

INTRODUCTION

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1. Nutrition

A. Definition?

- 1) To "Nourish!"
- 2) "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 out 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 CO₂ & H₂O (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:

- a) Those cannot be synthesized in the body from other substances, or those cannot be synthesized fast enough to meet its needs.

- b) Thus, must be supplied from the diet!
- 3) Dispensable nutrients:
 - a) Those can be synthesized from other substances in sufficient quantity to meet its needs.
 - b) But, still very important!
- 4) Use of the term, "Essential or Non-Essential Nutrient" for amino acids, minerals, and vitamins?
 - a) May not be appropriate terminology for some nutrients - e.g., amino acids!
 - b) 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.):

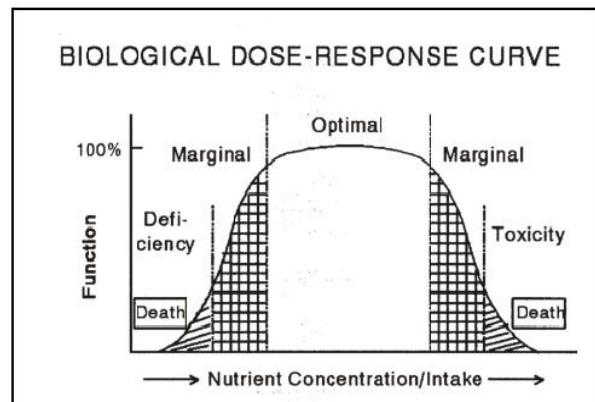
*"... Should reexamine the whole concept of requirements for a certain nutrients. In the past, we have been mainly concerned with crude quantitative aspects - **how much?***

*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?

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

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 from 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 “ $BM \text{ (kcal)} = 70Wkg^{0.75}$ ”, 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 on 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 characteristic 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 from 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 depleted 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 beneficent 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:

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

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:

$$\text{Apparent digestibility} = 100 - \left(100 \frac{\% \text{ indicator in feed}}{\% \text{ indicator in feces}} \times \frac{\% \text{ nutrient in feces}}{\% \text{ nutrient in feed}} \right)$$

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:
 - 1) "Fe and health" - Fe as a constituent of blood (1832).
 - 2) 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	Micro
0.001-.009	Fe, Zn, F, Sr, Mo, Cu	
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 produce 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) - $\text{KHbO}_2 \rightarrow \text{O}_2 + \text{KHb}$; $\text{KHb} + \text{H}_2\text{CO}_3 \rightarrow \text{HHb} + \text{KHCO}_3$; $\text{HHb} + \text{O}_2 + \text{KHCO}_3 \rightarrow \text{KHbO}_2 + \text{H}_2\text{CO}_3$; $\text{H}_2\text{CO}_3 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$ (account for > 70% of buffering capacity in blood).
 - (2) Phosphate buffer system (Na_2HPO_4) - $\text{Na}_2\text{HPO}_4 \rightarrow 2 \text{Na ions} + \text{HPO}_4^{2-}$; $\text{HPO}_4^{2-} + \text{H}^+ \rightleftharpoons \text{H}_2\text{PO}_4^-$; $\text{H}_2\text{PO}_4^- + \text{OH}^- \rightarrow \text{HPO}_4^{2-} + \text{H}_2\text{O}$ (only small buffering capacity in blood & tissues, but 1° buffers in urine).
 - (3) Carbonate buffer system (NaHCO_3) - $\text{NaHCO}_3 \rightarrow \text{Na}^+ + \text{HCO}_3^-$; $\text{HCO}_3^- + \text{H}^+ \rightleftharpoons \text{H}_2\text{CO}_3$; $\text{H}_2\text{CO}_3 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$

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 \ominus -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 B₁₂, 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

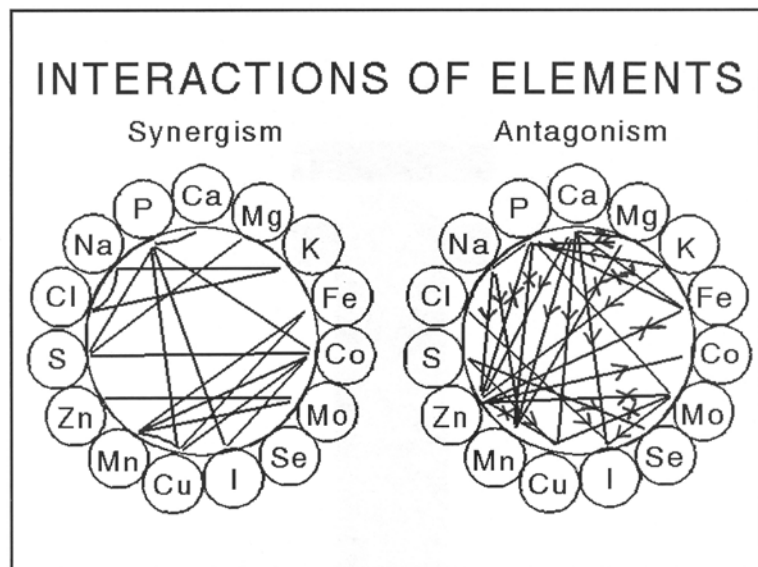
A. Interactions in general:

- 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.
- 3) 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, Cyprinidae & 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 = $\text{Element}_{\text{feed}} - \text{Element}_{\text{feces}}$
- 2) Retention = $\text{Element}_{\text{feed}} - (\text{Element}_{\text{feces}} + \text{Element}_{\text{urine}})$

- 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 = $100 \times [1 - (\text{E:label}) \text{ in feces or chyme} / (\text{E:label}) \text{ in feed}]$

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

^aMineral requirements for 20-50 kg pigs (NRC, 1988).

VITAMINS IN GENERAL

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1. Historical Perspectives [Please see Maynard et al. (1979), McDowell (1989), and 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:
 - 1) Derived from words "vital amine!"
 - 2) Found to be later that not all vitamins 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.

C. Some compounds deviate from the classic definition:

- 1) Ascorbic acid - produced by most species from glucose, and the amount is often sufficient for their needs:
 - a) Young or under stress conditions - ???
 - b) Some species such as fish, guinea pig, Indian fruit bat, and higher primates lack the enzyme, L-gulonolactone oxidase.
- 2) Vitamin D - biosynthesis from precursors in the skin by ultraviolet light.
 - Animals in the confinement system and(or) during the winter months ... ?
- 3) Niacin - can be synthesized from Trp, but the efficiency of conversion is very low, especially in cats, fishes, and ducks!
- 4) Choline - produced by amination and subsequent methylation of Ser, but may not be sufficient for rapidly growing chicks and poults!
 - Some are considered as vitamins only in certain contexts!

3. 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

4. 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. (Thus, 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, thus, must be supplied continuously in the diet.
- 4) Excess (i.e., > tissue saturation) - Excreted in urine, thus, generally non-toxic.
- 5) Deficiency:
 - a) Rarely caused by a single vitamin.
 - b) Difficult to relate signs to functions in most instances, i.e., non-specific!
 - c) Symptoms are often reflection of the most limiting vitamin in the diet.

5. Vitamin Deficiencies

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.

6. Requirements

A. 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	1,300
Vitamin D, IU	-	-	-	150
Vitamin E, IU	21	3	17	11
Vitamin K, mg	-	-	-	0.5
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	2,600	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

^aRequirements for 20-50 kg pigs (NRC, 1988).

- Vitamins routinely supplemented in swine diet - Vitamins, A, D, E & K, riboflavin, pantothenic acid, niacin, vitamin B₁₂ (& choline?)
- Pyridoxine, folacin, and biotin - ???

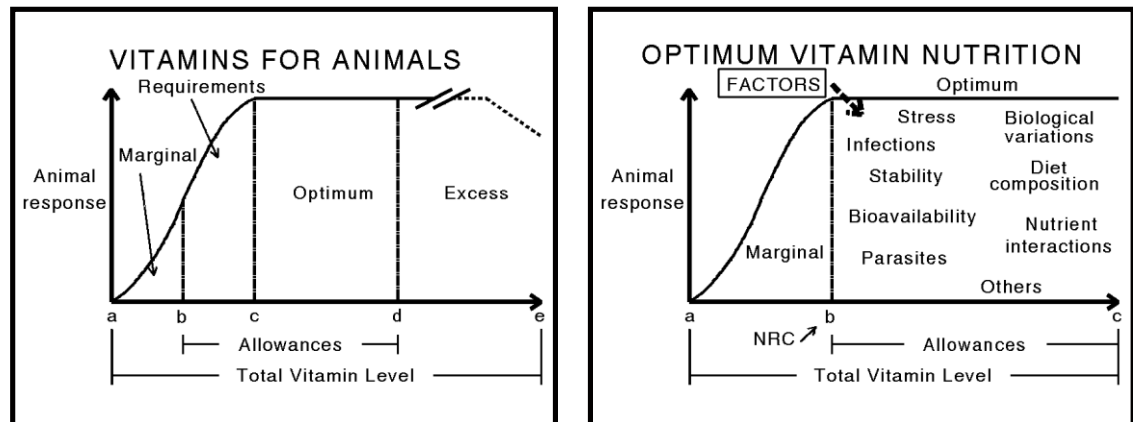
B. Requirements/allowances:

- a) Requirement – e.g., NRC values are usually close to minimum levels needed to prevent deficiency signs.
- b) Allowances - Total levels fed to compensate for factors affecting the need.

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 B₁₂, 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.
- Optimum vitamin nutrition for animals: (Adapted & redrawn from McDowell, 1989)



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:
 - a) Although not extensive vs ruminants, considerable!
 - b) 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.)

7. Vitamin Stability in Feed

- A. Affected by moisture, oxidation, reduction, trace minerals, heat, light, acidic pH, neutral pH, and basic pH.
- B. Vitamin stability in feeds (% retention): (M.B. Coelho, BASF)

Vitamin	Month							% Avg. loss/month
	0.5	1	2	3	4	5	6	
A (beadlet)	92	83	76	69	60	51	43	9.5
D ₃ (beadlet)	93	88	84	78	72	65	55	7.5
E (acetate)	98	96	94	92	91	89	88	2.0
E (alcohol)	78	59	33	20	11	5	0	40.0
MSBC	85	75	61	52	44	37	32	17.0
MPB	86	76	63	54	47	40	37	15.0
Thiamin-HCl	93	86	74	65	57	53	47	11.0
Thiamin Mono	98	97	88	83	77	72	65	5.0
Riboflavin	97	93	92	88	86	84	82	3.0
Pyridoxine	95	91	87	84	81	78	76	4.0
B ₁₂	98	97	96	95	94	93	92	1.4
Ca Pantothenate	98	94	93	90	88	87	86	2.4
Folic acid	98	97	88	83	77	72	65	5.0
Biotin	95	90	86	82	78	76	74	4.4
Niacin	93	88	84	80	76	74	72	4.6
Ascorbate	80	64	45	31	22	15	7	30.0
Choline	99	99	99	98	98	97	97	1.0