	2.4	0.0	0.0
24. Citrus pulp, dehy	91.1	6.1		-	11.6	3.4	6.0	21.0	21.0
4-01-237	100.0	6.7	30	-	12.8	3.7	6.6	23.0	23.0
25. Clover, Landino, fresh	17.7	4.4		-	2.5	0.9	1.9	-	-
2-01-383	100.0	24.7	-	-	14.2	4.8	10.5	-	-
26. Clover, Landino, hay	89.1	20.0		-	18.5	2.4	8.4	28.5	32.0
1-01-378	100.0	22.4	22	-	20.8	2.7	9.4	32.0	36.0
27. Clover, Red, fresh	26.2	3.8		-	6.8	0.8	2.0	9.0	11.0
2-01-429	100.0	14.6	22	-	26.1	2.9	7.8	35.0	43.0
28. Clover, Red, hay	88.4	13.0		-	27.1	2.5	6.7	36.2	41.0
1-01-415	100.0	14.7	24	-	30.7	2.8	7.5	41.0	46.0
29. Coconut, meal	91.1	21.3		-	14.4	2.1	6.1	21.9	-
5-01-573	100.0	23.4	(63)	-	15.8	2.3	6.7	24.0	-
30. Corn, cobs, ground	89.8	2.8		-	32.2	0.6	1.6	39.5	80.0
1-02-782	100.0	3.1	-	-	35.8	0.7	1.8	44.0	89.0
31. Corn, DG, dehy	93.5	27.8		-	11.5	8.9	2.2	15.9	40.0
5-02-842	100.0	29.7	(54)	-	12.3	9.5	2.4	17.0	43.0
32. Corn, DG w/solubles	91.8	27.1		-	9.1	9.2	4.5	16.5	40.0
5-02-843	100.0	29.5	(47)	-	9.9	10.1	4.9	18.0	44.0

- continues -

Table 1. Proximate Analysis & General Nutrients (Continued)

Ingredient name/ description & IFN	DM, %	CP %	RUP %	Cellulose, %	Crude fiber, %	Ether extract, %	Ash, %	ADF, %	NDF, %
33. Corn, distiller's solubles	92.9	27.4		-	4.6	8.6	7.2	6.5	21.0
5-02-844	100.0	29.5	-	-	4.9	9.3	7.7	7.0	23.0
34. Corn, gluten feed	89.9	22.9		-	8.7	2.2	6.7	10.8	40.0
5-02-903	100.0	25.5	(22)	-	9.7	2.5	7.4	12.0	45.0
35. Corn, gluten meal	91.3	43.2		-	4.5	2.2	3.1	8.2	34.0
5-02-900	100.0	47.3	(55)	-	4.9	2.4	3.4	9.0	37.0
36. Corn, grain	88.0	9.1		2.1	2.2	3.6	1.3	3.8	8.0
4-02-935	100.0	10.4	(52)	2.4	2.5	4.1	1.5	4.3	9.0
37. Corn, hominy feed	90.2	10.3		-	4.8	6.5	2.8	11.7	50.0
4-02-887	100.0	11.4	24	-	5.3	7.2	3.1	13.0	55.0
38. Corn, silage	34.1	2.8		-	8.1	1.0	1.5	9.7	17.0
3-02-823	100.0	8.1	(31)	-	23.7	3.1	4.5	28.3	51.0
39. Cottonseed, hulls	90.4	3.8		-	43.2	1.5	2.6	59.0	81.0
1-01-599	100.0	4.2	50	-	47.8	1.7	2.9	65.3	90.0
40. Cottonseed, ground	92.2	21.7		-	18.2	22.4	3.5	24.0	34.0
5-01-608	100.0	23.6	-	-	19.8	24.3	3.8	26.0	37.0
41. Cottonseed, meal, mech ext	92.6	41.0		9.1	11.9	4.7	6.2	16.7	26.0
5-01-617	100.0	44.3	(36)	9.8	12.9	5.0	6.6	18.0	28.0
42. Cottonseed, meal, sol ext	91.0	41.3		12.0	12.2	1.5	6.5	18.2	24.0
5-01-621	100.0	45.4	(50)	13.2	13.4	1.7	7.1	20.0	26.0
43. Feather meal, hydrolyzed	92.9	83.4		-	1.3	5.5	2.9	5.7	-
5-03-795	100.0	89.8	76	-	1.4	5.9	3.1	6.2	-
44. Fescue, fresh	28.4	3.5		-	8.6	1.0	2.4	-	-
2-01-920	100.0	12.5	-	-	30.1	3.7	8.4	-	-
45. Fescue, hay	87.5	8.2		-	28.0	2.4	7.9	43.8	63.0
1-01-912	100.0	9.4	-	-	32.0	2.7	9.0	50.0	72.0
46. Fish, anchovy, mech ext	92.0	65.5		-	1.0	4.1	14.7	-	-
5-01-985	100.0	71.2	60	-	1.1	4.5	16.0	-	-
47. Fish, herring, mech ext	91.8	71.1		-	1.8	8.4	10.7	-	-
5-02-000	100.0	77.4	-	-	1.9	9.1	11.7	-	-
48. Fish, menhaden, mech ext	91.7	62.2		-	0.7	9.8	18.9	-	-
5-02-009	100.0	67.9	60	-	0.8	10.7	20.6	-	-
49. Fish, white, mech ext	91.2	62.9		-	0.5	4.6	22.9	-	-
5-02-025	100.0	68.9	-	-	0.6	5.1	25.1	-	-
50. Fish, solubles, condensed	50.4	31.5		-	0.5	6.0	10.1	-	-
5-01-969	100.0	62.5	-	-	1.0	11.9	20.1	-	-
51. Fish, solubles, dehy	92.8	60.3		-	2.0	9.2	13.1	-	-
5-01-971	100.0	65.0	-	-	2.1	9.9	14.1	-	-
52. Meat meal, rend	93.8	50.6		-	2.7	8.9	28.1	-	-
5-00-385	100.0	54.0	56	-	2.9	9.5	29.9	-	-
53. Meat meal w/bones	93.3	50.2		-	2.3	10.4	27.8	-	-
5-00-388	100.0	53.8	(49)	-	2.4	11.2	29.7	-	-
54. Milk, skim, dehy	94.1	33.4		0.0	0.2	1.0	7.9	0.0	0.0
5-01-175	100.0	35.5	-	0.0	0.2	1.0	8.4	0.0	0.0
55. Millet, grain	89.9	11.9		-	6.2	3.9	2.8	15.3	-
4-03-098	100.0	13.2	-	-	6.9	4.3	3.1	17.0	-
56. Molasses, sugar beet	77.9	6.6		-	-	0.2	8.9	-	-
4-00-668	100.0	8.5	20	-	-	0.2	11.4	-	-
57. Molasses, sugarcane	74.3	4.3		-	0.4	0.2	9.9	0.3	-
4-04-696	100.0	5.8	20	-	0.5	0.2	13.3	0.4	-
58. Oats, grain	89.2	11.8		-	10.7	4.6	3.1	14.2	28.0
4-03-309	100.0	13.3	17	-	12.0	5.2	3.4	15.9	32.0
59. Oats, groats	89.6	15.5		-	2.5	6.1	2.0	-	-
4-03-331	100.0	17.3	-	-	2.8	6.8	2.3	-	-
60. Oats, hay	90.7	8.6		-	29.1	2.2	7.2	34.8	56.0
1-03-280	100.0	9.5	20	-	32.0	2.4	7.9	38.4	62.0
61. Oats, hulls	92.4	3.8		27.3	30.6	1.4	6.1	36.5	72.0
1-03-281	100.0	4.1	25	29.5	33.2	1.5	6.6	39.6	78.0
62. Oats, silage	30.5	2.9		-	9.6	1.0	2.6	11.6	-
3-03-298	100.0	9.5	-	-	31.4	3.3	8.5	38.1	-
63. Oats, straw	92.2	4.1		39.5	37.2	2.0	7.2	44.2	64.0
1-03-283	100.0	4.4	30	42.8	40.4	2.2	7.8	47.9	70.0
64. Orchardgrass, fresh	23.5	3.0		6.0	7.5	0.9	1.9	7.2	-
2-03-442	100.0	12.8	20	25.6	32.0	3.7	8.1	30.7	-
65. Orchardgrass, hay	89.6	10.5		26.4	31.1	2.8	6.5	34.0	56.0
1-03-438	100.0	11.8	-	29.4	34.7	3.1	7.3	37.9	63.0
66. Pea, seeds	89.1	23.4		-	5.6	0.9	2.8	-	-
5-03-600	100.0	26.3	(22)	-	6.3	1.0	3.2	-	-
67. Peanut, meal, mech ext	92.6	49.2		4.2	6.2	5.6	5.0	5.6	13.0
5-03-649	100.0	53.1	-	4.5	6.7	6.0	5.4	6.1	14.0

- continues -

Table 1. Proximate Analysis & General Nutrients (Continued)

Ingredient name/ description & IFN	DM, %	CP %	RUP %	Cellulose, %	Crude fiber, %	Ether extract, %	Ash, %	ADF, %	NDF, %
68. Peanut, meal, sol ext	92.4	48.9		-	7.7	2.1	5.8	-	-
5-03-650	100.0	52.9	30	-	8.4	2.3	6.3	-	-
69. Poultry by-pro, meal, rend	93.8	61.1		-	2.1	13.1	14.6	-	-
5-03-798	100.0	65.1	-	-	2.3	13.9	15.6	-	-
70. Rice, bran	90.5	13.1		-	11.7	13.6	10.4	25.7	30.0
4-03-928	100.0	14.4	25	-	12.9	15.0	11.5	28.4	33.0
71. Rice, grain/groats	88.5	8.0		0.4	0.8	0.8	0.9	1.2	14.0
4-03-932	100.0	9.0	-	0.5	0.9	0.9	1.0	1.4	16.0
72. Rice, hulls	91.9	2.8		34.2	39.2	1.0	19.0	63.1	75.0
1-08-075	100.0	3.1	35	37.2	42.7	1.1	20.6	68.7	82.0
73. Rye, grain	87.5	12.0		2.1	2.2	1.5	1.8	3.7	-
4-04-047	100.0	13.7	(19)	2.4	2.5	1.7	1.9	4.2	-
74. Ryegrass, fresh	22.6	4.0		-	4.7	0.9	3.9	7.5	9.0
2-04-073	100.0	17.9	20	-	20.9	4.1	17.4	33.0	38.0
75. Safflower, meal, sol ext	91.7	22.9		-	29.9	1.2	5.3	37.6	53.0
5-04-110	100.0	25.0	27	-	32.6	1.3	5.8	41.0	58.0
76. Safflower, meal wo/hulls	91.0	42.7		-	13.4	1.2	7.8	-	-
5-07-959	100.0	46.9	-	-	14.7	1.3	8.5	-	-
77. Sesame, meal, mech ext	92.7	45.6		-	5.7	6.4	11.4	15.7	16.0
5-04-220	100.0	49.2	-	-	6.2	6.9	12.3	17.0	17.0
78. Sorghum, grain	90.1	11.5		5.0	2.6	2.7	1.7	8.3	-
4-04-383	100.0	12.7	57	5.6	2.8	3.0	1.9	9.3	-
79. Sorghum, sorgo, silage	28.8	1.9		-	7.0	0.7	2.4	11.0	-
3-04-468	100.0	6.7	-	-	24.4	2.5	8.3	38.0	-
80. Soybean, hulls	90.3	11.2		41.8	35.5	1.9	4.4	44.2	60.0
1-04-560	100.0	12.4	25	46.1	39.3	2.1	4.9	49.0	67.0
81. Soybean, meal, sol ext	89.6	45.7		-	5.8	1.2	6.2	-	-
5-04-604	100.0	51.0	-	-	6.5	1.3	6.9	-	-
82. Soybean, meal wo/hulls	89.9	49.3		4.1	3.5	1.0	6.0	5.5	7.0
5-04-612	100.0	54.8	34	4.5	3.8	1.1	6.7	6.1	8.0
83. Soybean, prot conc - (NRC, 1998)	90.0	64.0		-	-	3.0	-	-	-
84. Soybean, seeds, heat proc	92.6	36.6		-	5.1	18.7	4.7	-	-
5-04-597	100.0	39.5	29	-	5.6	20.2	5.1	-	-
85. Sunflower, meal wo/hulls	92.5	45.2		-	11.7	2.7	7.5	-	-
5-04-739	100.0	48.9	26	-	12.7	2.9	8.1	-	-
86. Timothy, fresh	26.7	3.3		-	8.6	1.0	2.0	-	-
2-04-903	100.0	12.2	20	-	32.1	3.8	7.5	-	-
87. Timothy, hay	89.1	9.6		31.2	30.0	2.5	5.1	31.4	54.0
1-04-882	100.0	10.8	22	35.0	33.6	2.8	5.7	35.2	61.0
88. Triticale, grain	89.2	14.7		-	2.9	1.5	1.8	-	-
4-20-362	100.0	16.5	-	-	3.3	1.6	2.0	-	-
89. Urea	97.0	276.9		-	-	-	1.5	-	-
5-05-070	100.0	285.4	-	-	-	-	1.5	-	-
90. Wheat, bran	89.0	15.4		9.5	10.0	3.8	5.9	12.5	45.0
4-05-190	100.0	17.4	20	10.7	11.3	4.3	6.6	14.0	51.0
91. Wheat, grain, hard red spring	87.6	14.9		7.2	2.5	1.8	1.6	11.0	-
4-05-258	100.0	17.1	(22?)	8.2	2.8	2.0	1.8	12.6	-
92. Wheat, grain, hard red winter	88.8	12.8		-	2.6	1.6	1.8	3.9	-
4-05-268	100.0	14.4	(22?)	-	2.9	1.8	2.0	4.4	-
93. Wheat, grain, soft red winter	88.4	11.4		-	2.3	1.6	1.9	-	-
4-05-294	100.0	12.9	(22?)	-	2.6	1.8	2.1	-	-
94. Wheat, grain, soft white winter	90.2	10.4		-	2.3	1.5	1.5	3.6	13.0
4-05-337	100.0	11.5	(22?)	-	2.6	1.7	1.7	4.0	14.0
95. Wheat, hay	88.7	7.7		-	25.7	2.0	7.0	36.4	60.0
1-05-172	100.0	8.7	23	-	29.0	2.2	7.9	41.0	68.0
96. Wheat, middlings	88.9	16.4		7.5	7.8	4.2	4.6	10.5	33.0
4-05-205	100.0	18.4	21	8.4	8.8	4.7	5.2	11.8	37.0
97. Wheat, red dog	88.3	15.7		4.9	2.9	3.4	2.5	8.1	-
4-05-203	100.0	17.7	-	5.6	3.3	3.9	2.8	9.2	-
98. Wheat, shorts	88.4	16.7		-	6.3	4.3	4.4	-	-
4-05-201	100.0	18.9	-	-	7.2	4.8	5.0	-	-
99. Whey, dehy	93.3	13.1		-	0.2	0.7	8.7	0.2	-
4-01-182	100.0	14.0	-	-	0.2	0.8	9.4	0.2	-
100. Yeast, Torula, dehy	93.0	49.5		-	2.5	1.6	8.6	4.0	-
7-05-534	100.0	53.2	(42)	-	2.7	1.7	8.6	4.0	-

2. **Table 2. Energy Content for Various Species** [DM = dry matter; TDN = total digestible nutrients; DE = digestible energy; ME = metabolizable energy; NEm = net energy for maintenance; NEg = NE for gain; NEl = NE for lactation; MEn = nitrogen-corrected ME]

Ingredient name/ description & IFN	DM, %	TDN (Cattle), %	TDN (Sheep), %	DE (Sheep), Mcal/kg	ME (Cattle), Mcal/kg	ME (Sheep), Mcal/kg	NEm (Cattle), Mcal/kg	NEg (Cattle), Mcal/kg	NEl (Cattle), Mcal/kg	MEn (Poultry), Mcal/kg	DE (Horse), Mcal/kg	DE (Pig), Mcal/kg	ME (Pig), Mcal/kg
1. Alfalfa, fresh	26.0	15.9	15.8	0.70	0.59	0.59	0.35	0.20	0.36	-	0.58	-	-
2-00-196	100.0	61.0	60.7	2.67	2.27	2.25	1.34	0.77	1.37	-	2.23	-	-
2. Alfalfa, hay	91.0	52.1	52.2	2.14	1.99	1.75	1.17	0.65	1.15	-	2.07	-	-
1-00-063	100.0	57.2	57.4	2.35	2.19	1.92	1.28	0.71	1.27	-	2.28	-	-
3. Alfalfa, dehy 17% CP	91.8	55.6	55.0	2.28	2.06	1.88	1.27	0.73	1.25	1.51	2.16	1.42	1.32
1-00-023	100.0	60.6	60.0	2.48	2.25	2.05	1.38	0.80	1.37	1.64	2.36	1.54	1.44
4. Alfalfa, dehy 20% CP	91.6	57.4	55.7	2.38	2.15	1.99	1.28	0.75	1.30	1.63	2.07	2.08	1.92
1-00-024	100.0	62.7	60.8	2.59	2.34	2.17	1.40	0.82	1.42	1.77	2.27	2.27	2.10
5. Bakery, waste, dehy	91.2	81.3	81.8	3.60	3.16	3.23	2.19	1.54	1.88	3.84	-	3.96	3.71
4-00-466	100.0	89.1	89.6	3.95	3.46	3.54	2.41	1.69	2.06	4.20	-	4.34	4.07
6. Barley, grain-	88.6	73.7	76.0	3.35	2.57	2.99	1.73	1.16	1.81	2.62	3.26	3.08	2.94
4-00-549	100.0	83.2	85.9	3.79	2.91	3.37	1.95	1.31	2.05	2.96	3.68	3.48	3.32
7. Barley, straw	91.4	41.8	43.6	1.92	1.40	1.53	0.64	0.15	0.91	-	1.47	-	-
1-00-498	100.0	45.7	47.7	2.10	1.54	1.67	0.70	0.16	1.00	-	1.62	-	-
8. Beet pulp, dehy	91.0	67.7	67.2	2.96	2.44	2.58	1.60	1.04	1.55	0.65	2.33	2.88	2.70
4-00-669	100.0	74.4	73.8	3.26	2.68	2.84	1.76	1.14	1.70	0.71	2.56	3.16	2.97
9. Bermudagrass, fresh	28.9	17.8	17.4	0.77	0.66	0.64	0.39	0.23	0.40	-	0.60	-	-
2-00-712	100.0	61.5	60.0	2.65	2.29	2.22	1.36	0.78	1.39	-	2.06	-	-
10. Bermudagrass, hay	91.2	41.1	44.5	1.96	1.41	1.57	0.65	0.16	0.88	-	1.69	-	-
1-00-703	100.0	45.1	48.8	2.15	1.55	1.72	0.71	0.18	0.96	-	1.85	-	-
11. Blood, meal, spray dried	92.6	85.4	84.3	3.71	3.38	3.34	2.13	1.48	1.98	2.77	-	2.70	1.94
5-00-381	100.0	92.2	91.0	4.01	3.66	3.60	2.30	1.60	2.14	2.99	-	2.92	2.10
13. Bluegrass, fresh	30.8	22.2	20.2	0.89	0.85	0.76	0.52	0.33	0.51	-	0.64	-	-
2-00-777	100.0	72.0	65.5	2.89	2.76	2.47	1.70	1.08	1.64	-	2.08	-	-
14. Bluegrass, hay	88.9	51.4	53.9	2.38	1.89	2.00	1.10	0.59	1.15	-	1.52	-	-
1-00-776	100.0	57.8	60.6	2.67	2.12	2.25	1.23	0.67	1.30	-	1.71	-	-
15. Brewer's grain, dehy	92.2	65.1	65.9	2.91	2.22	2.52	1.41	0.86	1.48	2.31	2.53	2.18	2.12
5-02-141	100.0	70.6	71.5	3.15	2.41	2.73	1.53	0.93	1.61	2.51	2.75	2.37	2.30
16. Brewer's yeast, dehy	93.1	73.7	72.1	3.18	2.86	2.79	1.79	1.19	1.69	2.07	3.07	-	2.87
7-05-527	100.0	79.2	77.4	3.41	3.08	3.00	1.92	1.28	1.82	2.23	3.30	-	3.08
17. Brome, fresh	27.0	16.9	13.9	0.61	0.63	0.50	0.38	0.22	0.38	-	0.54	-	-
2-00-963	100.0	62.8	51.4	2.27	2.35	1.84	1.40	0.82	1.42	-	1.98	-	-
18. Brome, hay	89.6	53.5	53.4	2.55	2.01	2.17	1.19	0.67	1.17	-	1.71	-	-
1-00-947	100.0	59.7	59.6	2.84	2.24	2.42	1.33	0.75	1.30	-	1.91	-	-
19. Buckwheat, grain	88.4	61.9	64.6	2.85	2.36	2.48	1.44	0.91	1.41	2.67	-	3.06	2.88
4-00-994	100.0	70.0	73.1	3.22	2.67	2.80	1.63	1.03	1.60	3.02	-	3.46	3.26
20. Canary grass, fresh	22.8	14.8	14.0	0.62	0.56	0.52	0.34	0.20	0.34	-	0.58	-	-
2-01-113	100.0	65.0	61.2	2.70	2.44	2.28	1.47	0.88	1.47	-	2.54	-	-
21. Canary grass, hay	89.3	49.2	44.1	1.95	1.79	1.56	1.02	0.52	1.10	-	1.78	-	-
1-01-104	100.0	55.1	49.5	2.18	2.00	1.75	1.14	0.58	1.23	-	2.00	-	-
22. Canola, meal	91.2	62.9	68.2	3.01	2.39	2.63	1.46	0.91	1.43	1.75	-	3.01	2.75
5-03-871	100.0	69.0	74.8	3.30	2.62	2.88	1.60	1.00	1.57	1.92	-	3.30	3.01
23. Casein, dehy	91.6	75.3	87.6	3.86	2.71	3.49	1.83	1.23	1.73	4.16	-	3.54	3.10
5-01-162	100.0	82.2	95.7	4.22	2.96	3.81	2.00	1.35	1.89	4.54	-	3.87	3.39
24. Citrus pulp, dehy	91.1	74.1	76.4	3.37	2.47	2.99	1.63	1.06	1.71	1.34	2.56	3.06	2.42
4-01-237	100.0	81.4	83.8	3.70	2.71	3.28	1.79	1.16	1.87	1.47	2.81	3.36	2.66
25. Clover, Landino, fresh	17.7	13.8	13.2	0.58	0.54	0.51	0.33	0.22	0.32	-	0.44	-	-
2-01-383	100.0	78.2	74.7	3.29	3.03	2.88	1.89	1.25	1.80	-	2.48	-	-
26. Clover, Landino, hay	89.1	56.6	59.2	2.61	2.12	2.24	1.27	0.75	1.28	-	1.96	-	-
1-01-378	100.0	63.5	66.5	2.93	2.38	2.51	1.42	0.84	1.44	-	2.20	-	-
27. Clover, Red, fresh	26.2	16.8	17.2	0.76	0.63	0.65	0.38	0.22	0.38	-	0.66	-	-
2-01-429	100.0	64.0	65.7	2.90	2.40	2.48	1.44	0.86	1.45	-	2.25	-	-
28. Clover, Red, hay	88.4	51.6	52.0	2.67	1.90	2.30	1.11	0.61	1.16	-	1.96	-	-
1-01-415	100.0	58.4	58.9	3.02	2.15	2.60	1.26	0.69	1.31	-	2.22	-	-
29. Coconut, meal	91.1	68.3	68.6	3.02	2.63	2.64	1.63	1.06	1.55	1.53	-	3.22	3.06
5-01-573	100.0	75.0	75.3	3.32	2.89	2.90	1.79	1.16	1.70	1.67	-	3.53	3.35
30. Corn, cobs, ground	89.8	43.6	45.4	2.00	1.62	1.62	0.86	0.37	0.96	-	1.25	-	-
1-02-782	100.0	48.5	50.5	2.23	1.80	1.80	0.96	0.42	1.07	-	1.39	-	-
31. Corn, DG, dehy	93.5	80.4	81.6	3.60	2.82	3.21	1.91	1.30	1.86	2.07	3.26	2.75	2.64
5-02-842	100.0	86.0	87.3	3.85	3.02	3.44	2.05	1.39	1.99	2.22	3.49	2.94	2.82
32. Corn, DG w/solubles	91.8	81.7	79.9	3.52	2.95	3.14	2.03	1.40	1.89	2.53	-	3.24	2.82
5-02-843	100.0	89.1	87.1	3.84	3.22	3.43	2.21	1.52	2.06	2.76	-	3.53	3.07
33. Corn, distiller's solubles	92.9	81.6	79.3	3.50	2.96	3.11	2.03	1.40	1.89	2.92	-	3.25	3.13
5-02-844	100.0	87.9	85.4	3.76	3.19	3.35	2.19	1.50	2.03	3.14	-	3.50	3.37
34. Corn, gluten feed	89.9	74.4	74.8	3.30	2.67	2.93	1.80	1.21	1.72	1.73	-	3.03	2.48
5-02-903	100.0	82.8	83.2	3.67	2.96	3.25	2.00	1.35	1.91	1.92	-	3.37	2.76

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Table 2. Energy Content for Various Species (Continued)

Ingredient name/ description & IFN	DM, %	TDN (Cattle), %	TDN (Sheep), %	DE (Sheep), Mcal/kg	ME (Cattle), Mcal/kg	ME (Sheep), Mcal/kg	NEm (Cattle), Mcal/kg	NEg (Cattle), Mcal/kg	NEl (Cattle), Mcal/kg	MEn (Poultry), Mcal/kg	DE (Horse), Mcal/kg	DE (Pig), Mcal/kg	ME (Pig), Mcal/kg
35. Corn, gluten meal	91.3	76.0	79.4	3.50	2.73	3.13	1.85	1.25	1.75	3.01	-	3.61	3.17
5-02-900	100.0	83.2	87.0	3.84	2.99	3.42	2.03	1.37	1.92	3.30	-	3.96	3.47
36. Corn, grain	88.0	78.0	82.9	3.59	2.78	3.23	1.90	1.31	1.81	3.31	3.38	3.44	3.24
4-02-935	100.0	88.7	94.2	4.08	3.16	3.68	2.16	1.48	2.05	3.77	3.84	3.92	3.68
37. Corn, hominy feed	90.2	84.8	83.5	3.68	2.85	3.31	1.95	1.34	2.00	2.89	-	3.57	3.38
4-02-887	100.0	93.9	92.5	4.08	3.15	3.67	2.16	1.48	2.22	3.21	-	3.96	3.75
38. Corn, silage	34.1	23.9	24.0	1.06	0.91	0.92	0.56	0.35	0.54	-	-	-	-
3-02-823	100.0	70.0	70.5	3.11	2.67	2.69	1.63	1.03	1.60	-	-	-	-
39. Cottonseed, hulls	90.4	40.6	43.8	1.93	1.31	1.55	0.55	0.08	0.86	-	1.71	-	-
1-01-599	100.0	44.9	48.5	2.14	1.45	1.71	0.61	0.08	0.95	-	1.89	-	-
40. Cottonseed, ground	92.2	90.3	90.3	3.98	3.61	3.61	2.28	1.60	2.10	-	-	3.57	3.12
5-01-608	100.0	98.0	98.0	4.32	3.91	3.91	2.47	1.74	2.28	-	-	3.87	3.29
41. Cottonseed, meal, mech ext	92.6	73.6	69.7	3.37	2.44	2.51	1.60	1.02	1.67	2.24	-	2.88	2.64
5-01-617	100.0	79.4	75.2	3.64	2.63	2.71	1.72	1.11	1.81	2.41	-	3.11	2.85
42. Cottonseed, meal, sol ext	91.0	71.0	64.9	3.45	2.48	2.67	1.64	1.07	1.61	1.95	2.74	2.67	2.34
5-01-621	100.0	78.0	71.3	3.79	2.73	2.93	1.80	1.17	1.77	2.14	3.01	2.93	2.59
43. Feather meal, hydrolyzed	92.9	63.0	70.1	4.14	1.84	3.76	1.05	0.53	1.43	2.43	-	2.73	2.21
5-03-795	100.0	67.8	75.5	4.45	1.98	4.05	1.13	0.57	1.54	2.62	-	2.94	2.38
44. Fescue, fresh	28.4	17.6	17.2	0.76	0.65	0.64	0.39	0.22	0.40	-	0.63	-	-
2-01-920	100.0	61.8	60.7	2.67	2.30	2.25	1.37	0.79	1.39	-	2.22	-	-
45. Fescue, hay	87.5	54.3	52.1	2.30	2.02	1.93	1.20	0.70	1.22	-	1.75	-	-
1-01-912	100.0	62.0	59.6	2.63	2.31	2.20	1.38	0.80	1.40	-	2.00	-	-
46. Fish, anchovy, mech ext	92.0	71.7	73.0	3.22	2.78	2.84	1.73	1.14	1.65	2.75	2.76	3.02	2.48
5-01-985	100.0	78.0	79.3	3.50	3.02	3.08	1.88	1.24	1.79	2.99	3.00	3.28	2.70
47. Fish, herring, mech ext	91.8	72.6	75.2	3.32	2.82	2.94	1.76	1.17	1.67	3.26	-	3.93	2.78
5-02-000	100.0	79.0	81.9	3.61	3.07	3.20	1.91	1.27	1.82	3.55	-	4.28	3.03
48. Fish, menhaden, mech ext	91.7	69.2	64.0	2.82	2.67	2.44	1.65	1.08	1.59	2.85	2.93	3.48	2.60
5-02-009	100.0	75.5	69.9	3.08	2.91	2.66	1.80	1.18	1.73	3.11	3.20	3.80	2.84
49. Fish, white, mech ext	91.2	71.2	69.2	3.05	2.76	2.67	1.72	1.14	1.63	2.59	-	3.06	2.66
5-02-025	100.0	78.0	75.8	3.34	3.02	2.93	1.88	1.24	1.79	2.84	-	3.36	2.91
50. Fish, solubles, condensed	50.4	42.0	40.9	1.80	1.73	1.60	1.20	0.84	0.97	1.66	-	1.91	1.62
5-01-969	100.0	83.3	81.1	3.58	3.42	3.16	2.37	1.66	1.92	3.30	-	3.78	3.22
51. Fish, solubles, dehy	92.8	73.8	80.6	3.55	2.66	3.17	1.78	1.19	1.70	2.92	-	3.24	2.82
5-01-971	100.0	79.6	86.8	3.83	2.87	3.42	1.92	1.28	1.83	3.14	-	3.49	3.04
52. Meat meal, rend	93.8	66.9	66.3	2.92	1.95	2.53	1.15	0.62	1.53	2.09	-	2.60	2.22
5-00-385	100.0	71.3	70.7	3.12	2.08	2.70	1.23	0.66	1.63	2.23	-	2.77	2.37
53. Meat meal w/bones	93.3	66.8	65.0	2.87	2.55	2.48	1.57	1.00	1.52	2.02	-	2.37	2.27
5-00-388	100.0	71.5	69.7	3.07	2.74	2.65	1.68	1.07	1.63	2.16	-	2.54	2.43
54. Milk, skim, dehy	94.1	79.0	80.3	3.54	2.37	3.15	1.52	0.95	1.82	2.54	3.81	3.87	3.59
5-01-175	100.0	84.0	85.3	3.76	2.51	3.35	1.62	1.01	1.94	2.70	4.05	4.12	3.82
55. Millet, grain	89.9	64.5	57.2	2.52	3.02	2.14	1.90	1.29	1.79	3.18	-	2.90	2.70
4-03-098	100.0	71.7	63.6	2.80	3.36	2.38	2.11	1.44	1.99	3.54	-	3.23	3.00
56. Molasses, sugar beet	77.9	62.0	60.3	2.66	2.29	2.33	1.54	1.04	1.42	1.93	-	2.49	2.34
4-00-668	100.0	79.6	77.4	3.41	2.94	2.99	1.98	1.33	1.83	2.48	-	3.20	3.00
57. Molasses, sugarcane	74.3	61.1	58.7	2.59	2.46	2.28	1.70	1.18	1.41	1.90	2.60	2.50	2.19
4-04-696	100.0	82.2	79.0	3.48	3.31	3.07	2.28	1.58	1.89	2.56	3.50	3.36	2.95
58. Oats, grain	89.2	68.9	68.5	3.02	2.62	2.65	1.77	1.19	1.55	2.54	2.95	2.82	2.63
4-03-309	100.0	77.3	76.7	3.38	2.94	2.97	1.98	1.33	1.74	2.85	3.30	3.16	2.94
59. Oats, groats	89.6	83.6	91.0	4.01	3.21	3.65	2.24	1.58	1.94	3.25	3.09	3.11	2.93
4-03-331	100.0	93.4	101.7	4.48	3.59	4.08	2.50	1.77	2.17	3.63	3.45	3.47	3.30
60. Oats, hay	90.7	54.3	48.9	2.16	2.04	1.77	1.26	0.73	1.22	-	1.75	-	-
1-03-280	100.0	59.9	53.9	2.38	2.25	1.95	1.39	0.81	1.35	-	1.92	-	-
61. Oats, hulls	92.4	31.8	32.0	1.41	1.00	1.01	0.36	-0.12	0.67	0.36	1.59	-	0.87
1-03-281	100.0	34.4	34.6	1.53	1.08	1.09	0.39	-0.13	0.72	0.39	1.72	-	0.94
62. Oats, silage	30.5	17.6	18.4	0.81	0.65	0.68	0.38	0.20	0.39	-	-	-	-
3-03-298	100.0	57.6	60.5	2.67	2.12	2.25	1.23	0.66	1.29	-	-	-	-
63. Oats, straw	92.2	47.9	43.7	2.52	1.72	2.14	0.94	0.43	1.06	-	1.49	-	-
1-03-283	100.0	52.0	47.5	2.74	1.86	2.32	1.02	0.47	1.15	-	1.62	-	-
64. Orchardgrass, fresh	23.5	15.5	14.3	0.63	0.59	0.53	0.35	0.22	0.35	-	0.54	-	-
2-03-442	100.0	66.0	60.7	2.68	2.49	2.25	1.51	0.91	1.50	-	2.29	-	-
65. Orchardgrass, hay	89.6	51.5	51.6	2.72	1.89	2.34	1.10	0.59	1.15	-	1.69	-	-
1-03-438	100.0	57.4	57.6	3.03	2.11	2.61	1.22	0.66	1.29	-	1.89	-	-
66. Pea, seeds	89.1	77.2	78.1	3.44	3.04	3.07	1.91	1.31	1.79	2.11	3.07	3.26	2.84
5-03-600	100.0	86.7	87.6	3.86	3.41	3.45	2.14	1.47	2.00	2.37	3.45	3.66	3.19
67. Peanut, meal, mech ext	92.6	74.1	87.1	3.84	3.01	3.46	1.89	1.28	1.78	2.66	-	4.32	4.02
5-03-649	100.0	80.0	94.1	4.15	3.25	3.74	2.04	1.38	1.92	2.87	-	4.66	4.34
68. Peanut, meal, sol ext	92.4	71.3	74.7	3.29	2.76	2.91	1.71	1.13	1.63	2.71	3.00	2.85	2.79
5-03-650	100.0	77.1	80.8	3.56	2.98	3.15	1.85	1.22	1.76	2.93	3.25	3.09	3.01
69. Poultry by-pro, meal, rend	93.8	73.3	74.4	3.28	2.66	2.89	1.78	1.18	1.68	2.87	-	3.10	2.87
5-03-798	100.0	78.1	79.3	3.50	2.83	3.08	1.89	1.25	1.79	3.05	-	3.31	3.06

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Table 2. Energy Content for Various Species (Continued)

Ingredient name/ description & IFN	DM, %	TDN (Cattle), %	TDN (Sheep), %	DE (Sheep), Mcal/kg	ME (Cattle), Mcal/kg	ME (Sheep), Mcal/kg	NEm (Cattle), Mcal/kg	NEg (Cattle), Mcal/kg	NEl (Cattle), Mcal/kg	MEn (Poultry), Mcal/kg	DE (Horse), Mcal/kg	DE (Pig), Mcal/kg	ME (Pig), Mcal/kg
70. Rice, bran	90.5	60.6	67.4	2.97	2.17	2.59	1.37	0.84	1.18	2.01	2.62	3.10	2.97
4-03-928	100.0	66.9	74.5	3.28	2.40	2.87	1.52	0.92	1.30	2.22	2.90	3.43	3.28
71. Rice, grain/groats	88.5	-	78.7	3.47	-	3.11	-	-	-	3.09	-	3.72	3.31
4-03-932	100.0	-	88.9	3.92	-	3.51	-	-	-	3.49	-	4.20	3.74
72. Rice, hulls	91.9	11.5	9.9	0.44	0.35	0.03	-0.57	-1.04	0.17	0.08	1.15	-	-
1-08-075	100.0	12.5	10.8	0.47	0.38	0.03	-0.62	-1.13	0.19	0.09	1.25	-	-
73. Rye, grain	87.5	72.3	74.8	3.30	2.60	2.94	1.75	1.18	1.63	2.65	3.36	3.25	2.91
4-04-047	100.0	82.6	85.4	3.77	2.97	3.35	2.01	1.35	1.86	3.03	3.84	3.72	3.33
74. Ryegrass, fresh	22.6	14.0	13.7	0.60	0.52	0.51	0.31	0.18	0.32	-	0.51	-	-
2-04-073	100.0	62.0	60.5	2.67	2.31	2.24	1.38	0.80	1.40	-	2.20	-	-
75. Safflower, meal, sol ext	91.7	52.2	51.4	2.27	1.82	1.88	1.04	0.53	1.17	1.19	-	-	-
5-04-110	100.0	56.9	56.1	2.47	1.99	2.05	1.14	0.58	1.27	1.29	-	-	-
76. Safflower, meal wo/hulls	91.0	69.2	64.6	2.85	2.67	2.47	1.66	1.08	1.59	1.84	-	2.35	2.00
5-07-959	100.0	76.0	71.0	3.13	2.93	2.71	1.82	1.19	1.94	2.03	-	2.58	2.19
77. Sesame, meal, mech ext	92.7	69.5	71.7	3.16	2.68	2.77	1.66	1.08	1.59	2.17	-	3.43	3.03
5-04-220	100.0	75.0	77.3	3.41	2.89	2.99	1.79	1.16	1.72	2.35	-	3.70	3.27
78. Sorghum, grain	90.1	54.0	80.3	3.54	2.00	3.17	1.18	0.66	1.21	3.41	3.21	3.52	3.25
4-04-383	100.0	59.9	89.1	3.93	2.22	3.52	1.31	0.73	1.35	3.79	3.56	3.91	3.61
79. Sorghum, sorgo, silage	28.8	16.5	17.2	0.76	0.61	0.64	0.35	0.19	0.37	-	-	-	-
3-04-468	100.0	57.4	59.6	2.63	2.10	2.20	1.22	0.66	1.29	-	-	-	-
80. Soybean, hulls	90.3	69.1	51.1	2.25	2.67	1.87	1.66	1.09	1.58	0.66	1.70	1.95	0.67
1-04-560	100.0	76.5	56.6	2.50	2.96	2.07	1.84	1.20	1.75	0.73	1.88	2.16	0.74
81. Soybean, meal, sol ext	89.6	75.0	78.8	3.47	2.94	3.11	1.84	1.25	1.73	2.33	3.15	3.49	3.01
5-04-604	100.0	83.7	87.9	3.88	3.28	3.47	2.05	1.39	1.93	2.60	3.52	3.90	3.36
82. Soybean, meal wo/hulls	89.9	75.3	77.9	3.43	2.95	3.06	1.85	1.25	1.74	2.47	3.36	3.77	3.36
5-04-612	100.0	83.7	86.6	3.82	3.28	3.41	2.05	1.39	1.93	2.75	3.73	4.19	3.74
83. Soybean, prot conc	90.0	-	-	-	-	-	-	-	-	-	-	4.10	3.50
- (NRC, 1998)													
84. Soybean, seeds, heat proc	92.6	92.3	92.4	4.07	3.70	3.70	2.33	1.65	2.15	-	3.52	4.13	3.64
5-04-597	100.0	99.7	99.8	4.40	3.99	3.99	2.52	1.78	2.32	-	3.80	4.46	3.93
85. Sunflower, meal wo/hulls	92.5	60.1	69.0	3.04	2.26	2.66	1.36	0.82	1.36	2.07	2.59	3.04	2.64
5-04-739	100.0	65.0	74.6	3.29	2.44	2.87	1.47	0.88	1.47	2.24	2.80	3.29	2.85
86. Timothy, fresh	26.7	17.9	16.4	0.72	0.68	0.61	0.41	0.25	0.41	-	0.70	-	-
2-04-903	100.0	67.0	61.2	2.70	2.53	2.27	1.54	0.94	1.52	-	2.37	-	-
87. Timothy, hay	89.1	52.7	50.4	2.22	1.94	1.84	1.14	0.63	1.18	-	1.83	-	-
1-04-882	100.0	59.1	56.5	2.49	2.18	2.07	1.28	0.71	1.33	-	2.06	-	-
88. Triticale, grain	89.2	69.0	75.3	3.32	2.67	2.95	1.66	1.10	1.58	3.14	-	3.21	3.14
4-20-362	100.0	77.4	84.4	3.72	3.00	3.31	1.86	1.23	1.78	3.52	-	3.60	3.52
89. Urea	97.0	-	-	-	-	-	-	-	-	-	2.45	-	-
5-05-070	100.0	-	-	-	-	-	-	-	-	-	2.52	-	-
90. Wheat, bran	89.0	62.4	62.8	2.77	2.24	2.40	1.44	0.90	1.41	1.23	2.94	2.65	2.37
4-05-190	100.0	70.1	70.5	3.11	2.51	2.69	1.62	1.01	1.58	1.38	3.30	2.97	2.66
91. Wheat, grain, hard red spring	87.6	77.1	78.5	3.46	3.04	3.10	1.91	1.31	1.78	2.70	-	3.10	2.95
4-05-258	100.0	88.0	89.6	3.95	3.47	3.54	2.18	1.50	2.04	3.08	-	3.54	3.37
92. Wheat, grain, hard red winter	88.8	78.5	78.4	3.46	3.10	3.09	1.95	1.34	1.82	3.21	3.43	3.38	3.22
4-05-268	100.0	88.4	88.3	3.89	3.49	3.48	2.19	1.51	2.05	3.62	3.86	3.81	3.63
93. Wheat, grain, soft red winter	88.4	78.7	78.0	3.44	3.11	3.07	1.95	1.35	1.82	3.09	3.41	3.23	3.05
4-05-294	100.0	89.0	88.2	3.89	3.51	3.48	2.21	1.52	2.06	3.50	3.86	3.65	3.45
94. Wheat, grain, soft white winter	90.2	80.2	79.7	3.51	3.17	3.14	1.99	1.37	1.86	2.86	3.54	3.35	3.16
4-05-337	100.0	88.9	88.3	3.90	3.51	3.48	2.21	1.52	2.06	3.17	3.92	3.71	3.51
95. Wheat, hay	88.7	53.0	45.8	2.02	1.74	1.64	0.99	0.49	1.19	-	1.68	-	-
1-05-172	100.0	59.7	51.7	2.28	1.96	1.85	1.11	0.56	1.34	-	1.90	-	-
96. Wheat, middlings	88.9	75.1	72.6	3.20	2.57	2.83	1.73	1.15	1.73	2.08	3.04	2.93	2.71
4-05-205	100.0	84.4	81.7	3.60	2.89	3.19	1.94	1.29	1.95	2.33	3.42	3.30	3.05
97. Wheat, red dog	88.3	71.6	82.0	3.62	2.87	3.25	1.80	1.22	1.70	2.59	-	3.15	2.88
4-05-203	100.0	81.1	92.8	4.09	3.25	3.68	2.04	1.38	1.92	2.94	-	3.57	3.26
98. Wheat, shorts	88.4	75.8	76.3	3.36	2.75	3.00	1.88	1.28	1.75	2.21	-	3.12	2.93
4-05-201	100.0	85.7	86.2	3.80	3.11	3.39	2.12	1.45	1.98	2.50	-	3.52	3.31
99. Whey, dehy	93.3	74.4	78.0	3.44	2.83	3.05	1.92	1.30	1.71	1.94	3.79	3.19	3.10
4-01-182	100.0	79.7	83.6	3.69	3.03	3.27	2.06	1.40	1.83	2.08	4.06	3.42	3.33
100. Yeast, Torula, dehy	93.0	74.4	70.3	3.10	2.90	2.71	1.81	1.21	1.71	2.14	-	2.84	2.42
7-05-534	100.0	80.0	75.6	3.33	3.12	2.92	1.95	1.30	1.84	2.30	-	3.05	2.60

3. **Table 3. Amino Acid Content** [*NRC = NRC (1994) for Gly & Ser & NRC (1998) for the rest; IFN for some ingredients may differ vs. other tables. Values for few ingredients from Jurgens (2002)] [DM = dry matter; Arg = arginine; Cys = cystine; Gly = glucine; His = histidine; Ile = isoleucine; Leu = leucine; Lys - lysine; Met = methionine; Phe = phenylalanine; Ser = serine; Thr = threonine; Trp = tryptophan; Tyr = tyrosine; Val = valine]

Ingredient name/ description & IFN	DM %	Arg %	His %	Ile %	Leu %	Lys %	Met %	Cys %	Phe %	Tyr %	Thr %	Trp %	Val %	Gly %	Ser %
1. Alfalfa, fresh 2-00-196	26.0	0.2	0.1	0.2	0.4	0.2	0.1	0.1	0.3	0.2	0.2	-	0.3	0.2	0.2
3. Alfalfa, dehy 17% CP 1-00-023 (NRC)	92.0	0.71	0.37	0.68	1.21	0.74	0.25	0.18	0.84	0.55	0.70	0.24	0.86	0.82	0.72
4. Alfalfa, dehy 20% CP 1-00-024 (NRC)	92.0	0.91	0.38	0.89	1.40	0.90	0.34	0.26	0.93	0.60	0.82	0.35	1.05	0.97	0.89
5. Bakery, waste, dehy 4-00-466 (NRC)	91.0	0.46	0.24	0.38	0.80	0.27	0.18	0.23	0.50	0.36	0.33	0.10	0.46	0.82	0.65
6. Barley, grain 4-00-572 (NRC)	89.0	0.54	0.25	0.39	0.77	0.41	0.20	0.28	0.55	0.29	0.35	0.11	0.52	-	-
8. Beet pulp, dehy 4-00-669 (NRC)	91.0	0.32	0.23	0.31	0.53	0.52	0.07	0.06	0.30	0.40	0.38	0.10	0.45	-	-
11. Blood, meal, spray dried 5-00-381 (NRC)	93.0	3.69	5.30	1.03	10.81	7.45	0.99	1.04	5.81	2.71	3.78	1.48	7.03	3.95	4.25
12. Blood, plasma, spray dried - (NRC)	92.0	4.55	2.55	2.71	7.61	6.84	0.75	2.63	4.42	3.53	4.72	1.36	4.94	-	-
15. Brewer's grain, dehy 5-02-141 (NRC)	92.0	1.53	0.53	1.02	2.08	1.08	0.45	0.49	1.22	0.88	0.95	0.26	1.26	1.09	0.80
16. Brewer's yeast, dehy 7-05-527 (NRC)	93.0	2.20	1.09	2.15	3.13	3.22	0.74	0.50	1.83	1.55	2.20	0.56	2.39	2.09	-
19. Buckwheat, grain 4-00-994 (NRC)	88.0	0.92	0.25	0.40	0.64	0.57	0.19	0.23	0.45	0.31	0.41	0.17	0.56	0.71	0.41
22. Canola, meal 5-06-145 (NRC)	90.0	2.21	0.96	1.43	2.58	2.08	0.74	0.91	1.43	1.13	1.59	0.45	1.82	1.82	1.53
23. Casein, dehy 5-01-162 (NRC)	91.0	3.26	2.82	4.66	8.79	7.35	2.70	0.41	4.79	4.77	3.98	1.14	6.10	1.79	5.81
24. Citrus pulp, dehy 4-01-237	91.1	0.2	0.1	0.1	0.3	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.3	0.2	0.2
29. Coconut, meal 5-01-573 (NRC)	92.0	2.38	0.39	0.75	1.36	0.58	0.35	0.29	0.84	0.58	0.67	0.19	1.07	0.82	0.79
31. Corn, DG, dehy 5-02-842 (NRC)	94.0	0.90	0.63	0.95	2.63	0.74	0.43	0.28	0.99	0.82	0.62	0.20	1.24	-	-
32. Corn, DG w/solubles 5-02-843 (NRC)	93.0	1.13	0.69	1.03	2.57	0.62	0.50	0.52	1.34	0.83	0.94	0.25	1.30	-	-
33. Corn, distiller's solubles 5-02-844 (NRC)	92.0	0.90	0.66	1.21	2.25	0.82	0.51	0.46	1.38	0.80	1.03	0.23	1.50	-	-
34. Corn, gluten feed 5-02-903 (NRC)	90.0	1.04	0.67	0.66	1.96	0.63	0.35	0.46	0.76	0.58	0.74	0.07	1.01	-	-
35. Corn, gluten meal, 60% CP 5-28-242 (NRC)	90.0	1.93	1.28	2.48	10.19	1.02	1.43	1.09	3.84	3.25	2.08	0.31	2.79	1.67	2.96
36. Corn, grain 4-02-935 (NRC)	89.0	0.37	0.23	0.28	0.99	0.26	0.17	0.19	0.39	0.25	0.29	0.06	0.39	0.33	0.37
37. Corn, hominy feed 4-03-011 (NRC)	90.0	0.56	0.28	0.36	0.98	0.38	0.18	0.18	0.43	0.40	0.40	0.10	0.52	0.40	0.50
41. Cottonseed, meal, mech ext 5-01-617 (NRC)	92.0	4.26	1.11	1.29	2.45	1.65	0.67	0.69	1.97	1.23	1.34	0.54	1.76	1.69	1.68
42. Cottonseed, meal, sol ext 5-07-872 (NRC)	90.0	4.55	1.17	1.30	2.47	1.72	0.67	0.70	2.20	1.22	1.36	0.48	1.78	1.69	1.78
43. Feather meal, hydrolyzed 5-03-795 (NRC)	93.0	5.62	0.93	3.86	6.79	2.08	0.61	4.13	4.01	2.41	3.82	0.54	5.88	6.13	8.52
46. Fish, anchovy, mech ext 5-01-985 (NRC)	92.0	3.68	1.56	3.06	5.00	5.11	1.95	0.61	2.66	2.15	2.82	0.76	3.51	3.68	2.51
47. Fish, herring, mech ext 5-02-000 (NRC)	93.0	4.01	1.52	2.91	5.20	5.46	2.04	0.66	2.75	2.18	3.02	0.74	3.46	4.30	2.75
48. Fish, menhaden, mech ext 5-02-009 (NRC)	92.0	3.66	1.78	2.57	4.54	4.81	1.77	0.57	2.51	2.04	2.64	0.66	3.03	4.46	2.37
49. Fish, white, mech ext 5-02-025 (NRC)	91.0	4.04	1.34	2.61	4.39	4.51	1.76	0.68	2.32	2.03	2.60	0.66	3.06	4.42	3.06
50. Fish, solubles, condensed 5-01-969 (NRC)	51.0	1.61	1.56	1.06	1.86	1.73	0.50	0.30	0.93	0.40	0.86	0.31	1.16	3.41	0.83
51. Fish, solubles, dehy 5-01-971 (NRC)	92.0	2.67	1.23	1.56	2.68	2.84	0.98	0.49	1.22	0.62	1.40	0.34	1.94	5.89	2.02

- Continues -

Table 3. Amino Acid Content (Continued)

Ingredient name/ description & IFN	DM %	Arg %	His %	Ile %	Leu %	Lys %	Met %	Cys %	Phe %	Tyr %	Thr %	Trp %	Val %	Gly %	Ser %
52. Meat meal, rend 5-00-385 (NRC)	94.0	3.60	1.14	1.60	3.84	3.07	0.80	0.60	2.17	1.40	1.97	0.35	2.66	6.30	1.60
53. Meat meal w/bones 5-00-388 (NRC)	93.0	3.45	0.91	1.34	2.98	2.51	0.68	0.50	1.62	1.07	1.59	0.28	2.04	6.65	2.20
54. Milk, skim, dehy 5-01-175 (NRC)	96.0	1.24	1.05	1.87	3.67	2.86	0.92	0.30	1.78	1.87	1.62	0.51	2.33	-	-
55. Millet, grain 4-03-120 (NRC)	90.0	0.41	0.20	0.46	1.24	0.23	0.31	0.18	0.56	0.31	0.40	0.16	0.57	0.31	0.40
58. Oats, grain 4-03-309 (NRC)	89.0	0.87	0.31	0.48	0.92	0.40	0.22	0.36	0.65	0.41	0.44	0.14	0.66	0.50	0.40
59. Oats, groats 4-03-331 (NRC)	90.0	0.85	0.24	0.55	0.98	0.48	0.20	0.22	0.66	0.51	0.44	0.18	0.72	-	-
61. Oats, hulls 1-03-281	92.4	0.2	0.1	0.2	0.3	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.3
66. Pea, seeds 5-03-600 (NRC)	89.0	1.87	0.54	0.86	1.51	1.50	0.21	0.31	0.98	0.71	0.78	0.19	0.98	1.00	1.08
67. Peanut, meal, mech ext 5-03-649 (NRC)	92.0	4.79	1.01	1.41	2.77	1.48	0.50	0.60	2.02	1.74	1.16	0.41	1.70	2.18	1.83
68. Peanut, meal, sol ext 5-03-650 (NRC)	92.0	5.09	1.06	1.78	2.83	1.66	0.52	0.69	2.35	1.80	1.27	0.48	1.98	2.67	2.25
69. Poultry by-pro, meal, rend 5-03-798 (NRC)	93.0	3.94	1.25	2.01	3.89	3.32	1.11	0.65	2.26	1.56	2.18	0.48	2.51	6.17	2.71
70. Rice, bran 4-03-928 (NRC)	90.0	1.00	0.34	0.44	0.92	0.57	0.26	0.27	0.56	0.40	0.48	0.14	0.68	0.70	0.59
71. Rice, grain/groats 4-03-932 (NRC)	89.0	0.52	0.18	0.34	0.67	0.30	0.18	0.11	0.39	0.38	0.26	0.10	0.49	0.50	0.44
72. Rice, hulls 1-08-075	91.9	0.10	0.0	0.1	0.2	0.1	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1
73. Rye, grain 4-04-047 (NRC)	88.0	0.50	0.24	0.37	0.64	0.38	0.17	0.19	0.50	0.26	0.32	0.12	0.51	0.49	0.52
75. Safflower, meal, sol ext 5-04-110 (NRC)	92.0	2.04	0.59	0.67	1.52	0.74	0.34	0.38	1.07	0.77	0.65	0.33	1.18	1.53	0.99
76. Safflower, meal wo/hulls 5-07-959 (NRC)	92.0	3.59	1.07	1.69	2.57	1.17	0.66	0.69	2.00	1.08	1.28	0.54	2.33	2.32	-
77. Sesame, meal, mech ext 5-04-220 (NRC)	93.0	4.86	0.98	1.47	2.74	1.01	1.15	0.82	1.77	1.52	1.44	0.54	1.85	2.04	1.72
78. Sorghum, grain 4-20-893 (NRC)	88.0	0.38	0.23	0.37	1.21	0.22	0.17	0.17	0.49	0.35	0.31	0.10	0.46	0.31	0.40
80. Soybean, hulls 1-04-560	90.3	0.5	0.2	0.3	0.5	0.5	0.1	0.1	0.3	0.3	0.3	0.1	0.3	0.5	0.6
81. Soybean, meal, sol ext 5-04-604 (NRC)	89.0	3.23	1.17	1.99	3.42	2.83	0.61	0.70	2.18	1.69	1.73	0.61	2.06	1.90	2.29
82. Soybean, meal wo/hulls 5-04-612 (NRC)	90.0	3.48	1.28	2.16	3.66	3.02	0.67	0.74	2.39	1.82	1.85	0.65	2.27	2.05	2.48
83. Soybean, prot conc - (NRC)	90.0	5.79	1.80	3.30	5.30	4.20	0.90	1.00	3.40	2.50	2.80	0.90	3.40	-	-
84. Soybean, seeds, heat proc 5-04-597 (NRC)	90.0	2.60	0.96	1.61	2.75	2.22	0.53	0.55	1.83	1.32	1.41	0.48	1.68	1.55	1.87
85. Sunflower, meal wo/hulls 5-04-739 (NRC)	93.0	2.93	0.92	1.44	2.31	1.20	0.82	0.66	1.66	1.03	1.33	0.44	1.74	2.03	1.49
88. Triticale, grain 4-20-362 (NRC)	90.0	0.57	0.26	0.39	0.76	0.39	0.20	0.26	0.49	0.32	0.36	0.14	0.51	0.48	0.52
90. Wheat, bran 4-05-190 (NRC)	89.0	1.07	0.44	0.49	0.98	0.64	0.25	0.33	0.62	0.43	0.52	0.22	0.72	0.81	0.67
91. Wheat, grain, hard red spring 4-05-258 (NRC)	88.0	0.67	0.34	0.47	0.93	0.38	0.23	0.30	0.67	0.40	0.41	0.16	0.61	-	-
92. Wheat, grain, hard red winter 4-05-268 (NRC)	88.0	0.60	0.32	0.41	0.86	0.34	0.20	0.29	0.60	0.38	0.37	0.15	0.54	0.59	0.59
93. Wheat, grain, soft red winter 4-05-294 (NRC)	88.0	0.50	0.20	0.45	0.90	0.38	0.22	0.27	0.63	0.37	0.39	0.26	0.57	-	-
96. Wheat, middlings 4-05-205 (NRC)	89.0	0.97	0.44	0.53	1.06	0.57	0.26	0.32	0.70	0.29	0.51	0.20	0.75	0.63	0.75
97. Wheat, red dog 4-05-203 (NRC)	88.0	0.96	0.41	0.55	1.06	0.59	0.23	0.37	0.66	0.46	0.50	0.10	0.72	0.74	0.75
98. Wheat, shorts 4-05-201 (NRC)	88.0	1.07	0.43	0.58	1.02	0.70	0.25	0.28	0.70	0.51	0.57	0.22	0.87	0.96	0.77
99. Whey, dehy 4-01-182 (NRC)	96.0	0.26	0.23	0.62	1.08	0.90	0.17	0.25	0.36	0.25	0.72	0.18	0.60	0.30	0.32
100. Yeast, Torula, dehy 7-05-534 (NRC)	93.0	2.48	1.09	2.50	3.32	3.47	0.69	0.50	2.33	1.65	2.30	0.51	2.60	2.60	2.76

4. **Table 4. Mineral Content** [DM = dry matter; mg/kg = ppm]

Ingredient name/ description & IFN	DM %	Ca %	Cl %	Mg %	P %	K %	Na %	S %	Co mg/kg	Cu mg/kg	I mg/kg	Fe mg/kg	Mn mg/kg	Se mg/kg	Zn mg/kg
1. Alfalfa, fresh	26.0	0.40	0.12	0.09	0.07	0.83	0.04	0.10	0.09	3.24	-	82.07	24.11	-	9.39
2-00-196	100.0	1.52	0.46	0.34	0.28	3.18	0.17	0.38	0.35	12.44	-	315.43	92.68	-	36.08
2. Alfalfa, hay	91.0	1.24	0.34	0.32	0.22	1.42	0.11	0.26	0.36	16.09	-	204.44	25.47	-	28.09
1-00-063	100.0	1.37	0.38	0.35	0.24	1.56	0.12	0.28	0.39	17.67	-	224.60	28.00	-	30.86
3. Alfalfa, dehy 17% CP	91.8	1.38	0.47	0.29	0.23	2.40	0.10	1.22	0.30	8.56	0.15	404.93	31.05	0.34	19.32
1-00-023	100.0	1.51	0.52	0.32	0.25	2.61	0.11	0.24	0.33	9.33	0.16	441.11	33.83	0.37	21.05
4. Alfalfa, dehy 20% CP	91.6	1.59	0.47	0.33	0.28	2.42	0.11	0.40	0.26	12.17	0.14	352.41	45.23	0.29	21.84
1-00-024	100.0	1.73	0.51	0.37	0.31	2.64	0.12	0.44	0.28	13.29	0.15	384.77	49.48	0.31	23.84
5. Bakery, waste, dehy	91.2	0.14	1.47	0.16	0.22	0.39	1.02	0.02	1.22	5.95	-	160.48	65.00	0.16	17.77
4-00-466	100.0	0.15	1.61	0.18	0.24	0.43	1.12	0.02	1.34	6.52	-	175.90	71.24	0.18	19.48
6. Barley, grain	88.6	0.05	0.11	0.13	0.34	0.44	0.03	0.14	0.17	8.16	0.04	73.52	15.81	0.17	41.75
4-00-549	100.0	0.05	0.12	0.15	0.38	0.49	0.03	0.16	0.19	9.22	0.05	83.02	17.85	0.19	47.14
7. Barley, straw	91.4	0.27	0.61	0.21	0.06	2.16	0.13	0.15	0.06	4.93	-	183.46	15.13	-	6.80
1-00-498	100.0	0.30	0.67	0.23	0.07	2.36	0.14	0.17	0.06	5.39	-	200.76	16.56	-	7.44
8. Beet pulp, dehy	91.0	0.62	0.04	0.26	0.09	0.20	0.18	0.20	0.07	12.51	-	266.69	34.27	0.10	0.70
4-00-669	100.0	0.68	0.04	0.28	0.10	0.22	0.20	0.22	0.06	13.74	-	293.00	37.65	0.12	0.76
9. Bermudagrass, fresh	28.9	0.14	-	0.07	0.08	0.54	0.13	-	0.02	1.98	-	323.95	30.54	-	10.12
2-00-712	100.0	0.49	-	0.23	0.29	1.87	0.44	-	0.07	6.85	-	1119.96	105.60	-	35.00
10. Bermudagrass, hay	91.2	0.43	-	0.16	0.16	1.40	0.07	0.19	0.11	24.29	0.10	264.31	99.37	-	53.00
1-00-703	100.0	0.47	-	0.17	0.17	1.53	0.08	0.20	0.12	26.64	0.11	289.96	109.02	-	58.14
11. Blood, meal, spray dried	92.6	0.22	0.25	0.15	0.20	0.15	0.38	0.60	-	8.19	-	2772.21	6.42	-	-
5-00-381	100.0	0.24	0.27	0.17	0.21	0.16	0.42	0.65	-	8.85	-	2993.49	6.93	-	-
12. Blood, plasma	91.0	0.15	1.50	0.34	1.71	0.20	3.02	-	-	-	-	55.00	-	-	-
- (NRC, 1998)															
13. Bluegrass, fresh	30.8	0.15	-	0.05	0.14	0.70	0.04	0.05	-	-	-	92.46	-	-	-
2-00-777	100.0	0.50	-	0.18	0.44	2.27	0.14	0.17	-	-	-	299.96	-	-	-
14. Bluegrass, hay	88.9	0.28	0.55	0.35	0.16	1.85	0.10	0.11	-	9.76	-	248.68	216.82	0.03	68.75
1-00-776	100.0	0.31	0.62	0.39	0.18	2.08	0.11	0.13	-	10.98	-	279.60	243.78	0.03	77.30
15. Brewer’s grain, dehy	92.2	0.29	0.13	0.15	0.51	0.09	0.20	0.29	0.07	21.71	0.06	233.09	37.22	0.14	27.31
5-02-141	100.0	0.32	0.14	0.16	0.55	0.09	0.22	0.32	0.08	23.56	0.07	252.94	40.39	0.16	29.63
16. Brewer’s yeast, dehy	93.1	0.14	0.07	0.24	1.36	1.68	0.07	0.43	0.50	38.44	0.35	83.20	6.74	0.91	38.97
7-05-527	100.0	0.15	0.07	0.26	1.47	1.81	0.08	0.47	0.54	41.31	0.38	89.40	7.24	0.97	41.88
17. Brome, fresh	27.0	-	-	-	-	-	-	-	0.02	-	-	-	-	-	-
2-00-963	100.0	-	-	-	-	-	-	-	0.07	-	-	-	-	-	-
18. Brome, hay	89.6	0.34	0.48	0.21	0.24	1.88	0.56	0.22	-	10.14	-	142.66	41.76	-	-
1-00-947	100.0	0.38	0.54	0.23	0.26	2.10	0.63	0.26	-	11.32	-	159.27	46.63	-	-
19. Buckwheat, grain	88.4	0.08	0.04	0.16	0.31	0.45	0.01	0.14	0.04	8.83	-	227.00	31.43	0.22	15.72
4-00-994	100.0	0.10	0.05	0.18	0.36	0.50	0.02	0.15	0.05	9.98	-	256.67	35.54	0.24	17.77
20. Canary grass, fresh	22.8	0.08	-	-	0.06	0.83	-	-	-	-	-	-	-	-	-
2-01-113	100.0	0.36	-	-	0.33	3.64	-	-	-	-	-	-	-	-	-
21. Canary grass, hay	89.3	0.32	-	0.19	0.21	2.60	0.01	-	-	10.62	-	133.88	82.48	-	-
1-01-104	100.0	0.36	-	0.22	0.24	2.91	0.02	-	-	11.89	-	150.00	92.40	-	-
22. Canola, meal	91.2	0.60	0.10	0.43	0.96	1.07	0.09	1.13	-	7.94	-	222.41	45.67	0.97	35.75
5-03-871	100.0	0.66	0.11	0.48	1.06	1.18	0.10	1.25	-	8.71	-	244..01	50.11	1.06	39.22
23. Casein, dehy	91.6	0.61	-	0.00	0.85	0.00	0.01	-	-	4.12	-	17.37	3.76	-	32.18
5-01-162	100.0	0.67	-	0.01	0.93	0.01	0.01	-	-	4.50	-	18.97	4.11	-	35.14
24. Citrus pulp, dehy	91.1	1.71	-	0.16	0.12	0.70	0.08	0.07	0.16	5.59	-	328.14	6.62	-	13.76
4-01-237	100.0	1.88	-	0.17	0.13	0.77	0.08	0.08	0.18	6.14	-	360.12	7.26	-	15.10
25. Clover, Landino, fresh	17.7	0.22	-	0.09	0.07	0.33	0.02	0.02	-	-	-	63.80	12.66	-	-
2-01-383	100.0	1.27	-	0.48	0.42	1.87	0.12	0.12	-	-	-	361.45	71.70	-	-
26. Clover, Landino, hay	89.1	1.30	0.27	0.42	0.30	2.17	0.12	0.18	0.14	8.38	0.26	418.66	109.73	-	15.15
1-01-378	100.0	1.45	0.30	0.47	0.33	2.44	0.13	0.21	0.16	9.41	0.30	469.68	123.10	-	17.00
27. Clover, Red, fresh	26.2	0.26	-	0.13	0.07	0.51	0.05	0.04	-	-	-	78.59	-	-	-
2-01-429	100.0	1.01	-	0.51	0.27	1.96	0.20	0.17	-	-	-	299.96	-	-	-
28. Clover, Red, hay	88.4	1.22	0.28	0.34	0.22	1.60	0.16	0.14	0.13	18.76	0.21	210.82	95.15	-	32.47
1-01-415	100.0	1.38	0.32	0.38	0.24	1.81	0.18	0.16	0.15	21.23	0.24	238.51	107.65	-	36.73
29. Coconut, meal	91.1	0.17	0.03	0.31	0.65	1.41	0.04	-	-	-	-	-	54.47	-	-
5-01-573	100.0	0.19	0.03	0.34	0.71	1.55	0.04	-	-	-	-	-	59.78	-	-
30. Corn, cobs, ground	89.8	0.11	-	0.06	0.04	0.78	-	o.42	0.11	6.55	-	206.61	5.57	-	-
1-02-782	100.0	0.12	-	0.07	0.04	0.87	-	0.48	0.13	7.30	-	229.98	6.20	-	-
31. Corn, DG, dehy	93.5	0.09	0.07	0.07	0.39	0.16	0.09	0.43	0.07	38.94	0.04	191.73	19.32	0.35	41.74
5-02-842	100.0	0.10	0.08	0.07	0.42	0.17	0.09	0.46	0.08	41.66	0.05	205.13	20.67	0.37	44.65
32. Corn, DG w/solubles	91.8	0.16	0.17	0.18	0.69	0.47	0.47	0.30	0.15	52.60	0.05	231.33	23.98	0.33	80.68
5-02-843	100.0	0.17	0.18	0.20	0.75	0.51	0.52	0.33	0.16	57.31	0.05	252.07	26.11	0.36	87.91
33. Corn, distiller’s solubles	92.9	0.30	0.26	0.60	1.30	1.70	0.23	0.37	0.16	77.92	0.07	519.99	72.04	0.37	88.03
5-02-844	100.0	0.32	0.28	0.65	1.40	1.83	0.24	0.39	0.17	83.91	0.08	559.97	77.58	0.39	94.80
34. Corn, gluten feed	89.9	0.32	0.22	0.33	0.75	0.62	0.12	0.23	0.08	43.86	0.06	413.78	22.75	0.25	68.65
5-02-903	100.0	0.35	0.25	0.37	0.83	0.69	0.13	0.26	0.09	48.77	0.07	460.15	25.30	0.28	76.34
35. Corn, gluten meal	91.3	0.15	0.06	0.06	0.48	0.03	0.09	0.27	0.07	27.65	-	383.55	7.73	1.01	173.65
5-02-900	100.0	0.16	0.07	0.06	0.51	0.03	0.10	0.30	0.08	30.29	-	420.06	8.46	1.11	190.18

- Continues -

Table 4. Mineral Content (Continued)

Ingredient name/ description & IFN	DM %	Ca %	Cl %	Mg %	P %	K %	Na %	S %	Co mg/kg	Cu mg/kg	I mg/kg	Fe mg/kg	Mn mg/kg	Se mg/kg	Zn mg/kg
36. Corn, grain	88.0	0.05	0.05	0.11	0.27	0.32	0.01	0.11	0.12	3.67	-	30.96	5.47	0.12	19.02
4-02-935	100.0	0.05	0.06	0.12	0.31	0.37	0.01	0.12	0.14	4.17	-	35.20	6.22	0.13	21.63
37. Corn, hominy feed	90.2	0.05	0.05	0.24	0.51	0.59	0.08	0.03	0.05	13.60	-	67.28	14.51	-	-
4-02-887	100.0	0.05	0.06	0.26	0.57	0.65	0.09	0.03	0.06	15.08	-	74.58	16.09	-	-
38. Corn, silage	34.1	0.09	-	0.10	0.07	0.36	0.00	0.02	0.02	4.51	-	218.29	11.73	-	7.14
3-02-823	100.0	0.27	-	0.28	0.20	1.05	0.01	0.08	0.06	13.22	-	639.96	34.39	-	20.94
39. Cottonseed, hulls	90.4	0.13	0.02	0.13	0.08	0.79	0.02	0.07	0.01	11.98	-	118.65	107.76	0.08	19.84
1-01-599	100.0	0.15	0.02	0.14	0.09	0.88	0.02	0.08	0.01	13.26	-	131.27	119.22	0.09	21.95
40. Cottonseed, ground	92.2	0.14	-	0.32	0.67	1.10	0.03	0.23	-	50.27	-	138.72	8.79	-	-
5-01-608	100.0	0.15	-	0.35	0.73	1.20	0.03	0.25	-	54.54	-	150.51	9.54	-	-
41. Cottonseed, meal, mech ext	92.6	0.19	0.05	0.53	1.08	1.34	0.04	0.39	0.62	18.54	-	170.63	22.30	0.13	61.88
5-01-617	100.0	0.20	0.06	0.57	1.17	1.44	0.05	0.42	0.67	20.01	-	184.18	24.07	0.14	66.80
42. Cottonseed, meal, sol ext	91.0	0.17	0.05	0.54	1.11	1.38	0.04	0.26	0.48	19.49	-	187.71	20.66	0.37	60.74
5-01-621	100.0	0.18	0.05	0.59	1.22	1.52	0.05	0.28	0.53	21.42	-	206.27	22.70	0.41	66.75
43. Feather meal, hydrolyzed	92.9	0.35	0.28	0.17	0.51	0.27	0.52	1.49	0.11	7.31	0.04	523.14	11.94	0.91	71.83
5-03-795	100.0	0.38	0.30	0.19	0.55	0.29	0.56	1.61	0.12	7.86	0.04	563.10	12.86	0.98	77.32
44. Fescue, fresh	28.4	0.15	-	0.11	0.11	0.67	-	-	0.03	1.13	-	-	-	-	-
2-01-920	100.0	0.53	-	0.37	0.39	2.34	-	-	0.13	4.00	-	-	-	-	-
45. Fescue, hay	87.5	0.33	-	0.44	0.25	1.61	-	-	0.11	-	-	-	21.44	-	-
1-01-912	100.0	0.37	-	0.50	0.29	1.84	-	-	0.13	-	-	-	24.50	-	-
46. Fish, anchovy, mech ext	92.0	3.74	1.00	0.25	2.48	0.72	0.88	0.71	0.17	9.08	3.13	214.74	10.99	1.35	105.03
5-01-985	100.0	40.07	1.08	0.27	2.70	0.78	0.95	0.77	0.18	9.87	3.41	233.48	11.95	1.47	114.20
47. Fish, herring, mech ext	91.8	2.19	0.99	0.14	1.67	1.08	0.59	0.49	0.05	5.60	0.52	114.34	4.80	1.95	124.72
5-02-000	100.0	2.39	1.08	0.16	1.82	1.18	0.65	0.54	0.05	6.10	0.57	124.50	5.22	2.12	135.80
48. Fish, menhaden, mech ext	91.7	5.01	0.55	0.15	2.87	0.71	0.41	0.52	0.15	10.34	1.09	544.58	37.02	2.14	144.32
5-02-009	100.0	5.46	0.60	0.16	3.14	0.77	0.44	0.57	0.16	11.28	1.19	594.15	40.38	2.34	157.45
49. Fish, white, mech ext	91.2	6.64	-	0.18	3.97	0.53	0.62	-	3.38	4.09	-	250.93	10.04	1.61	68.43
5-02-025	100.0	7.27	-	0.20	4.35	0.58	0.68	-	3.68	4.48	-	275.03	11.00	1.77	75.00
50. Fish, solubles, condensed	50.4	0.17	3.00	0.03	0.58	1.66	2.50	0.12	0.06	47.38	1.11	325.29	12.58	-	43.14
5-01-969	100.0	0.33	5.95	0.06	1.11	3.29	4.97	0.24	0.13	93.96	2.20	645.08	24.95	-	85.56
51. Fish, solubles, dehy	92.8	1..09	-	0.30	1.27	-	0.37	-	-	-	-	-	50.44	-	76.65
5-01-971	100.0	1.17	-	0.32	1.37	-	0.40	-	-	-	-	-	54.35	-	82.59
52. Meat meal, rend	93.8	8.61	1.11	0.25	4.58	0.55	1.04	0.46	2.25	9.60	-	490.38	11.80	0.50	74.30
5-00-385	100.0	9.17	1.18	0.27	4.88	0.58	1.11	0.49	2.40	10.24	-	522.77	12.58	0.54	79.21
53. Meat meal w/bones	93.3	10.00	0.75	1.02	4.96	1.33	0.72	0.25	0.18	1.54	1.32	653.23	13.33	0.34	94.37
5-00-388	100.0	10.71	0.80	1.09	5.32	1.43	0.77	0.27	0.19	1.65	1.41	699.93	14.29	0.39	101.11
54. Milk, skim, dehy	94.1	1.28	0.90	0.12	1.02	1.60	0.51	0.32	0.11	11.68	-	7.67	2.14	0.12	38.51
5-01-175	100.0	1.36	0.96	0.13	1.09	1.70	0.54	0.34	0.12	12.41	-	8.14	2.27	0.13	40.91
55. Millet, grain	89.9	0.05	0.14	0.16	0.29	0.43	0.04	0.12	0.04	21.75	-	57.44	29.67	-	13.88
4-03-098	100.0	0.05	0.16	0.18	0.32	0.48	0.04	0.14	0.04	24.19	-	63.89	33.00	-	15.43
56. Molasses, sugar beet	77.9	0.12	1.28	0.23	0.02	4.72	1.16	0.46	0.36	16.79	-	66.06	4.50	-	14.02
4-00-668	100.0	0.15	1.64	0.29	0.03	6.06	1.48	0.59	0.46	21.55	-	87.39	5.78	-	18.00
57. Molasses, sugarcane	74.3	0.74	2.26	0.31	0.08	2.98	0.16	0.34	1.17	48.82	1.56	195.83	43.68	-	15.56
4-04-696	100.0	1.00	3.04	0.42	0.10	4.01	0.22	0.47	1.58	65.69	2.10	163.48	58.76	-	20.93
58. Oats, grain	89.2	0.08	0.09	0.14	0.34	0.40	0.05	0.21	0.05	5.95	0.11	65.45	36.14	0.21	35.03
4-03-309	100.0	0.09	0.10	0.16	0.38	0.45	0.06	0.23	0.06	6.67	0.12	73.35	40.51	0.24	39.25
59. Oats, groats	89.6	0.08	0.09	0.11	0.42	0.36	0.03	0.19	-	6.02	0.10	71.00	30.77	0.45	33.58
4-03-331	100.0	0.09	0.10	0.13	0.47	0.40	0.04	0.22	-	6.72	0.12	79.29	34.37	0.50	37.50
60. Oats, hay	90.7	0.29	0.47	0.26	0.23	1.35	0.17	0.21	0.06	4.37	-	368.66	89.56	-	40.82
1-03-280	100.0	0.32	0.52	0.29	0.25	1.49	0.18	0.23	0.07	4.82	-	406.43	98.74	-	45.00
61. Oats, hulls	92.4	0.15	0.08	0.12	0.14	0.55	0.06	0.09	-	6.59	-	128.00	25.35	0.39	26.89
1-03-281	100.0	0.16	0.06	0.13	0.15	0.59	0.07	0.10	-	7.13	-	138.51	27.43	0.43	29.10
62. Oats, silage	30.5	0.10	-	0.05	0.07	0.81	0.06	0.05	0.02	1.39	-	85.82	27.71	0.02	7.30
3-03-298	100.0	0.34	-	0.15	0.24	2.66	0.18	0.18	0.08	4.56	-	281.60	90.94	0.08	23.94
63. Oats, straw	92.2	0.22	0.71	0.16	0.06	2.33	0.39	0.20	-	9.46	-	151.21	28.99	-	5.47
1-03-283	100.0	0.23	0.78	0.17	0.06	2.53	0.42	0.22	-	10.27	-	164.04	31.45	-	5.94
64. Orchardgrass, fresh	23.5	0.06	-	0.07	0.09	0.80	0.01	0.06	-	7.76	-	184.76	24.49	-	-
2-03-442	100.0	0.25	-	0.31	0.39	3.38	0.04	0.26	-	33.06	-	784.96	104.06	-	-
65. Orchardgrass, hay	89.6	0.37	0.37	0.17	0.23	2.69	0.01	0.21	0.34	12.98	-	134.01	163.40	0.04	29.86
1-03-438	100.0	0.41	0.41	0.19	0.26	3.00	0.02	0.23	0.37	14.48	-	149.48	182.27	0.04	33.31
66. Pea, seeds	89.1	0.12	0.05	0.12	0.41	0.95	0.04	-	-	-	-	64.57	2.89	-	22.90
5-03-600	100.0	0.14	0.06	0.14	0.46	1.06	0.04	-	-	-	-	72.45	3.24	-	25.70
67. Peanut, meal, mech ext	92.6	0.20	0.03	0.27	0.56	1.15	0.08	0.23	0.11	15.40	0.06	296.41	25.52	-	33.00
5-03-649	100.0	0.22	0.03	0.29	0.60	1.24	0.09	0.25	0.12	16.62	0.07	320.07	27.56	-	35.64
68. Peanut, meal, sol ext	92.4	0.36	0.03	0.27	0.61	1.18	0.03	0.30	-	-	-	-	-	-	-
5-03-650	100.0	0.39	0.03	0.30	0.66	1.28	0.03	0.32	-	-	-	-	-	-	-
69. Poultry by-pro, meal, rend	93.8	3.95	0.54	0.17	2.06	0.52	0.78	0.51	4.92	19.87	3.10	639.00	16.51	0.91	117.41
5-03-798	100.0	4.21	0.58	0.19	2.19	0.55	0.83	0.55	5.26	21.18	3.30	681.08	17.60	0.98	125.15
70. Rice, bran	90.5	0.09	0.07	0.88	1.57	1.71	0.03	0.18	1.38	10.99	-	207.39	358.47	-	43.81
4-03-928	100.0	0.10	0.08	0.97	1.73	1.89	0.03	0.20	1.52	12.14	-	229.09	395.98	-	48.39

- Continues -

Table 4. Mineral Content (Continued)

Ingredient name/ description & IFN	DM %	Ca %	Cl %	Mg %	P %	K %	Na %	S %	Co mg/kg	Cu mg/kg	I mg/kg	Fe mg/kg	Mn mg/kg	Se mg/kg	Zn mg/kg
71. Rice, grain/groats	88.5	0.02	-	0.04	0.11	0.10	0.00	0.04	-	2.85	-	10.71	8.66	0.27	8.59
4-03-932	100.0	0.02	-	0.04	0.13	0.11	0.00	0.04	-	3.22	-	12.09	9.79	0.30	9.70
72. Rice, hulls	91.9	0.11	0.07	0.34	0.07	0.60	0.02	0.07	-	3.10	-	91.28	294.08	0.13	21.95
1-08-075	100.0	0.12	0.08	0.37	0.07	0.65	0.02	0.08	-	3.38	-	99.37	320.11	0.15	23.89
73. Rye, grain	87.5	0.06	0.03	0.11	0.32	0.45	0.02	0.14	-	7.55	-	62.83	72.01	-	28.47
4-04-047	100.0	0.07	0.03	0.12	0.36	0.51	0.03	0.16	-	8.63	-	71.80	82.30	-	32.54
74. Ryegrass, fresh	22.6	0.15	-	0.08	0.09	0.45	0.00	0.02	-	-	-	225.79	-	-	-
2-04-073	100.0	0.65	-	0.35	0.41	2.00	0.01	0.10	-	-	-	1000.0	-	-	-
75. Safflower, meal, sol ext	91.7	0.34	-	0.34	0.76	0.75	0.05	0.12	-	9.87	-	496.54	18.15	-	40.53
5-04-110	100.0	0.37	-	0.37	0.83	0.81	0.05	0.14	-	10.77	-	541.65	19.80	-	44.21
76. Safflower, meal wo/hulls	91.0	0.38	0.16	0.99	1.40	1.08	0.04	0.17	2.02	88.47	-	860.22	40.21	-	185.98
5-07-959	100.0	0.39	0.18	1.08	1.53	1.19	0.05	0.19	2.22	97.20	-	945.13	44.18	-	204.34
77. Sesame, meal, mech ext	92.7	2.01	0.06	0.46	1.36	1.27	0.05	0.35	-	-	-	92.70	47.76	-	99.67
5-04-220	100.0	2.17	0.07	0.50	1.46	1.37	0.05	0.38	-	-	-	100.0	51.51	-	107.51
78. Sorghum, grain	90.1	0.04	0.07	0.15	0.32	0.37	0.01	0.13	0.27	5.41	-	57.17	12.33	0.41	26.77
4-04-383	100.0	0.04	0.06	0.17	0.36	0.41	0.01	0.15	0.30	6.00	-	63.48	13.70	0.45	29.73
79. Sorghum, sorgo, silage	28.8	0.10	0.02	0.08	0.06	0.32	0.04	0.02	-	8.97	-	57.22	17.60	-	-
3-04-468	100.0	0.35	0.06	0.27	0.21	1.12	0.15	0.10	-	31.13	-	198.42	61.03	-	-
80. Soybean, hulls	90.3	0.48	0.02	0.20	0.17	1.17	0.02	0.09	0.10	16.07	-	369.35	9.92	0.12	43.27
1-04-560	100.0	0.53	0.02	0.22	0.18	1.29	0.03	0.11	0.12	17.80	-	409.10	10.99	0.14	47.93
81. Soybean, meal, sol ext	89.6	0.30	0.04	0.29	0.69	2.10	0.04	0.42	1.39	17.92	0.13	140.55	30.61	0.43	51.84
5-04-604	100.0	0.34	0.04	0.32	0.77	2.34	0.04	0.47	1.56	20.00	0.14	156.85	34.18	0.48	57.85
82. Soybean, meal wo/hulls	89.9	0.26	0.04	0.29	0.64	2.12	0.01	0.43	0.06	20.24	0.10	130.39	37.13	0.19	57.11
5-04-612	100.0	0.29	0.05	0.33	0.71	2.36	0.01	0.48	0.07	22.50	0.12	144.28	41.28	0.21	63.50
83. Soybean, prot conc	90.0	0.35	-	0.32	0.81	2.20	0.05	-	-	13.00	-	110.00	-	-	30
- (NRC, 1998)															
84. Soybean, seeds, heat proc	92.6	0.26	-	0.22	0.61	1.75	0.03	-	-	-	-	-	-	-	-
5-04-597	100.0	0.28	-	0.23	0.66	1.89	0.03	-	-	-	-	-	-	-	-
85. Sunflower, meal wo/hulls	92.5	0.42	0.15	0.65	0.94	1.17	0.03	0.30	-	37.76	-	262.99	18.91	2.12	97.57
5-04-739	100.0	0.45	0.17	0.70	1.02	1.27	0.03	0.33	-	40.84	-	284.41	20.45	2.29	105.52
86. Timothy, fresh	26.7	0.11	-	0.04	0.07	0.73	0.03	0.03	0.04	2.38	-	35.37	33.92	-	9.55
2-04-903	100.0	0.40	-	0.16	0.26	2.73	0.11	0.13	0.14	8.92	-	132.27	126.85	-	35.70
87. Timothy, hay	89.1	0.45	-	0.11	0.25	2.14	0.01	0.11	-	57.05	-	180.95	91.81	-	55.27
1-04-882	100.0	0.51	-	0.13	0.29	2.41	0.01	0.13	-	64.00	-	203.00	103.00	-	62.00
88. Triticale, grain	89.2	0.05	-	0.23	0.33	0.51	0.01	-	0.07	8.30	-	43.99	42.66	-	31.30
4-20-362	100.0	0.05	-	0.26	0.37	0.57	0.01	-	0.08	9.31	-	49.34	47.84	-	35.11
89. Urea	97.0	0.09	-	-	-	-	0.02	-	-	6.79	-	175.58	-	-	6.79
5-05-070	100.0	0.09	-	-	-	-	0.02	-	-	7.00	-	180.98	-	-	7.00
90. Wheat, bran	89.0	0.13	0.05	0.56	1.13	1.22	0.05	0.21	0.07	12.61	0.06	144.80	119.34	0.50	97.71
4-05-190	100.0	0.14	0.06	0.63	1.27	1.37	0.06	0.23	0.08	14.16	0.07	162.65	134.05	0.56	109.76
91. Wheat, grain, hard red spring	87.6	0.03	0.08	0.15	0.37	0.36	0.02	0.14	0.12	6.16	-	56.40	36.72	0.22	43.95
4-05-258	100.0	0.04	0.09	0.17	0.43	0.41	0.02	0.17	0.14	7.03	-	64.38	41.92	0.26	50.17
92. Wheat, grain, hard red winter	88.8	0.04	0.05	0.13	0.38	0.43	0.02	0.13	0.14	4.91	-	36.34	34.65	0.25	32.98
4-05-268	100.0	0.05	0.06	0.14	0.42	0.48	0.02	0.14	0.16	5.53	-	40.93	39.02	0.28	37.14
93. Wheat, grain, soft red winter	88.4	0.05	0.07	0.10	0.36	0.41	0.01	0.10	0.10	7.03	-	28.98	33.39	0.04	42.14
4-05-294	100.0	0.06	0.08	0.11	0.40	0.46	0.01	0.12	0.11	7.95	-	32.79	37.77	0.04	47.67
94. Wheat, grain, soft white winter	90.2	-	-	0.10	0.30	0.39	0.02	0.11	0.13	7.03	-	36.09	36.09	0.04	27.07
4-05-337	100.0	-	-	0.11	0.33	0.43	0.02	0.13	0.15	7.80	-	40.00	40.00	0.05	30.00
95. Wheat, hay	88.7	0.13	-	0.11	0.18	0.88	0.19	0.19	-	-	-	177.49	-	-	-
1-05-172	100.0	0.15	-	0.12	0.20	0.99	0.21	0.21	-	-	-	200.00	-	-	-
96. Wheat, middlings	88.9	0.13	0.04	0.34	0.89	0.98	0.02	0.16	0.10	15.89	0.10	89.78	114.16	0.73	97.08
4-05-205	100.0	0.14	0.05	0.38	1.00	1.10	0.02	0.18	0.11	17.87	0.12	100.94	128.35	0.82	109.14
97. Wheat, red dog	88.3	0.06	0.11	0.19	0.53	0.52	0.01	0.22	0.11	6.27	-	49.65	52.17	0.36	65.07
4-05-203	100.0	0.07	0.13	0.21	0.60	0.58	0.01	0.25	0.13	7.10	-	56.20	59.06	0.41	73.66
98. Wheat, shorts	88.4	0.08	0.05	0.27	0.90	0.93	0.02	0.19	0.10	11.51	-	73.48	114.18	0.47	102.49
4-05-201	100.0	0.10	0.06	0.31	1.01	1.05	0.03	0.21	0.11	13.01	-	83.07	129.10	0.53	115.87
99. Whey, dehy	93.3	0.85	0.07	0.13	0.76	1.16	0.62	1.04	0.11	46.51	-	194.15	5.86	-	4.79
4-01-182	100.0	0.92	0.08	0.14	0.81	1.25	0.66	1.11	0.11	49.87	-	208.15	6.29	-	5.14
100. Yeast, Torula, dehy	93.0	0.55	0.02	0.14	1.61	1.91	0.01	0.48	0.03	12.08	2.50	105.96	9.68	0.05	99.48
7-05-534	100.0	0.59	0.02	0.15	1.73	2.06	0.01	0.51	0.03	12.99	2.68	113.88	10.38	0.05	106.92

5. **Table 5. Vitamin Content** [DM = dry matter; Vitam = vitamin; IU = international unit; ICU = international chock unit; mg/kg = ppm]

Ingredient name/ description & IFN	DM %	Carotene mg/kg	Vitam D_2/D_3 IU/kg	Vitam D_s ICU/kg	Vitam E mg/kg	Vitam K mg/kg	Biotin mg/kg	Choline mg/kg	Folate mg/kg	Niacin mg/kg	Pantothenic acid mg/kg	Riboflavin mg/kg	Thiamin mg/kg	Vitam B_6 mg/kg	Vitam B_{12} μg/kg
1. Alfalfa, fresh	26.0	-	0.0	-	-	-	0.12	374	0.64	15.4	8.9	4.6	1.65	1.66	-
2-00-196	100.0	-	0.2	-	-	-	0.48	1439	2.47	59.1	34.3	17.5	6.35	6.38	-
2. Alfalfa, hay	91.0	-	1.4	-	-	-	-	-	-	-	-	9.6	-	-	-
1-00-063	100.0	-	1.5	-	-	-	-	-	-	-	-	10.6	-	-	-
3. Alfalfa, dehy 17% CP	91.8	-	-	-	105.9	8.2	0.32	1349	4.37	37.0	29.8	12.9	3.39	7.19	-
1-00-023	100.0	-	-	-	115.3	9.0	0.35	1470	4.76	40.3	32.4	14.1	3.69	7.83	-
4. Alfalfa, dehy 20% CP	91.6	-	-	-	143.3	14.2	0.35	1417	2.96	48.0	35.5	15.2	5.36	8.72	-
1-00-024	100.0	-	-	-	256.4	15.5	0.38	1547	3.24	52.4	38.8	16.6	5.85	9.52	-
5. Bakery, waste, dehy	91.2	-	-	-	41.0	-	0.06	916	0.18	25.6	8.2	1.4	2.92	4.29	-
4-00-466	100.0	-	-	-	44.9	-	0.07	1004	0.20	28.0	9.0	1.5	3.20	4.70	-
6. Barley, grain	88.6	-	-	-	23.2	0.2	0.15	1037	0.57	78.5	8.1	1.6	4.52	6.48	-
4-00-549	100.0	-	-	-	26.2	0.2	0.17	1170	0.64	88.6	9.1	1.8	5.11	7.32	-
7. Barley, straw	91.4	-	0.6	-	-	-	-	-	-	-	-	-	-	-	-
1-00-498	100.0	-	0.7	-	-	-	-	-	-	-	-	-	-	-	-
8. Beet pulp, dehy	91.0	-	0.6	-	-	-	-	820	-	16.8	1.4	0.7	0.39	-	-
4-00-669	100.0	-	0.6	-	-	-	-	901	-	18.4	1.5	0.8	0.42	-	-
11. Blood, meal, spray dried	92.6	-	-	-	-	-	0.27	597	0.37	22.2	3.2	2.9	0.32	4.44	12.20
5-00-381	100.0	-	-	-	-	-	0.30	645	0.40	23.9	3.5	3.1	0.35	4.79	13.18
13. Bluegrass, fresh	30.8	-	-	-	47.8	-	-	-	-	-	-	-	-	-	-
2-00-777	100.0	-	-	-	155.0	-	-	-	-	-	-	-	-	-	-
14. Bluegrass, hay	88.9	-	-	-	-	-	-	-	-	-	-	9.9	-	-	-
1-00-776	100.0	-	-	-	-	-	-	-	-	-	-	11.1	-	-	-
15. Brewer's grain, dehy	92.2	-	-	-	26.7	-	0.44	1651	0.22	43.7	8.2	1.5	0.63	1.03	3.63
5-02-141	100.0	-	-	-	29.0	-	0.48	1792	0.24	47.4	8.9	1.6	0.68	1.11	3.94
16. Brewer's yeast, dehy	93.1	-	-	-	2.1	-	1.04	3847	9.69	443.3	81.5	33.6	85.21	36.66	1.06
7-05-527	100.0	-	-	-	2.3	-	1.11	4133	10.41	476.4	87.6	36.1	91.56	39.40	1.14
17. Brome, fresh	27.0	-	0.0	-	-	-	-	-	-	-	-	2.1	0.83	-	-
2-00-963	100.0	-	0.1	-	-	-	-	-	-	-	-	7.7	3.09	-	-
19. Buckwheat, grain	88.4	-	-	-	-	-	-	442	-	18.4	11.6	4.8	3.75	-	-
4-00-994	100.0	-	-	-	-	-	-	500	-	20.9	13.1	5.4	4.24	-	-
21. Canary grass, hay	89.3	-	-	-	-	-	-	-	-	-	-	8.5	3.57	-	-
1-01-104	100.0	-	-	-	-	-	-	-	-	-	-	9.5	4.00	-	-
22. Canola, meal	91.2	-	-	-	-	-	-	6633	-	146.8	8.0	5.8	1.59	7.25	-
5-03-871	100.0	-	-	-	-	-	-	7277	-	161.1	8.8	6.4	1.74	7.95	-
23. Casein, dehy	91.6	-	-	-	-	-	0.04	210	0.46	1.3	2.7	1.5	0.42	0.43	-
5-01-162	100.0	-	-	-	-	-	0.04	230	0.50	1.4	2.9	1.7	0.46	0.47	-
24. Citrus pulp, dehy	91.1	-	-	-	-	-	-	790	-	22.2	14.0	2.1	1.47	-	-
4-01-237	100.0	-	-	-	-	-	-	867	-	24.4	15.4	2.3	1.61	-	-
25. Clover, Landino, fresh	17.7	-	-	-	-	-	-	-	-	-	-	4.2	-	-	-
2-01-383	100.0	-	-	-	-	-	-	-	-	-	-	24.1	-	-	-
26. Clover, Landino, hay	89.1	-	-	-	-	-	-	-	-	9.8	1.0	15.2	3.74	-	-
1-01-378	100.0	-	-	-	-	-	-	-	-	11.0	1.1	17.0	4.20	-	-
28. Clover, Red, hay	88.4	-	-	-	-	-	0.09	-	-	37.7	9.9	15.7	1.97	-	-
1-01-415	100.0	-	-	-	-	-	0.10	-	-	42.6	11.2	17.8	2.22	-	-
29. Coconut, meal	91.1	-	-	-	-	-	-	1089	0.30	23.8	6.5	3.5	-	4.36	-
5-01-573	100.0	-	-	-	-	-	-	1195	0.33	26.1	7.2	3.8	-	4.78	-
30. Corn, cobs, ground	89.8	-	-	-	-	-	-	-	-	7.0	3.8	1.0	0.90	-	-
1-02-782	100.0	-	-	-	-	-	-	-	-	7.8	4.2	1.1	1.00	-	-
31. Corn, DG, dehy	93.5	-	-	-	-	-	0.41	1113	1.00	38.3	11.3	5.0	1.77	4.22	0.25
5-02-842	100.0	-	-	-	-	-	0.44	1190	1.06	41.0	12.1	5.3	1.90	4.51	0.27
32. Corn, DG w/solubles	91.8	-	0.6	-	39.8	-	0.68	2581	0.91	73.4	13.8	8.5	3.01	4.74	1.51
5-02-843	100.0	-	0.6	-	43.4	-	0.74	2813	0.99	80.0	15.1	9.2	3.28	5.17	1.64
33. Corn, distiller's solubles	92.9	-	-	-	45.9	-	1.49	4750	1.34	123.6	23.3	15.1	6.76	9.41	4.18
5-02-844	100.0	-	-	-	49.4	-	1.60	5116	1.45	133.2	25.0	16.3	7.27	10.14	4.50
34. Corn, gluten feed	89.9	-	-	-	12.1	-	0.30	1587	0.27	70.5	13.6	2.2	1.99	13.93	-
5-02-903	100.0	-	-	-	13.5	-	0.34	1765	0.30	78.4	15.1	2.5	2.21	15.49	-
35. Corn, gluten meal	91.3	-	-	-	29.2	-	0.19	360	0.30	49.8	10.0	1.5	0.22	7.97	-
5-02-900	100.0	-	-	-	32.0	-	0.20	394	0.33	54.6	10.9	1.6	0.24	8.73	-
36. Corn, grain	88.0	-	-	-	20.9	0.2	0.06	495	0.31	22.5	5.1	1.1	3.73	6.16	-
4-02-935	100.0	-	-	-	23.8	0.2	0.07	563	0.35	25.6	5.8	1.2	4.24	7.01	-
37. Corn, hominy feed	90.2	-	-	-	-	-	0.13	1154	0.31	46.9	8.2	2.1	8.05	10.95	-
4-02-8878,	100.0	-	-	-	-	-	0.14	1279	0.34	52.0	9.1	2.4	8.92	12.14	-
38. Corn, silage	34.1	-	0.0	-	-	-	-	-	-	-	-	-	-	-	-
3-02-823	100.0	-	0.1	-	-	-	-	-	-	-	-	-	-	-	-
39. Cottonseed, hulls	90.4	-	-	-	-	-	-	-	-	-	-	3.7	-	-	-
1-01-599	100.0	-	-	-	-	-	-	-	-	-	-	4.1	-	-	-

- Continues -

Table 5. Vitamin Content (Continued)

Ingredient name/ description & IFN	DM %	Carotene mg/kg	Vitam D_2/D_3 IU/kg	Vitam D_s ICU/kg	Vitam E mg/kg	Vitam K mg/kg	Biotin mg/kg	Choline mg/kg	Folate mg/kg	Niacin mg/kg	Pantothenic acid mg/kg	Riboflavin mg/kg	Thiamin mg/kg	Vitam B_6 mg/kg	Vitam B_{12} μg/kg
41. Cottonseed, meal, mech ext	92.6	-	-	-	32.4	-	0.91	2755	2.45	35.2	10.2	5.2	7.07	5.01	-
5-01-617	100.0	-	-	-	34.9	-	0.98	2974	2.65	38.0	11.0	5.6	7.63	5.41	-
42. Cottonseed, meal, sol ext	91.0	-	-	-	14.6	-	0.55	2782	2.55	40.9	13.7	4.7	7.32	5.41	-
5-01-621	100.0	-	-	-	16.1	-	0.61	3058	2.81	44.9	15.1	5.2	8.04	5.95	-
43. Feather meal, hydrolyzed	92.9	-	-	-	-	-	0.04	894	0.22	21.1	8.9	2.0	0.11	4.39	80.35
5-03-795	100.0	-	-	-	-	-	0.04	962	0.23	22.7	9.6	2.2	0.12	4.72	86.49
44. Fescue, fresh	28.4	-	-	-	46.9	-	-	-	-	-	-	2.4	3.38	-	-
2-01-920	100.0	-	-	-	165.1	-	-	-	-	-	-	8.6	11.90	-	-
45. Fescue, hay	87.5	-	-	-	118.6	-	-	-	-	-	-	-	-	-	-
1-01-912	100.0	-	-	-	135.6	-	-	-	-	-	-	-	-	-	-
46. Fish, anchovy, mech ext	92.0	-	-	-	3.7	-	0.19	3700	0.16	80.5	10.0	7.3	0.52	4.71	14.47
5-01-985	100.0	-	-	-	4.0	-	0.21	4023	0.17	87.6	10.9	8.0	0.57	5.12	33.19
47. Fish, herring, mech ext	91.8	-	-	-	22.0	2.2	0.48	5262	0.34	85.2	17.3	9.7	0.38	4.65	28.79
5-02-000	100.0	-	-	-	24.0	2.3	0.53	5730	0.37	92.8	18.8	10.6	0.41	5.06	66.91
48. Fish, menhaden, mech ext	91.7	-	-	-	6.8	-	0.17	3114	0.15	54.6	8.6	4.8	0.57	3.81	22.12
5-02-009	100.0	-	-	-	7.4	-	0.19	3398	0.17	59.6	9.4	5.3	0.62	4.15	33.24
49. Fish, white, mech ext	91.2	-	-	-	8.9	-	0.08	4305	0.35	59.4	9.9	9.1	1.68	5.32	84.51
5-02-025	100.0	-	-	-	9.8	-	0.08	4718	0.38	65.1	10.9	10.0	1.84	5.83	92.63
50. Fish, solubles, condensed	50.4	-	-	-	-	-	0.14	3314	0.22	175.9	35.6	12.7	5.53	12.20	6.38
5-01-969	100.0	-	-	-	-	-	0.27	6573	0.44	348.9	70.7	25.2	10.96	24.19	4.20
51. Fish, solubles, dehy	92.8	-	-	-	6.1	-	0.39	5525	0.57	255.8	50.4	13.5	7.39	19.71	85.93
5-01-971	100.0	-	-	-	6.5	-	0.42	5953	0.61	275.6	54.3	14.6	7.96	21.23	23.57
52. Meat meal, rend	93.8	-	-	-	0.9	-	0.12	1979	0.39	56.0	6.0	5.2	0.22	4.23	75.12
5-00-385	100.0	-	-	-	1.0	-	0.13	2110	0.42	59.7	6.4	5.5	0.23	4.51	80.08
53. Meat meal w/bones	93.3	-	-	-	0.9	-	0.10	2049	0.37	51.3	5.5	4.7	0.16	5.86	18.41
5-00-388	100.0	-	-	-	0.9	-	0.10	2195	0.40	55.0	5.9	5.0	0.17	6.28	26.88
54. Milk, skim, dehy	94.1	-	0.4	-	9.1	-	0.32	1393	0.62	11.5	36.4	19.1	3.72	4.09	50.88
5-01-175	100.0	-	0.4	-	9.6	-	0.35	1479	0.66	12.2	38.6	20.3	3.95	4.35	54.05
55. Millet, grain	89.9	-	-	-	-	-	-	746	0.22	49.0	8.8	1.8	6.58	-	-
4-03-098	100.0	-	-	-	-	-	-	830	0.25	54.5	9.8	2.0	7.32	-	-
56. Molasses, sugar beet	77.9	-	-	-	4.0	-	-	827	-	41.0	4.5	2.3	-	-	-
4-00-668	100.0	-	-	-	5.1	-	-	1062	-	52.7	5.8	2.9	-	-	-
57. Molasses, sugarcane	74.3	-	-	-	5.4	-	0.68	763	0.11	36.4	37.4	2.8	0.86	4.21	-
4-04-696	100.0	-	-	-	7.3	-	0.92	1027	0.15	49.0	50.3	3.8	1.16	5.67	-
58. Oats, grain	89.2	-	-	-	15.0	-	0.26	967	0.39	14.0	9.7	1.4	6.13	2.61	-
4-03-309	100.0	-	-	-	16.8	-	0.29	1084	0.44	15.7	10.9	1.6	6.87	2.93	-
59. Oats, groats	89.6	-	-	-	14.8	-	-	1131	0.51	9.6	13.8	1.2	6.49	1.00	-
4-03-331	100.0	-	-	-	16.5	-	-	1263	0.56	10.7	15.4	1.3	7.25	1.12	-
60. Oats, hay	90.7	-	1.4	-	-	-	-	-	-	-	-	-	-	-	-
1-03-280	100.0	-	1.5	-	-	-	-	-	-	-	-	-	-	-	-
61. Oats, hulls	92.4	-	-	-	-	-	-	260	0.96	9.2	3.1	1.5	0.61	2.19	-
1-03-281	100.0	-	-	-	-	-	-	281	1.04	10.0	3.4	1.7	0.66	2.37	-
62. Oats, silage	30.5	-	-	-	-	-	-	302	-	-	-	-	-	-	-
3-03-298	100.0	-	-	-	-	-	-	991	-	-	-	-	-	-	-
63. Oats, straw	92.2	-	0.6	-	-	-	-	-	-	-	-	-	-	-	-
1-03-283	100.0	-	0.7	-	-	-	-	-	-	-	-	-	-	-	-
65. Orchardgrass, hay	89.6	-	-	-	171.3	-	-	-	-	-	-	6.1	2.57	-	-
1-03-438	100.0	-	-	-	191.1	-	-	-	-	-	-	6.8	2.87	-	-
66. Pea, seeds	89.1	-	-	-	3.0	-	0.17	545	0.22	30.5	27.7	1.8	4.61	1.96	-
5-03-600	100.0	-	-	-	3.3	-	0.20	612	0.25	34.3	31.1	2.0	5.17	2.20	-
67. Peanut, meal, mech ext	92.6	-	-	-	2.4	-	0.33	1974	0.66	172.7	47.8	9.1	5.72	6.12	-
5-03-649	100.0	-	-	-	2.6	-	0.35	2132	0.71	186.4	51.4	9.8	6.18	6.61	-
68. Peanut, meal, sol ext	92.4	-	-	-	2.9	-	-	1893	-	177.5	36.8	5.2	-	5.95	-
5-03-650	10.0	-	-	-	3.2	-	-	2048	-	192.0	39.8	5.7	-	6.43	-
69. Poultry by-pro, meal, rend	93.8	-	-	-	2.2	-	0.08	6052	0.51	53.5	12.4	10.6	0.23	4.43	22.61
5-03-798	100.0	-	-	-	2.4	-	0.09	6450	0.54	57.1	13.2	11.3	0.24	4.72	24.10
70. Rice, bran	90.5	-	-	-	85.3	-	0.42	1243	1.60	305.9	25.0	2.6	21.94	16.21	5.14
4-03-928	100.0	-	-	-	94.2	-	0.46	1373	1.77	337.9	27.6	2.8	24.23	17.90	5.68
71. Rice, grain/groats	88.5	-	-	-	-	-	-	877	-	22.6	3.3	0.4	1.39	-	-
4-03-932	100.0	-	-	-	-	-	-	990	-	25.5	3.7	0.5	1.57	-	-
72. Rice, hulls	91.9	-	-	-	7.5	-	-	-	-	28.1	7.9	0.5	2.21	0.07	-
1-08-075	100.0	-	-	-	8.1	-	-	-	-	30.6	8.6	0.6	2.41	0.08	-
73. Rye, grain	87.5	-	-	-	14.5	-	0.05	419	0.58	14.1	7.2	1.8	4.51	2.97	-
4-04-047	100.0	-	-	-	16.6	-	0.06	479	0.66	16.1	8.3	2.0	5.16	3.40	-
75. Safflower, meal, sol ext	91.7	-	-	-	0.8	-	1.42	814	0.45	61.9	26.2	2.0	-	-	-
5-04-110	100.0	-	-	-	0.9	-	1.55	888	0.49	67.5	28.5	2.2	-	-	-
76. Safflower, meal wo/hulls	91.0	-	-	-	0.7	-	1.70	3246	1.61	22.2	39.4	2.5	4.62	11.83	-
5-07-959	100.0	-	-	-	0.8	-	1.87	3567	1.77	24.4	43.3	2.7	5.08	13.00	-

- Continues -_

Table 5. Vitamin Content (Continued)

Ingredient name/ description & IFN	DM %	Carotene mg/kg	Vitam D_2/D_3 IU/kg	Vitam D_s ICU/kg	Vitam E mg/kg	Vitam K mg/kg	Biotin mg/kg	Choline mg/kg	Folate mg/kg	Niacin mg/kg	Pantothenic acid mg/kg	Riboflavin mg/kg	Thiamin mg/kg	Vitam B_6 mg/kg	Vitam B_{12} µg/kg
77. Sesame, meal, mech ext	92.7	-	-	-	-	-	-	1534	-	18.8	5.9	3.4	2.80	12.46	-
5-04-220	100.0	-	-	-	-	-	-	1654	-	20.3	6.4	3.6	3.02	13.44	-
78. Sorghum, grain	90.1	-	-	-	-	-	0.26	692	0.22	46.6	10.2	1.2	4.52	5.40	-
4-04-383	100.0	-	-	-	-	-	0.29	768	0.24	51.8	11.3	1.4	5.02	6.00	-
80. Soybean, hulls	90.3	-	-	-	6.6	-	-	586	-	24.8	13.4	3.8	1.59	1.70	-
1-04-560	100.0	-	-	-	7.3	-	-	649	-	27.4	14.8	4.0	1.76	1.88	-
81. Soybean, meal, sol ext	89.6	-	-	-	2.4	-	0.32	2619	0.55	27.7	16.3	2.9	5.98	6.00	-
5-04-604	100.0	-	-	-	2.7	-	0.36	2923	0.61	30.9	18.2	3.2	6.68	6.70	-
82. Soybean, meal wo/hulls	89.9	-	-	-	3.3	-	0.32	2746	0.74	21.5	14.8	2.9	3.10	4.92	-
5-04-612	100.0	-	-	-	3.7	-	0.35	3053	0.82	23.9	16.4	3.3	3.45	5.47	-
84. Soybean, seeds, heat proc	92.6	-	-	-	-	-	0.29	2489	3.62	22.6	16.1	2.7	6.11	-	-
5-04-597	100.0	-	-	-	-	-	0.31	2688	3.91	24.4	17.4	2.9	6.60	-	-
85. Sunflower, meal wo/hulls	92.5	-	-	-	11.1	-	-	3627	-	242.1	40.6	3.5	-	13.67	-
5-04-739	100.0	-	-	-	12.0	-	-	3923	-	261.9	43.9	3.8	-	14.78	-
87. Timothy, hay	89.1	-	-	-	11.6	-	-	-	-	-	-	-	-	-	-
1-04-882	100.0	-	-	-	13.0	-	-	-	-	-	-	-	-	-	-
88. Triticale, grain	89.2	-	-	-	-	-	0.05	458	0.60	14.7	6.8	2.3	8.25	4.21	-
4-20-362	100.0	-	-	-	-	-	0.06	514	0.67	16.5	7.6	2.6	9.25	4.73	-
90. Wheat, bran	89.0	-	-	-	14.3	-	0.37	1201	1.77	196.7	27.9	3.6	8.36	10.33	-
4-05-190	100.0	-	-	-	16.0	-	0.42	1349	1.98	221.0	31.4	4.0	9.39	11.61	-
91. Wheat, grain, hard red spring	87.6	-	-	-	12.6	-	0.08	1009	0.43	57.2	9.5	1.4	4.22	5.16	-
4-05-258	100.0	-	-	-	14.4	-	0.09	1152	0.49	65.2	10.8	1.6	4.82	5.89	-
92. Wheat, grain, hard red winter	88.8	-	-	-	11.1	-	0.11	1006	0.38	53.0	10.1	1.3	4.52	3.02	-
4-05-268	100.0	-	-	-	12.5	-	0.12	1133	0.43	59.7	11.4	1.5	5.09	3.40	-
93. Wheat, grain, soft red winter	88.4	-	-	-	15.6	-	-	891	0.41	53.4	10.1	1.5	4.71	3.21	-
4-05-294	100.0	-	-	-	17.7	-	-	1008	0.46	60.4	11.4	1.7	5.33	3.63	-
94. Wheat, grain, soft white winter	90.2	-	-	-	30.9	-	-	-	-	62.1	11.1	-	-	4.77	-
4-05-337	100.0	-	-	-	34.2	-	-	-	-	68.8	12.3	-	-	5.29	-
95. Wheat, hay	88.7	-	1.4	-	-	-	-	-	-	-	-	15.1	-	-	-
1-05-172	100.0	-	1.5	-	-	-	-	-	-	-	-	17.0	-	-	-
96. Wheat, middlings	88.9	-	-	-	23.9	-	0.24	1228	1.24	95.0	17.8	2.0	14.18	9.15	-
4-05-205	100.0	-	-	-	26.9	-	0.27	1381	1.39	106.8	20.0	2.3	15.94	10.29	-
97. Wheat, red dog	88.3	-	-	-	37.4	-	0.10	1455	0.82	46.0	13.3	2.2	21.85	5.40	-
4-05-203	100.0	-	-	-	42.4	-	0.12	1647	0.93	52.1	15.0	2.5	24.73	6.12	-
98. Wheat, shorts	88.4	-	-	-	36.0	-	-	1698	1.51	105.2	21.9	4.1	19.52	-	-
4-05-201	100.0	-	-	-	40.7	-	-	1919	1.71	119.0	24.8	4.6	22.07	-	-
99. Whey, dehy	93.3	-	-	-	0.2	-	0.35	1791	0.85	10.6	46.2	27.4	4.00	3.22	18.89
4-01-182	100.0	-	-	-	0.2	-	0.37	1920	0.91	11.4	49.6	29.4	4.29	3.45	20.26
100. Yeast, Torula, dehy	93.0	-	-	-	-	-	1.17	2962	25.66	509.1	104.4	50.0	6.66	34.48	4.00
7-05-534	100.0	-	-	-	-	-	1.25	3184	27.58	547.2	112.2	53.8	7.16	37.06	4.30

6. **Table 6. Mineral Supplements** [DM = dry matter]

Ingredient name/ description & IFN	DM %	Ca %	Cl %	Mg %	P %	K %	Na %	S %	Co %	Cu %	I %	Fe %	Mn %	Se %	Zn %
1. Ammonium, dibasic phosphate	97.8	0.504	-	0.454	20.082	-	0.040	2.468	-	0.008	-	0.154	1.512	0.050	0.030
6-00-370	100.0	0.516	-	0.464	20.544	-	0.041	2.525	-	0.008	-	0.158	1.547	0.051	0.030
2. Ammonium, monobasic phosphate	97.7	0.380	-	0.460	24.411	0.138	0.078	0.821	-	0.008	-	0.183	0.990	0.046	0.063
6-09-338	100.0	0.389	-	0.471	24.994	0.141	0.080	0.841	-	0.008	-	0.187	1.013	0.047	0.065
3. Bone, meal, steamed	96.1	27.723	0.010	0.552	12.858	0.182	0.403	0.344	-	0.001	0.003	0.064	0.103	0.003	0.036
6-00-400	100.0	28.849	0.010	0.574	13.380	0.190	0.419	0.358	-	0.001	0.003	0.066	0.107	0.003	0.038
4. Calcium, carbonate	99.6	37.881	0.034	0.350	0.020	0.063	0.082	0.080	0.000	0.001	-	0.000	0.051	0.013	0.001
6-01-069	100.0	38.052	0.034	0.352	0.020	0.064	0.082	0.080	0.000	0.001	-	0.000	0.051	0.013	0.001
5. Calcium, dibasic phosphate	97.6	21.811	0.003	0.461	18.538	0.086	1.377	0.692	0.000	0.000	-	0.104	0.848	0.025	0.012
6-01-080	100.0	22.353	0.003	0.473	18.999	0.088	1.412	0.709	0.000	0.000	-	0.106	0.869	0.026	0.012
6. Calcium, mono basic phosphate	98.0	16.393	-	0.800	21.907	0.400	0.060	0.800	0.000	0.000	-	0.140	1.000	0.020	0.041
6-01-082	100.0	16.728	-	0.816	22.354	0.408	0.061	0.816	0.000	0.000	-	0.142	1.020	0.020	0.042
7. Calcium, anhydrous sulfate	79.1	23.274	0.002	-	-	-	-	18.616	-	-	-	-	0.002	-	-
6-01-087	100.0	29.429	0.003	-	-	-	-	23.539	-	-	-	-	0.002	-	-
8. Cobalt, carbonate	99.0	-	0.010	-	-	-	0.250	0.030	46.500	0.001	-	-	0.020	0.010	0.001
6-01-566	100.0	-	0.010	-	-	-	0.253	0.030	46.969	0.001	-	-	0.020	0.010	0.001
9. Collodial clay (soft rock phos[hate)	99.5	16.005	-	-	9.000	-	-	-	-	-	-	1.206	-	-	-
6-03-947	100.0	16.086	-	-	9.045	-	-	-	-	-	-	1.212	-	-	-
10. Cupric, pentahydrate sulfat	100.0	-	0.001	-	-	-	-	12.840	-	39.740	-	-	0.003	-	-
6-01-720	100.0	-	0.001	-	-	-	-	12.840	-	39.740	-	-	0.003	-	-
11. Curacao phosphate, ground	99.0	35.099	-	-	14.237	-	-	-	-	-	-	-	-	-	-
6-05-586	100.0	35.454	-	-	14.381	-	-	-	-	-	-	-	-	-	-
12. Ferrous, heptahydrate sulfate	99.5	-	-	0.205	-	-	-	10.999	-	0.010	-	-	20.898	0.000	0.010
6-20-734	100.0	-	-	0.206	-	-	-	11.055	-	0.010	-	-	21.005	0.000	0.010
13. Limestone, ground	99.7	37.113	0.025	1.056	0.214	0.112	0.055	0.040	-	0.001	-	-	0.186	0.012	0.002
6-02-632	100.0	37.220	0.025	1.059	0.215	0.113	0.055	0.040	-	0.001	-	-	0.187	0.012	0.002
14. Magnesium, anhydrous carbonate	98.0	0.020	-	30.810	-	-	-	-	-	-	0.020	-	-	-	-
6-02-754	100.0	0.020	-	31.444	-	-	-	-	-	-	0.020	-	-	-	-
15. Magnesium, oxide	98.3	1.660	-	55.188	-	-	-	0.099	-	0.000	-	0.025	1.047	0.008	0.000
6-02-756	11.0	1.689	-	56.147	-	-	-	0.101	-	0.000	-	0.025	1.066	0.008	0.000
16. Mangonous, oxide	99.0	-	-	-	-	-	-	-	-	-	-	-	-	76.670	-
6-03-056	100.0	-	-	-	-	-	-	-	-	-	-	-	-	77.450	-
17. Phosphate	99.6	31.955	-	0.293	16.907	0.100	2.067	0.130	-	0.004	-	0.179	0.839	0.049	0.009
6-01-780	100.0	32.086	-	0.294	16.977	0.100	2.075	0.130	-	0.004	-	0.180	0.842	0.049	0.009
18. Phosphate, rock	100.0	35.000	-	-	13.000	-	-	-	-	-	-	3.700	-	-	-
6-03-945	100.0	35.000	-	-	13.000	-	-	-	-	-	-	3.700	-	-	-
19. Potassium, bicarbonate	99.0	-	-	-	-	38.65	-	-	-	-	-	-	-	-	-
6-29-493	100.0	-	-	-	-	39.05	-	-	-	-	-	-	-	-	-
20. Potassium, iodide	99.0	-	-	-	-	21.00	0.100	-	-	68.170	-	-	-	-	-
6-03-759	100.0	-	-	-	-	21.02	0.100	-	-	68.238	-	-	-	-	-
21. Salt, iodine added	99.8	0.154	-	0.140	0.050	0.007	40.525	-	-	0.000	0.007	-	0.000	0.000	0.000
6-04-151	100.0	0.154	-	0.140	0.050	0.007	40.592	-	-	0.000	0.007	-	0.000	0.000	0.000
22. Salt, NaCl	99.5	-	59.950	-	-	-	38.811	-	-	-	-	-	-	-	-
6-04-152	100.0	-	60.257	-	-	-	39.011	-	-	-	-	-	-	-	-
23. Sodium, bicarbonate	99.7	0.010	-	-	-	-	28.094	-	-	-	-	-	-	-	-
6-04-272	100.0	0.010	-	-	-	-	28.188	-	-	-	-	-	-	-	-
24. Sodium, phosphate, monobasic	94.0	0.085	0.019	0.009	24.186	0.094	21.461	-	-	0.000	-	-	-	-	0.000
6-04-288	100.0	0.090	0.020	0.010	25.717	0.100	22.820	-	-	0.000	-	-	-	-	0.000
25. Sodium, selenite	99.2	-	-	0.010	-	-	26.799	-	-	0.001	-	-	0.030	-	-
6-26-013	100.0	-	-	0.010	-	-	27.003	-	-	0.001	-	-	0.030	-	-
26. Sodium, sulphate	97.0	-	-	-	-	-	13.840	9.659	-	-	-	-	0.001	-	-
6-04-292	100.0	-	-	-	-	-	14.268	9.958	-	-	-	-	0.001	-	-
27. Sodium, tripolyphosphate	96.7	-	-	-	24.529	-	30.184	-	-	-	-	0.024	0.003	-	-
6-08-076	100.0	-	-	-	25.375	-	31.225	-	-	-	-	0.025	0.004	-	-
28. Zinc, oxide	100.0	4.290	-	0.295	-	-	-	1.000	0.150	0.050	-	-	0.550	0.080	72.496
6-05-553	100.0	4.290	-	0.295	-	-	-	1.000	0.150	0.050	-	-	0.550	0.080	72.496
29. Zinc, monohydrate sulfate	99.2	0.050	0.199	-	-	-	-	17.621	-	0.005	-	-	0.052	0.016	35.907
6-05-555	100.0	0.050	0.200	-	-	-	-	17.755	-	0.005	-	-	0.052	0.017	36.181

7. **Table 7. Energy Values of Various Sources of Fats and Oils**[a,b] [Based on NRC (1998); as-fed basis] [Tot SFA = total saturated fatty acids; Tot UFA = total unsaturated fatty acids; U:S ratio = unsaturated to saturated fatty acid ratio; Tot n-6 = total n-6 or omega-6 fatty acids; Tot n-3 = total total n-3 or omega-3 fatty acids; DE = digestible energy; ME = metabolizable energy; NE = net energy]

	Selected fatty acids (% of total fatty acids)																Energy (kca1'kg)		
Type of lipid/ IFN	≤ 10	12:O	14:O	16:0	16:1	18:O	18:1	18:2	18:3	≥ 20	Tot SFA	Tot UFA	U:S ratio	Iodine value	Tot n–6	Tot n–3	DE[c]	ME[d]	NE[e]
Animal fats:																			
Beef tallow/ 4-08-127	0.0	0.9	2.7	24.9	4.2	18.9	36.0	3.1	0.6	0.3	52.1	47.9	0.92	44	3.1	0.6	8,000	7,680	4,925
Choice white grease/ -	0.2	0.2	1.9	21.5	5.7	14.9	41.1	11.6	0.4	1.8	40.8	59.2	1.45	60	11.6	0.4	8,290	7,955	5,095
Lard/ 4-04-790	0.1	0.2	1.3	23.8	2.7	13.5	41.2	10.2	1.0	1.0	41.1	58.9	1.44	64	10.2	1.0	8,285	7,950	5,100
Poultry fat 4-09-319	0.0	0.1	0.9	21.6	5.7	6.0	37.3	19.5	1.0	1.2	31.2	68.8	2.20	78	19.5	1.0	8,520	8,180	5,230
Restaurant grease/ -	-	-	1.9	16.2	2.5	10.5	47.5	17.5	1.9	1.0	29.9	70.1	2.34	75	17.5	1.9	8,550	8,205	5,245
Fish oils:																			
Anchovy/ -	-	-	7.4	17.4	10.5	4.0	11.6	1.2	0.8	30.3	34.6	65.4	1.89	-	1.3	31.2	8,445	8,105	5,185
Herring/ 7-08-048	-	0.2	7.1	11.7	9.6	0.8	11.9	1.1	0.8	45.6	22.8	77.2	3.39	-	1.4	17.8	8,680	8,330	5,320
Menhaden/ 7-08-049	-	-	8.0	15.1	10.5	3.8	14.5	2.1	1.5	29.5	33.3	68.7	2.00	-	1.5	25.1	8,475	8,135	5,200
Vegetable oils:																			
Canola (Rapeseed)/ 4-06-144	0.0	0.0	0.0	4.0	0.2	1.8	56.1	20.3	9.3	3.6	7.4	92.6	12.46	118	20.3	9.3	8,760	8,410	5,365
Coonnut[f]/ 4-00-320	14.1	44.6	16.8	8.2	0.0	2.8	5.8	1.8	0.0	-	91.9	8.1	0.09	10	1.8	0.0	8,405	8,070	5,160
Corn/ 4-07-882	0.0	0.0	0.0	10.9	0.0	1.8	24.2	59.0	0.7	-	13.3	86.7	6.53	125	58.0	0.7	8,755	8,405	5,360
Cottonseed 4-20-636	0.0	0.0	0.8	22.7	0.8	2.3	17.0	51.5	0.2	0.1	27.1	72.9	2.69	105	51.5	0.2	8,605	8,260	5,275
Olive/ -	0.0	0.0	0.0	11.0	0.8	2.2	72.5	7.9	0.6	0.3	14.1	85.9	6.08	86	7.9	0.6	8,750	8,400	5,360
Palm/ -	0.0	0.1	1.0	43.5	0.3	4.3	36.6	9.1	0.2	0.1	51.6	48.4	0.94	50	9.1	0.2	8,010	7,690	4,935
Peanut/ 4-03-658	0.0	0.0	0.1	9.5	0.1	2.2	44.8	32.0	-	6.4	17.8	82.2	4.63	92	32.0	0.0	8,735	8,385	5,350
Saffower 4-20-526	0.0	0.0	0.1	6.2	0.4	2.3	11.7	74.1	0.4	-	9.5	90.5	9.52	140	74.1	0.4	8,760	8,410	5,365
Sesame/ -	0.0	0.0	0.0	8.9	0.2	4.8	39.3	41.3	0.3	0.2	14.8	85.2	5.73	110	41.3	0.3	8,750	8,400	5,360
Soybean/ 4-07-983	0.0	0.0	0.1	10.3	0.2	3.8	22.8	51.0	6.8	0.2	15.1	84.9	5.84	130	51.0	6.8	8,750	8,400	5,360
Sunflower/ 4-20-833	0.0	0.0	0.0	5.4	0.2	3.5	45.3	39.8	0.2	-	10.6	89.4	8.47	133	39.8	0.2	8,760	8,410	5,365

[a]Dash indicates that no data were available.

[b]The fatty acid data were obtained from Pearl (1995) of the Fats and Protein Research Foundation and USDA Food Composition Standard Release 11 (1997). Values for fatty acid content do not always total 100% but represent means as obtained from various fat analysis conducted by gas-Iiquid chromatography.

[c]Calculated by the following relationship (Powles et al., 1995): DE (kcal/kg) = $(36.898 - (0.005 \text{ X FFA}) - (7.330 \text{ X } e^{-0.906xU:S}))/4.184$ where FFA is the free fatty acid content in g/kg and U:S is the ratio of unsaturated to saturated fatty acids. In calculating the DE, the free fatty acid concentrations of all fats were assumed to be 50 g/kg (or 5%).

[d]Calculated as 96% of DE.

[e]Calculated by Equation 1-12 in Chapter 1 of NRC (1998).

[f]Coconut oil was considered outside the range of the data used to develnp the relationship in footnote c. The DE concentration of coconut oil was calculated from the digestibility (89.42% of GE) reported by Cera et al. (1989) for pigs from 2 to 4 weeks after weaning at 3 weeks of age.

GLOSSARY

[*Based on Kellems, R.O. and D. C. Church (1998) and Jurgens, M. H (2002)*]

A

Abomasum - The fourth compartment of a ruminant's stomach, which has functions similar to the glandular stomach of nonruminants.
Absorption - The movement of nutrients (or other compounds) from the digestive tract (or through other tissues such as the skin) into the blood and/or lymph system.
Acetic acid - One of the volatile fatty acids commonly found in silage, rumen contents, and vinegar as a result of microbial fermentation.
Acidification - The act of reducing the pH of a substance or solution; or increasing the acidity.
Acidosis - A condition in ruminants where excess acid from the rumen is absorbed into the blood stream causing a lowered bicarbonate concentration.
Additive - An ingredient or combination of ingredients added in small quantities to a basic feed mix for the purpose of fortifying the basic mix with trace nutrients, medicines, or drugs.
ADF - Acid detergent fiber; the fraction of a feedstuff not soluble by acid detergent; roughly comparable to a crude fiber plus lignin.
Adipose - Consisting of, resembling, or having relation to fat.
Ad libitum - Unrestricted consumption of feed or water.
Aerobic - Living or functioning in the presence of oxygen.
Afterbirth - The placenta and allied membranes expelled from the uterus following parturition.
Air-dry - The refers to feed that is dried by means of natural air movement, usually in open.
Albumin - A group of globular proteins; a major component of blood serum protein.
Algae - Single cell plants which synthesize, among others, proteins by the use of sunlight.
Alimentary - Having to do with feed or food.
Alimentary tract - A term synonymous with the digestive or gastrointestinal tract.
Alkali/alkaline - Any of various base, the hydroxides of alkali metals and ammonium, which neutralize acids to form salts and turn red red litmus paper blue.
Ambient temperature - The prevailing or surrounding temperature.
Amino acids - The simplest organic structure of which proteins are formed; all have the common property of containing a carboxyl group and an amino group on the adjacent carbon atom.
Amino acids, essential (“indispensable”) - Those that must be present in the diet; they include arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine.
Amino acids, nonessential (“dispensable”) - Amino acids found in common proteins but which may be partly or completely synthesized by the animal’s tissues; they include alanine, aspartic acid, citrulline, cystine, glutamic acid, glycine, hydroxyproline, proline, serine, and tyrosine.
Ammoniated - Combined or impregnated with ammonia or an ammonium compound.
Amylase - Any of several enzymes that can hydrolyze starch to maltose or glucose.
Anabolism - Constructive metabolism in which simple substances are converted into more complex substances by living cells.
Anaerobic - Living or functioning in the absence of oxygen.
Analogue - Something having analogy (or similarity) to something else.
Anemia - A deficiency in the blood of red cells, hemoglobin, or both.
Anorexia - Lack or loss of the appetite for food.
Anoxia - Oxygen deficiency.
Antagonist - A substance that exerts a nullifying or opposing action to another substance.
Anthelmintic - A product which destroys or expells internal parasites.
Antibiotic - A substance produced by one microorganism that has an inhibitory effect on another microorganism.
Antioxidant - A substance that inhibits the oxidation of other compounds.
Antivitamin - A substance that interferes with the synthesis or metabolism of a vitamin.
Anus - The distal opening of the gastrointestinal tract.
Appetite - A desire for food or water; generally a long-term phenomenon, in contrast to short term satiety.
Artificially dried - (Process) Moisture having been removed by other than natural means.
Ascorbic acid - See Vitamin.
Aspirated, aspirating - Having removed chaff, dust, or other light materials by use of air.

As fed - As consumed by the animal.
Ash - The residue remaining after complete incineration at 500˚ to 600˚C of a feed or animal tissue. Only metallic oxides or contaminants such as soil should remain.
Available nutrient - A nutrient which can be digested, absorbed, and(or) used in the body.
Avidin - A substance found in egg white which prevents the action of biotin.

B

Bactericide - A product that destroys bacteria.
Balanced ration (or diet) - A combination of feeds that provides the essential nutrients in the required proportions.
Basal diet - A diet common to all groups of experimental animals to which the expermental substance(s) is added.
Basal metabolic rate - The basal metabolism expressed in kilocalories per unit of body size; the heat production of an animal during physical, digestive, and emotional rest.
Beriberi - A deficiency (acute) of thiamin, one of the B-complex vitamins.
Bile - A secretion from the liver containing metabolites such as cholesterol and bile acids, which aid in the digestion of fats.
Bioassay - Determination of th relative effective potency of a substance by comparing its effect on a test organisms with that of a standard preparation.
Biological value - The efficiency with which a protein furnishes the required amounts of essential amino acids; usually expressed as a percentage.
Biopsy - The removal and examination of tissue or other material from the living body.
Blending - (Process) To mingle or combine two or more ingredients of feed. It does not imply a uniformity of dispersion.
Bloat - A distention of the rumen or oaunch or the large colon by gases by fermentation.
Blocked, blocking - (Process) Having agglomerated individual ingredients or mixtures into a large mass.
Blocks - (Physical form) Agglomerated feed compressed into a solid mass cohesive enough to hold its form, weighing over 2 pounds, and generally weighing 30 to 50 lb.
Bolus - A solid mass of ingesta (synonymous with cud) that, in ruminants, is regurgitated for remastication during rumination.
Bomb calorimeter - An instrument used for measuring the gross energy (GE) content of any material that will burn.
Bone meal - Animal bones hat were steamed ubderand then ground.
Bran - The pericarp or seed coat of grain which is removed during processing and used as animal feed.
Brand name - Any word, name, symbol, or device or any combination thereof identifying the commercial feed of a distributor and distinguishing it from that of others.
Buffer - Any substance that can reduce changes in pH when an acid or alkali is added to it.
Bushel - A unit of dry measure equivalent to 2150.42 cubic inches (approximately 1.25 cubic feet).
Butyric acid - One of the volatile fatty acids commonly found in rumen contents and in poor-quality silages.
By-product - (Part) Secondary products produced in addition to the principal product.

C

Cake - (Physical form) The mass resulting from the pressing of seeds, meat, or fish in order to remove oils, fats, or other liquids.
Calcification - The process by which organic tissue becomes hardened by a deposit of calcium salts.
Calculi - An occurrence in which mineral deposits in the urinary tract.
Calorie - The amount of energy required to raise the temperature of water from 14.5˚ to 15.5˚C.
Calorimeter - The equipment used to measure the heat generated in a system.
Cannula - A tube inserted into the body to connect internal structures with the outside of the animal.
Carbohydrate - Organic substances containing C, H, and 0, with the Hand ˚ present in the same proportions as in water. Many different kinds are found in plant tissues; some are vital to animal metabolism.
Carcinogen - Any cancer-producing substance.
Carotene - A yellow organic compound that is the precursor of vitamin A.
Carrier - An edible material used to facilitate the addition of micronutrients to a ration.
Cartilage - A connective tissue characterized by nonvascularity (absence of blood vessels) and firm texture.
Casein - The protein precipitated from milk by acid and/or rennin.
Cassava - A tropical plant of the spurge family with edible starchy roots.
Catalyst - A substance that changes the rate of a chemical reaction but is not itself used up in the reaction. The use of platinum in hydrogenating unsaturated fats is an example.
Catabolism - The breaking down of complex substances into more simple compounds by living cells.
Cecum (or caecum) - A blind pouch located at the

junction of the small intestine with the colon (the appendix in humans); it is part of the large intestine.
Cellulose - A polymer of glucose characterized by a linkage between the glucose molecules that is resistant to hydrolysis by most digestive enzymes (except some produced by microorganisms).
Chaff - (Part) Glumes, husks, or other seed covering together with other plant parts separated from seed in threshing or processing.
Chelate - Refers to a ring-like structure that is formed between an organic molecule and a metal ion.
Cholesterol - The most common member of the sterol group found in blood and many other animal tissues; not present in arty plant tissues.
Cholic acid - A family of steroids comprising the bile acids; they are derived from metabolism of cholesterol by the liver.
Chyme - A semiliquid material produced by the action of gastric juice on ingested food.
Chymotrypsin - A proteolytic digestive enzyme secreted by the pancreas.
Cleaned, cleaning - (Process) Removal of material by such methods as scalping, aspirating, or magnetic separation, or by any other method.
Cleaning - (Part) Chaff, weed seeds, dust, and other foreign matter removed from cereal grains.
Clipped, clipping - (Process) Removal of the ends of whole grains.
Coagulated - Curdled, clotted, or congealed.
Coenzyme - An organic molecule required by some enzymes to produce enzymic activity; vitamin coenzymes include niacin, pyridoxine, thiamin, riboflavin, pantothenic acid, and folic acid.
Collagen - A principal supportive protein in connective tissue.
Colon - Part of the large intestine; divided into the transverse, descending, and ascending segments.
Colostrum milk - The milk secreted during the first day or two of lactation.
Commercial feed - As defined in the Uniform Feed Bill, all materials distributed for use as feed or for mixing in feed for animals other than humans, except as follows: (A) Option A, unmixed seed, whole or processed, made directly from the entire seed. Option B, unmixed or unprocessed whole seeds. (B) Hay, straw, stover, silage, cobs, husks, and hulls (a) when unground and (b) when unmixed with other materials. (C) Individual chemical compounds when not mixed with other materials.
Compensated growth - Accelerated growth following a period of limited feed intake.
Complete feed - A single feed mixture used as the only source of food for an animal.
Concentrate - Any feed containing relatively low fiber (20% or less) and with 60% or more TDN. Opposite of roughage; or a concentrated source of one or more nutrients used to supplement a feed mix.
Condensed, condensing - (Process) Reduced to denser form by removal of moisture.
Conditioned, conditioning - (Process) Having achieved predetermined moisture characteristics and/or temperature of ingredients or a mixture of ingredients prior to further processing.
Convulsion - An involuntary spasm or contraction of muscles, often in vary rapid sequence.
Cooked, cooking - (Process) Heated in the presence of moisture to alter chemical and/or physical characteristics or to sterilize.
Cooled, cooling - (Process) Temperature reduced by air movement, usually accompanied by a simultaneous drying action.
Coprophagy - The ingestion of fecal material.
Cracked, cracking - (Process) Particle size reduced by a combined breaking and crushing action.
Creep - A feeder or an enclosure used for supplemental feeding of nursing young, which excludes their dams.
Cribber - A horse that has the vice of biting or setting the teeth against some object, such as manger, while sucking air.
Crude fat - The portion of a feed (or other material) that is soluble in ether; also referred to as ether extract.
Crude fiber - The fibrous, less digestible portion of a feed.
Crude protein - Total ammoniacal nitrogen x 6.25, based on the fact that feed protein, on the average, contains 16% nitrogen; many nonprotein nitrogen compounds may be included.
Crumbled, crumbling - (Process) Pellets reduced to granular form.
Crumbles - (Physical form) Pelleted feed reduced to granular form.
Cubes - (Physical form) See Pellets.
Cubes, range - (Physical form) See Pellets, Range cubes.
Cud - The solid mass of ingesta regurgitated and remasticated in the process of rumination (synonymous with bolus).
Curd - The semisolid mass that is formed when milk comes in contact with an acid or rennin.

D

Deamination - Removal of the amino group from an amino acid.
Debeaking - The removal of part of the beak of chickens and poults with an electronic debeaker to prevent cannibalism.

Defluorinated - Having the fluorine content reduced to a level that is nontoxic under normal feed use.
Degradation - Conversion of a chemical compound to one that is less complex.
Dehulled, dehulling - (Process) Having removed the outer covering from grains or other seeds.
Dehydrated, dehydrating - (Process) Having been freed of moisture by thermal means.
Dermatitis - An inflammation of the skin.
Desiccate - To dry completely.
Dextrin - An intermediate polysaccharide product obtained during starch hydrolysis.
Diet - A regulated selection or mixture of feedstuffs provided on a continuous or prescribed schedule.
Digestibility, apparent - The percentage of a feed or nutrient that is apparently absorbed from the GI tract as indicated by intake minus fecal output; it differs from true digestibility in that feces contain substances derived from the body, many microbial products, and various secretions, as well as undigested food.
Digestibility, true - The percentage of a feed nutrient actually absorbed from the GI tract.
Digestion - The process involved in preparing food for absorption.
Dilute - (Physical form) An edible substance used to mix with and reduce the concentration of nutrients and/or additives to make them more acceptable to animals, safer to use, and more capable of being mixed uniformly in a feed. It may also be a carrier.
Disaccharide - Any of several dimers (contains two simple sugar molecules); for example, sucrose (common table sugar) yields glucose and fructose.
Dispensable amino acid - Synonymous with nonessential amino acid.
Diuretic - A drug or agent used to increase the flow of urine.
Dressed, dressing - (Process) Made uniform in texture by breaking or screening of lumps from feed and/or the application of liquid(s).
Dried, drying - (Process) Materials from which water or other liquid has been removed.
Drug - As defined by FDA as applied to feed, a substance (a) intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease in humans or other animals, or (b) a substance other than food intended to affect the structure or any function of the body of humans or other animals.
Dry matter - The portion of a feed or tissue remaining after water is removed by drying in an oven.
Drylot - A relatively small area in which animals are confined as opposed to being allowed to have free access to pasture.
Dry period - The period of time between lactation.
Duodenum - The first segment of the small intestine.
Dust - (Part) Fine, dry pulverized particles of matter usually resulting from the cleaning or grinding of grain.

E

Edema - An abnormal accumulation of fluid in apart of or in the entire body.
Element - Anyone of the chemical atoms of which all matter is composed.
Emaciated - Excessive leanness; a wasted condition of the body.
Emulsifier - A material capable of causing fat or oils to remain in liquid suspension.
Emulsify - To disperse small drops of liquid into another liquid.
Endemic - A disease of low morbidity that persists over a long period of time in a certain region.
Endocrine - Pertains to internal secretions that affect metabolic processes or specific target organs.
Endogenous - Originating from within the organism.
Endosperm - The carbohydrate or starchy portion of seed.
Ensilage - The same as silage.
Ensiled - Having been subjected to an anaerobic fermentation to form silage.
Enteritis - Inflammation of the intestines.
Enzyme - A protein formed in plant or animal cells that acts as an organic catalyst.
Epithelial - Refers to those cells that form theouter layer of the skin or that line body cavities.
Ergosterol - A sterol found chiefly in plant tissues; on exposure to ultraviolet irridiation it becomes vitamin D.
Ergot - A disease of rye and other cereals because of fungus which replaces the grain by a long, hard, hornlike, dark-colored body.
Eructation - Belching of gas by ruminants as a normal means of expelling gases of fermentation.
Esophagus - The passageway (tube) from the mouth to the stomach.
Estrogens - Estrus-producing hormones secreted by the ovaries.
Evaporated, evaporating - (Process) Reduced to denser form; concentrated as by evaporation or distillation.
Eviscerated - Having had all organs in the great cavity of the body removed.
Excreta - The products of excretion, primarily feces and urine.
Exogenous - Originating from outside the body.
Expanded, expanding - (Process) Subjected to moisture, pressure, and temperature to gelatinize the starch portion. When extruded, its volume is increased

due to abrupt reduction in pressure.

Extracted, mechanical - (Process) Having removed fat or oil from materials by heat and mechanical pressure. Similar terms are expeller extracted, hydraulic extracted, and "old process."

Extracted, solvent - (Process) Having removed fat or oil from materials by organic solvents. Similar term is "new process."

Extruded (Process) - A process by which feed has been pressed, pushed, or protruded through orifices under pressure.

F

Fasting - To abstain from all food.

Fat soluble - Soluble in fats and fat solvents but generally not soluble in water.

Fattening - The deposition of excess energy in the form of adipose tissue (fat).

Feces - The excreta discharged from the digestive tract through the anus; composed of undigested food residues, micfoorganisms, and various materials originating in the liver and intestinal tract.

Feed Any material used as food by an animal; same as feedstuff.

Feed additive concentrate - (Part) As defined by FDA, an article intended to be further diluted to produce a complete feed or a feed additive supplement and not suitable for offering as a supplement or for offering free choice without dilution. It contains, among other things, one or more additives in amounts in a suitable feed base such that from 10 to 100 lb of concentrate must be diluted to produce 1 ton of a complete feed. A feed additive concentrate is unsafe if fed free choice or as a supplement because of danger to the health of the animal or because of the production of residues in the edible products from food-producing animals in excess of the safe levels established.

Feed additive premix - As defined by FDA, an article that must be diluted for safe use in a feed additive concentrate, a feed additive supplement, or a complete feed. It contains, among other things, one or more additives in high concentration in a suitable feed base such that up to 100 lb must be diluted to produce 1 ton of complete feed. A feed additive premix contains additives at levels for which safety to the animal has not been demonstrated and/or that may result when fed undiluted in residues in the edible products from food-producing animals in excess of the safe levels established.

Feed additive supplement - As defined by FDA, an article for the diet of an animal that contains one or more food additives and is intended to be (a) further diluted and mixed to produce a complete feed; or (b) fed undiluted as a supplement to other feeds; or (c) offered free choice with other parts of the rations separately available. Note: A feed additive supplement is safe for the animal and will not produce unsafe residues in the edible products from food-producing animals if fed according to directions.

Feed grade - Suitable for animal food but not permitted by regulating agencies to be used in human foods.

Feedlot - An area of land on which animals are fed or finished for market.

Feedstuff - See Feed.

Fermentation - Chemical changes brought about by enzymes produced by various microorganisms.

Fibrous - High in content of cellulose and/or lignin (or in cell walls of NDF, neutral detergent fiber).

Fines - (Physical form) Any material that will pass through a screen whose openings are immediately smaller than the specified minimum crumble size of pellet diameter.

Finish - To fatten an animal in preparation for slaughtering for food; also, the degree of fatness of such an animal.

Fistula - An abnormal passage from some part of the body to another part or the exterior, sometimes surgically inserted.

Flaked, flaking - (Process) See Rolled.

Flakes - (Physical form) An ingredient rolled or cut into flat pieces with or without prior steam conditioning.

Flora - The plant life of a given region or locality. In nutrition, it generally refers to te bacteria present in the digestive tract.

Flour - (Part) Soft, finely ground and bolted meal obtained from the milling of cereal grains, other seeds, or products. It consists essentially of the starch and gluten of the endosperm.

Flush - The practice of feeding females more generously approximately two weeks before breeding.

Fodder - The entire above ground part of nearly mature corn or sorghum in the fresh or cured form.

Food(s) - When used in reference to animals is synonymous with feed(s). See Feed.

Forage - Crops used as pasture, hay, haylage, silage, or green chop for feeding animals.

Formula feed - Two or more ingredients proportioned, mixed, and processed according to specifications.

Fortify - To add one or more nutrients to a feed to increase its content to a needed level.

Founder - A condition of indigestion or overloaded stomach in the animals due to over eating. Or, may also be the crippled condition of an animal afflicted with laminitis.

Free choice - The method of feeding in which the

animal may choose to eat its feed at will.
Fresh - Usually denotes the green or wet form of a feed or forage.
Fructose - A six-carbon monosaccharide; one of the components of sucrose.
Full-feed - A term indicating that animals are being provided as much as they will consume safely without going off the feed.

G

Galactose - A six-carbon monosaccharide; one of the components of lactose.
Gall bladder - A membranous sac attached to the liver of farm livestock (except for the horse) in which bile is stored.
Gastric juice - A clear liquid secreted by the wall of the stomach; it contains HCI and the enzymes rennin, pepsin, and gastric lipase.
Gastritis - Inflammation of the stomach.
Gastrointestinal - Pertaining to the stomach and intestine.
Gelatinized, gelatinizing - (Process) Having had the starch granules completely ruptured by a combination of moisture, heat, and pressure, and, in some instances, by mechanical shear.
Germ - When used as a feed term, the embryo of a seed.
Glucogenesis - The formation of glucose by the breaddown of glycogen.
Gluconeogenesis - The formation of glucose and glycogen from non-glucose matter.
Glucose - A six-carbon monosaccharide found in the blood and as a component of sucrose and maltose and other sugars.
Gluten - The tough, viscid, nitrogenous substance remaining when the flour of wheat or other grain is washed to remove the starch.
Glycerol - An alcohol containing three carbons and three hydroxy groups; a component of a fat.
Glycogen - A polysaccharide found in the liver and muscles as a reserve form of quickly available energy.
Glycogenesis - The formation of glycogen.
Glycolysis - The decomposition of sugars and metabolism to lactic acid in animals or pyruvic acid in enzymatic reactions.
Goiter - An enlargement of the thyroid gland sometimes caused by an iodine deficiency.
Gossypol - A substance present in cottonseed (and meal) that is toxic to swine and some other nonruminant species.
Grain - (Part) Seed from cereal plants.
GRAS - Abbreviation for the phrase "generally recognized as safe." A substance that is generally recognized as safe by experts qualified to evaluate the safety of the substance for its intended use.
Gravid - Pregnant.
Green chop - Forage harvested and fed in the green, chopped form.
Grits - (Part) Coarsely ground grain from which the bran and germ have been removed, usually screened to uniform particle size.
Groat - Grain from which the hull has been removed.
Gross energy - The total heat of combustion of material burned in a bomb calorimeter.
Ground, grinding - (Process) Reduced in particle size by impact, shearing, or attrition.
Growth - An increase in muscle, bone, vital organs, and connective tissue as contrasted to an increase in adipose tissue (fat deposition).
Gruel - A feed prepared by mixing ground ingredients with hot or cold water.

H

Hay - The aerial part of forage crops stored in the dry form for feeding to animals.
Heat increment - The heat that is unavoidably produced by an animal incidental with nutrient digestion and utilization.
Heat labile - Unstable to heat.
Heat processed, heat processing - (Process) Subjected to a method or preparation involving the use of elevated temperatures with or without pressure.
Hematocrit - The volume of whole blood made up by the red blood cells after centrifugation.
Hemoglobin - The oxygen-carrying red protein of the red corpuscles.
Hemorrhage - Copious loss of blood through bleeding.
Hepatitis - Inflammation of the liver.
Homogenized - A process in which particles are broken down into evenly distributed globules small enough to remain emulsified for a long period of time.
Hormone - A chemical secreted in the body fluids by an endocrine gland that has a specific effect on other tissues.
Hulls - (Process) Outer covering of grain or other seed.
Hunger - The desire for food; the antithesis of satiety.
Hydrogenation - The chemical addition of hydrogen to any unsaturated compound (double bond), often to fatty acids.
Hydrolysis - The chemical process whereby a compound is split into simpler units with the uptake of water.
Hygroscopicity - The tendency for a substance to absorb or attract moisture from the air.
Hyperthyroidism - A condition due to excessive functional activity of the thyroid gland and characterized by increased basal metabolism.
Hypervitaminosis - An abnormal condition resulting

from the intake of (or treatment with) an excess of one or more vitamins.
Hypocalcemia - A below normal concentration of Ca in blood.
Hypoglycemia - A below normal concentration of blood glucose.

I

Ileum - The third section of the small intestine.
Implant - A substance that is inserted into the body tissue for the purpose of growth promotion or controlling some physical functrion.
Inert - Relatively inactive.
Ingest - To eat or take in through the mouth.
Ingredient, feed ingredient - A component part or constituent of any combination or mixture making up a commercial feed.
Ingesta - Food and drink taken into the stomach.
Inorganic - Pertaining to compounds not containing carbon.
Insulin - A hormone secreted by the pancreas into the blood; it is involved in regulation and utilization of blood glucose.
International chick unit (ICU) - The unit used to express vitamin D for poultry .
International unit (IU) - A standar unit of potency of a biological unit as defined by the International Conference for Unification of Formulae.
Intestinal tract - The small and large intestines.
Intrinsic factor - A chemical substance in the normal stomach necessary for absorption of vitamin B_{12}.
Inulin - A polysaccharide found in some root crops. Composed of fructose.
In vitro - "In a glass." Occurring in an artificial environment, as in a test tube.
In vivo - Occurring in the living body.
Iodine number - The amount of iodine (in grams) that can be taken up by 100 g of a fat or fatty acid; it is a measure of unsaturation.

J

Jejunum - The middle portion of the small intestine.
Joule - A unit of work or energy, as well as the concept of heat (4.184j = 1 calorie).

K

kcal - An abbreviation for kilocalorie; 1000 calories.
Keratin - An S-containing protein found in tissues such as hair, wool, feathers, horn, and hooves.
Ketone - A group of chemicals that includes acetone, acetoacetic acid, and betahydroxy butyric acid; they are produced in excess when carbohydrate metabolism is low and fat is being metabolized for energy.
Ketosis - A condition characterized by an elevated concentration of ketone bodies in body tissues and fluids.
Kibbled, kibbling - (Process) Cracked or crushed baked dough or extruded feed that has been cooked pIjor to or during the extrusion process.
Kwashiorkor - A nutritional disorder of children caused by a severe protein deficiency, which is characterized by changes in pigmentation of skin and hair, edema, skin lesions, anemia, and apathy.

L

Labile - Unstable; easily destroyed.
Lactase - An enzyme present in the intestinal juice that acts on lactose to produce glucose and galactose.
Lactic acid - An organic acid commonly found in sour milk and silage and one that is important in the body during anaerobic glycolysis.
Laminitis - An Inflammation of the sensitive laminae under the horny wall of the hoof; often associated with overfeeding.
Laxative - A medicine of agent that can induce bowel movement and relieve constipation.
Lesion - An unhealthy change in the structure of a part of the body.
Legume - A plant member of the leguminosae family (alfalfa, clovers, etc.), with the character of forming N-fixing nodules on its roots.
Lignin - A biologically unavailable polymer that is a major structural component of the cell walls of plants.
Limited feeding - A feeding system in which animals are fed less than their voluntary intake.
Limiting amino acid - The indispensable amino acid of a protein which shows the greatest percentage deficit.
Linoleic acid - An 18-carbon unsaturated fatty acid; one of the essential fatty acids; it occurs widely in plant glycerides.
Lipase - A fat-splitting enzyme; different lipases are produced by the stomach and the pancreas.
Lipids - Substances that are diverse in chemical nature but are soluble in fat solvents.
Lipolysis - The decomposition or splitting up of fat to yield glycerol and fatty acids.
Lymph - The slightly yellow, transparent fluid occupying the lymphatic channels of the body.

M

Malignant - Virulent or destructive as applied to cancer.
Malnutrition - An overall term for poor nourishment.
Malt - Sprouted and steamed whole grain from which the radicle has been removed.
Maltase - An enzyme that splits maltose to produce two molecules of glucose.
Manure - The refuse from animal quarters consisting of excreta with or without litter or bedding.
Mash - (Physical form) A mixture of ingredients in

meal form. Similar term is mash feed.
Mastitis - An inflammation of the mammary gland.
Meal - (Physical form) An ingredient that has been ground or otherwise reduced in particle size.
Meconium - A dark green excrement material accumulated in the intestines during the fetal development.
Medicated feed - Any feed that contains drug ingredients intended or represented for the cure, mitigation, treatment, or prevention of diseases of animals other than humans or that contains drug ingredients intended to affect the structure or function of the body of animals other than humans.
Megacalorie (Mcal) - 1000 kcal or 1 million calories; synonymous with therm.
Metabolic size - The body weight raised to the 3/4 power ($W^{0.75}$); a means of relating body weight to heat production of an animal.
Metabolism - The sum of all the physical and chemical processes taking place in a living organism.
Metabolite - Any compound produced during metabolism.
Metabolizable energy (ME) - Digestible energy minus the energy of the urine and combustible gases from the gastrointestinal tract (primarily methane).
Methane - A major product of anaerobic fermentation of carbohydrates; found in the rumen.
Metritis - An inflammation of the uterus.
Microbes - The same as microorganisms.
Microingredient - Any ration component normally measured in milligrams of micrograms per kilogram or in parts per million (ppm).
Microorganism - A minute living organism, usually microscopic, such as bacteria and protozoa.
Mill by-product - (Part) A secondary product obtained in addition to the principal product in milling practice.
Mill dust - (Part) Fine feed particles of undetermined origin resulting from handling and processing feed and feed ingredients.
Mill run - (Part) The state in which a material comes from the mill, ungraded and usually uninspected.
Mineralize, mineralized - (Process) To supply, impregnate, or add inorganic mineral compounds to a feed ingredient or mixture.
Minerals - As applied to animal nutrition, elements that are essential to the plant or animal and that are found in its tissues.
Minerals, macro - The major minerals (in terms of the amounts required in the diet or found in body tissues): calcium (Ca), chlorine (Cl), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na), and sulfur (S).
Minerals, micro - The trace elements required by animal tissues that must be in the diet: cobalt (Co), copper (Cu), chromium (Cr), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silicon (Si), vanadium (V), and zinc (Zn).
Miscible - Capable of being mixed easily with another substance.
Mixing - (Process) To combine by agitation two or more materials to a specific degree of dispersion.
Molasses - The thick, viscous by-product resulting from refined sugar production, or the concentrated partially dehydrated juices from fruits.
Monogastric - The simple stomach; often used for nonruminant animals, but technically a misnomer because ruminants have only one stomach with four compartments.
Monosaccharide - Anyone of several simple sugars.
Morbidity - A state of sickness.
Moribund - A dying state-near death.
Mucosa - The membranes that line the passages and cavities of the body.
Mucus - A slimy liquid secreted by the mucous glands and membranes.
Mycotoxin - A fungal toxin; quite often present in feeds, sometimes at lethal levels.

N

National Research Council (NRC) - A division of the National Academy of Sciences established in 1916 to promote the effective utilization of scientific and technical resources.
NDF - Neutral detergent fiber, the fraction containing mostly cell wall constituents of low biological availability.
Necrosis - Death of a part of the cells making up a living tissue.
Nephritis - Inflammatiori of the kidneys.
Net energy (NE) - Metabolizable energy minus the heat increment.
Neuritis - Inflammation of the peripheral nerves.
NFE (nitrogen-free extract) - Consists primarily of readily available carbohydrates such as sugars and starches; part of the proximate analysis.
Nitrogen balance - A nutritional state in the animal determined from the N intake minus the N in feces and urine.
Nonprotein nitrogen (NPN) - Anyone of a group of N-containing compounds that are not true proteins that can be precipitated from a solution; ammonia and urea are examples.
Nonruminant - A simple-stomached animal that does not ruminate.
Nutrient - Any chemical substance that provides nourishment to the body.

O

Obesity - The accumulation of body fat beyond the amount needed for good health.

Offal - Material left as a by-product from the preparation of some specific product, less valuable portions, and the by-products of milk.

Oil - Usually a mixture of pure fats that is liquid at room temperature.

Oleic acid - An 18-carbon fatty acid that contains one double bond; it is found in animal and vegetable fat.

Omasum - The third compartment of the ruminant stomach.

Orts - Fragments of feed that an animal refuse to eat.

Ossification - The process of deposition of bone salts in the cartilage of the bones.

Osteitis - Inflammation of a bone.

Osteomalacia - A weakening of the bones caused by inadequate Ca, P, and/or vitamin D or by some diseases.

Osteoporosis - A reduction in the normal amount of bone salts (often occurring with age) such that the bone becomes porous and brittle.

Oxidation - The union of a substance with oxygen; the increase of positive charges on an atom or loss of negative charges.

P

Paddock - A small fenced field used for grazing purposes.

Palatability - The relative attractiveness of feed to the animal.

Palmitic acid - A saturated fatty acid with 16 carbon atoms.

Pancreas - An organ located near the stomach; it produces pancreatic juice, which is secreted into the small intestine via the pancreatic duct. It is also an endocrine gland that secretes insulin and glucagon, hormones that control metabolism of glucose.

Parakeratosis - Any abnormality of the outmost or horny layer of the skin, especially the condition caused by edema between the cells which prevents the formation of keratin.

Pathogen Any disease-producing microorganism or material.

Pearled, pearling - (Process) Dehulled grains reduced by machine brushing into smaller smooth particles.

Pellets - (Physical form) Agglomerated feed formed by compacting and forcing through die openings by a mechanical process. Similar terms are pelleted feed and hard pellet.

Pellet, soft - (Physical form) Pellets containing sufficient liquid to require immediate dusting and cooling. Similar term is high-molasses pellets.

Pelleted, pelleting - (Process) Having agglomerated feed by compacting it and forcing it through die openings.

Pentosan - A polysaccharide made up primarily of five-carbon sugars; araban and xylan are examples.

Pentose - A five-carbon sugar such as arabinose, xylose, or ribose.

Pepsin - A proteolytic enzyme produced by the stomach.

Permeable - Capable of being penetrated.

Physiological - Pertaining to the science that deals with the functions of living organisms or their parts.

Pica - A depraved appetite characterized by a craving for unnatural articles of food (dirt, sand, feces, etc.)l

Plasma - The fluid portion of the blood; serum is plasma from which the fibrinogen has been removed by the clotting process.

Polyneuritis - An inflammation encompassing many peripheral nerves.

Polyuria - An excessive excretion of urine.

Precursor - A compound that can be used by the body to form another compound, such as carotene used to produce vitamin A.

Premix - A uniform mixture of one or more microingredients and a carrier, used in the introduction of microingredients into a larger batch.

Premixing - (Process) The preliminary mixing of ingredients with diluents and/or carriers.

Product - (Part) A substance produced from one or more other substances as a result of chemical or physical change.

Propionic acid - One of the volatile fatty acids commonly found in rumen contents.

Protein - Any of many complex organic compounds formed from various combinations of amino acids and, sometimes, other nonprotein components.

Protein equivalent - A term indicating the total N contribution of a substance in comparison with the N content of protein (e.g., urea - 45% N x 6.25 = 281%).

Provitamin - A precursor of vitamin.

Proximate analysis - A combination of analytical procedures used to describe feeds, excreta, and other agricultural products.

Pulverized, pulverizing - (Process) See Ground, grinding.

Purified diet - A mixture of the known essential dietary nutrients in a pure form that is fed to experimental animals in nutrition studies.

Putrefaction - The decomposition of proteins by microorganisms under anaerobic conditions.

Pyrexia - A feverish condition.

R

Radioactive - An element that emits particles during the disintegration of the nuclei; the emissions include

alpha and beta particles and gamma rays.
Radioisotope - A radioactive form of an element; often used in experimental work with plants and animals to trace metabolic activity in the animal.
Rancid - A term used to describe fats that have undergone partial decomposition; rancid fats may have objectional tastes or odors and may be toxic.
Range cake - (Physical form) See cake.
Range cubes - (Physical form) Large pellets designed to be fed on the ground. Similar to range wafer.
Ration - A fixed portion of feed, usually expressed as the amount of a diet allowed daily.
Rennin - A milk-curdling enzyme present in the gastric juice of young mammals.
Resorption - A return of the nutritive compounds of a partially developed fetus and fetal membranes to the system of the mother.
Reticular groove - A muscular structure at the lower end of the esophagus that, when closed, forms a tube allowing milk to go directly into the abomasum; sometimes called the esophageal groove.
Reticulum - The first compartment of the ruminant stomach.
Rolled, rolling - (Process) Having changed the shape and/or size of particles by compressing between rollers. It may entail tempering or conditioning.
Rumen - The second compartment of the ruminant stomach.
Ruminant - Any of a group of hooved mammals that has a four-compartmented stomach and that chew a cud while ruminating.
Rumination - The process of regurgitating previously eaten feed, reswallowing the liquids, and rechewing the solids (cud).

S

Salmonella - A pathogenic, diarrhea-producing organism sometimes present in contaminated feeds.
Saponifiable - Having the capacity to react with alkali to form soap.
Sarcoma - A tumor of fleshy consistency, often highly malignant.
Satiety - The condition of being fully satisfied with food; the opposite of hunger.
Saturated fat A fat that contains no fatty acids with double bonds.
Scalped, scalping - (Process) Having removed larger material by screening.
Scratch - (Physical form) Whole, cracked, or coarsely cut grain. Similar terms are scratch grain, scratch feed.
Screened, screening - (Process) Having separated various-sized particles by passing them over and/or through screens.
Self-fed - Provided with part or all of the ration on a continuous basis so that the animal may eat at will.
Separating - (Process) Classification of particle size, shape, and/or density.
Separating, magnetic - (Process) Removing ferrous materials by ma~etic attraction.
Septicemia - A diseased condition resulting from the presence of pathogenic bacteria and their associated poisons in the blood.
Serum - The colorless fluid portion of blood remaining after clotting and removal of corpuscles. Differs from plasma in that fibrinogen has been removed.
Shorts - The particle of bran, germ, flour or offal from the tail of the mill from commercial flour milling.
Shrinkage - A term used to indicate the body weight loss due to stressful conditions such as being transported, severe weather, or feed shortage.
Silage - Feed resulting from the storage and fermentation of wet crops under anaerobic conditions.
Sizing - (Process) See Screened, screening.
Slotted floor - Floors in an animal pen with slots through which the feces and urine pass to a storage area below or nearby.
Solubles - Liquid containing dissolved substances obtained from processing animals or plant materials. May contain some fine suspended solids.
Solvent extracted - A process for the extraction of oil from seeds involving the use of an organic solvent.
Specific heat - The heat absorbing capacity of a substance in relation to that of water.
Stabilized - Made more resistant to chemical change by the addition of a particular substance.
Starch - A polysaccharide that yields glucose on hydrolysis; found in high concentrations in most seed grains.
Steamed, steaming - (Process) Having treated ingredients with steam to alter physical and/or chemical properties. Similar terms are steam cooked, steam rendered, tanked.
Stearic acid - An 18-carbon saturated fatty acid.
Sterol - An alcohol of high molecular weight, such as cholesterol; a basic compound used to synthesize many vital chemicals for both plants and animals.
Stocker cattle - Usually, young cattle that are light and thin, and lack finish.
Stocking rate - A pasture management terms pertaning to animal numbers in relation to carrying capacity of a unit o or area of the pasture.
Stomach - The part of the digestive tract in which chemical digestion is initiated in most animal species. It normally lies between the esophagus and the small intestine.
Stover - The mature, curled stalks and leaves of dorn after the ears, or sorghum after the heads have been

harvested.

Stress - Any circumstance that tends to disrupt the normal, steady functioning of the body and its parts.

Sucrose - A disaccharide (common table sugar) composed of one molecule each of glucose and fructose.

Supplement - A feed used with another to improve the nutritive balance or performance of the total and intended to be (a) fed undiluted as a supplement to other fueds, (b) offered free choice with other parts of the ration separately available, or (c) further diluted and mixed to produce a complete feed.

Syndrome - A medical term meaning a set of symptoms that occur together.

T

Taste - The ability to distinguish flavors between or among solid or liquid components of the diet.

TDN (total digestible nutrients) - A value that indicates the relative energy value of a feed for an animal.

Tempered, tempering - (Process) See Conditioned, conditioning.

Tetany - A condition in animals in which there are localized, spasmodic, muscular contractions.

Thyroxine - An iodine-containing hormone that is produced by the thyroid gland.

Toasted - (Process) Browned, dried, or parched by exposure to a fire or to gas or electric heat.

Trace minerals - Mineral nutrients required by animals in micro amounts only (measured in milligrams per pound or smaller amounts).

Triglyceride (fat) - An ester composed of glycerol and three fatty acids.

True protein - A precipitable protein rather than any of several nonprotein compounds.

Trypsin - A proteolytic digestive enzyme produced by the pancreas.

U

Underfeeding - A term referring to not providing the animal sufficient dietary energy.

Unsaturated fat - A fat containing from one to three fatty acids that contain one or more double bonds.

Unthriftness - Lack of vigor, poor gorwth or development.

Urea - The chief end product of protein metabolism in mammals; one of the main nitrogenous constituents in urine; a synthetic product sometimes used as a nitrogen source in rations for ruminants.

Urease - An enzyme that acts on urea to produce carbon dioxide and ammonia; it is present in numerous microorganisms in the rumen.

Uremia - A toxic accumulation of urinary constituents in the blood because of faulty kidney excretion.

Uric acid - A nitrogenous end product of purine metabolism; it is the principal N-containing component in urine of birds.

USP (United States Pharmacopoeia) - A unit of measure or potency of biologicals that usually coincides with an international unit (IU).

V

Veal - A calf fed for early slaughter.

V FA - Volatile fatty a.cids.

Villi - Small threadlike projections attached to the interior of the wall of the small intestine to increase its absorptive surface area.

Viscera - The organs of the great cavities of the body, which are removed at slaughter.

Viscosity - The freedom of flow of liquids.

Vitamin - One of a group of organic substances that is essential in small amounts for the lives of animals.

Vitamins, fat soluble - Vitamins soluble in fats. This group includes vitamins A, D_2, D_3, E (tocopherol), and K.

Vitamins, water soluble - Vitamins soluble in water. This group includes ascorbic acid (vitamin C) and the B complex: biotin, choline, cobalamin or cyanocobalamin, folacin, niacin, pantothenic acid, pyridoxine, riboflavin, and thiamin.

W

Wafer - (Physical form) A form of agglomerated feed based on fibrous ingredients in which the finished form usually has a diameter or cross section measurement greater than its length.

Wafered, wafering - (Process) Having agglomerated a feed of a fibrous nature by compressing into a form usually having a diameter or cross section measurement greater than its length.

Weaning - The stopping of young animals from nursing or suckling their mothers.

Weanling - A recently weaned animal.

Wet-milled - A process in which feed materials is steeped in water with or without sulphur dioxide to soften the kernel in order to facilitate the separation of various component parts.

Wet rendered - A process in which material is cooked with steam under pressure in closed tanks.

Whey - The watery part of milk separated from the curd.

Wort - The liquid portion of malted grain. A solution of malt sugar and other soluble extracts from malted mash.

Y

Yearling - Refer to a male or a female farm animal (especially, cattle and horses) during the first year of its life.

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[a]Only some books, handbooks, proceedings & other major publications used for this handbook are listed in this section. Most other references are cited accordingly in the text.