AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY ARDA D
Batch 98

1. SUBJECT CLASSIFICATION
A. PRIMARY: Food production and nutrition — AL30-5200-0000
B. SECONDARY: Animal production--Animal nutrition--Ruminants

2. TITLE AND SUBTITLE
Latin American Symposium on Mineral Nutrition Research with Grazing Ruminants; proceedings of the conference

3. AUTHOR(S)
(100) Conrad,J.H.; McDowell,L.R.; (101) Fla.Univ.Inst.of Food and Agr.Sciences; Latin American Sym.on Mineral Nutrition Research with Grazing Ruminants,Belo Horizonte,Brazil, 1976

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1978	203p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Fla.

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)

9. ABSTRACT

10. CONTROL NUMBER
PN-AAG-333

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Latin America
Livestock
Meetings
Mineral deficiencies

13. PROJECT NUMBER
931060000

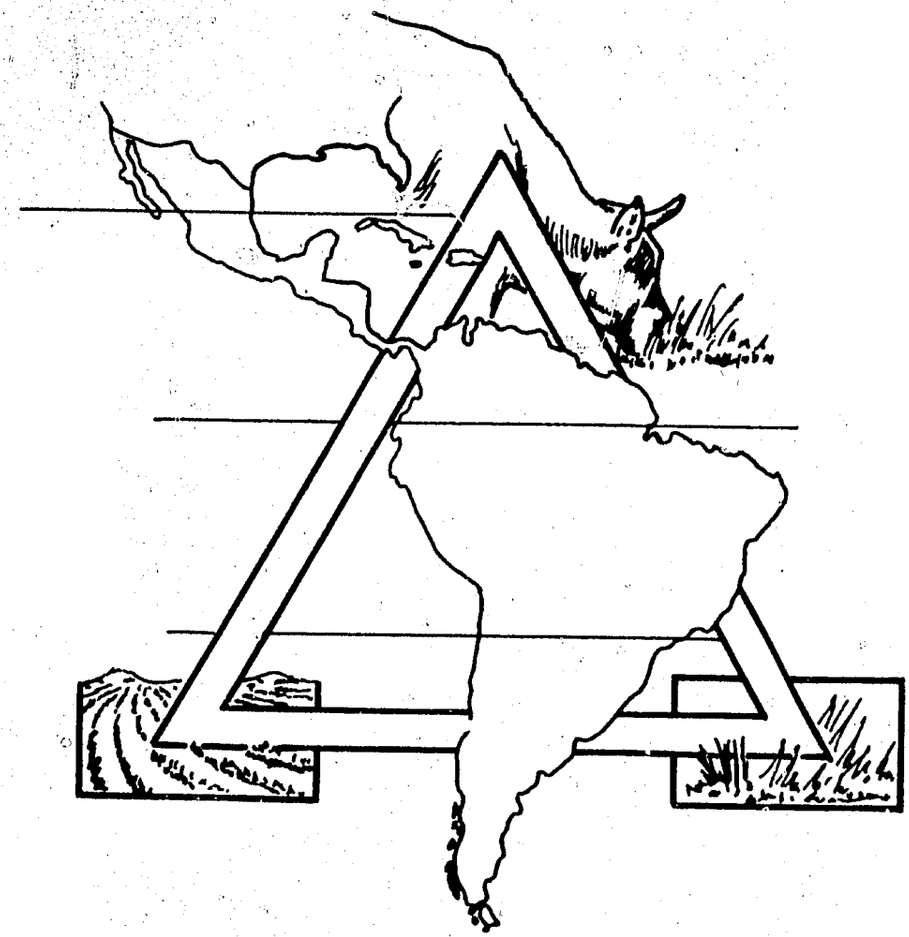
14. CONTRACT NUMBER
AID/ta-C-1153 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-73)

1.A.

LATIN AMERICAN SYMPOSIUM ON MINERAL NUTRITION RESEARCH WITH GRAZING RUMINANTS



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University of Florida/Institute of Food and Agricultural Sciences
United States Agency for International Development

LATIN AMERICAN SYMPOSIUM ON MINERAL NUTRITION RESEARCH WITH GRAZING RUMINANTS

Proceedings of the Conference held in Belo Horizonte, Brazil
from March 22 to 26, 1976

Edited by

Joe H. Conrad and Lee R. McDowell
Animal Science Department
University of Florida
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University of Florida
Gainesville, Florida
1978

Federal University of Minas Gerais
Federal University of Viçosa
Superior School of Agricultural of Lavras
Agricultural Research Service of Minas Gerais
University of Florida
United States Agency for International Development

ACKNOWLEDGEMENT

The University of Florida has a contract with the Technical Assistance Bureau of the United States Agency for International Development to support the study of mineral deficiencies and toxicities in grazing ruminants in the tropics. The project title is "Research in Mineral Deficiencies for Grazing Ruminants" Contract number: AID/ta-c-1153. Collaborative mineral research between the University of Florida and cooperating research groups is currently in progress in the Bahamas, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Peru, Uruguay, and Venezuela. Discussions are underway with interested personnel in some tropical countries of Africa and Asia.

The project leaders gratefully acknowledge the following people whose dedicated efforts have made this publication and the Latin American mineral research program possible: Former Animal Science Faculty Tony J. Cunha, Karl R.Fick, and Richard H. Houser for their major contribution to the early phases of the project; Graduate Research Assistants, Mangeye Kiatoko, Carlos Lang, Soekanto Lebdosoekojo, Marcelo O. Mendes, David Morillo, Armando Primo, Julio Cesar de Sousa and Ricardo Valdivia; Center for Tropical Agriculture administrative assistant Arlene Remington; and staff technician John Bell for laboratory training and analysis; Animal Science Faculty C. B. Ammerman, J. K. Loosli, J. E. Moore, R. L. Shirley, J. F. Easley and G. K. Davis for project assistance and support; Brazilian personnel Alberto Duque Portugal, Jose Fernando Coelho da Silva, Robert M. Silva, and Jose de Alencar Carneiro Viana for contributing to the Symposium organization and publication of the proceedings. A number of bilingual secretaries have assisted with translating, typing and proofing of the manuscripts. For this valuable assistance we are indebted to Rossina Fernandez, Debora McDonald, Cristina Parra, Rebecca Pearse and Ana T. Aguilar-Zometa.

The project leaders are indebted to the Technical Assistance Bureau (AID) personnel: Mike Galli, Nels Konnerup, Ned S. Raun, Ed Shuart, and Carl Sierk for their administrative skills and untiring support of this mineral research program.

The Institute of Food and Agricultural Sciences at the University of Florida is fortunate to have a number of Portuguese and Spanish speaking students who are studying toward their Master of Sciences or Doctor of Philosophy degrees. Most are professors or research scientists at universities or agricultural research institutions throughout Latin America. The symposium and the publication of the proceedings in English, Portuguese and Spanish have been possible only because of their excellent cooperation. The project leaders wish to express their sincere thanks to each who helped with writing or translating the 27 technical papers. The representatives from the various countries are as follows:

Argentina	Norberto Mario Rodríquez
Brazil	J. M. S. Andrade, José Herculano de Carvalho, Edvaldo Correia de Araujo, Antonio Carlos Guedes, Arthur Mariante, Marcelo O. Mendes, José Ribeiro, H. M. Silva, J. C. de Sousa, Emanuel A. Serrão, Leonidas Valle and J. C. Werner.
Colombia	Joaquín Avila P. and María Elena Siniesterra
Costa Rica	Carlos Campabadal and Carlos Chávez
El Salvador	Ana T. Aguilar-Zometa and Carlos A. Zometa
Honduras	Karl R. Fick and Juan José Osorto
Mexico	Carlos Lever and Heriberto Román-Ponce
Nicaragua	Dean Padgett
Paraguay	Juan F. Villalba
Peru	Ricardo Valdivia
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PREFACE TO THE PORTUGUESE EDITION

The University of Florida with funds from the United States Agency for International Development are developing cooperative mineral nutrition research programs in various countries of Latin America including Brazil. This research emphasizes grazing ruminants and is in collaboration with the universities and research institutions.

The scientists at the University of Florida (UF), Federal University of Minas Gerais (UFMG), Federal University of Viçosa (UFV), and the Agricultural Research Service of Minas Gerais (EPAMIG) planned the Latin American Symposium on Mineral Nutrition Research with Grazing Ruminants with the objective of discussing and determining methodology, reviewing available information, and increasing the interchange between countries, institutions, and scientists.

The University of Florida had the responsibility of organizing the Symposium on the international level while the UFMG, UFV, and EPAMIG organized it at the national level within Brazil.

In addition to the Portuguese edition, the Symposium papers will also be published in English and Spanish.

The organizing committee would like to thank all of the participating people and institutions who have cooperated to make this symposium possible. These meetings and proceedings represent distinct progress and support for a sector which has the important potential of increasing the supplies of milk and meat available for human consumption.

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Preface

This publication records the proceedings of a conference entitled "Latin American Symposium on Mineral Nutrition Research with Grazing Ruminants" held at Belo Horizonte, Brazil, March 22-26, 1976. The Symposium was conceived and organized by a combined effort of the following organizations: Federal University of Minas Gerais (UFMG), Federal University of Viçosa (UFV), Superior School of Agriculture of Lavras (ESAL), Agricultural Research Service of Minas Gerais (EPAMIG), University of Florida, and United States Agency for International Development (USAID).

The objectives of this conference were to bring together Latin American scientists active in ruminant mineral nutrition research to review the basic knowledge, methodology and recent findings relating to mineral deficiencies and toxicities in Latin America. Paper presentation progressed through discussions of soil mineral concentrations and properties, individual mineral characteristics, soil-plant-animal mineral relationships, techniques of mineral research, current status of locating regions of mineral deficiencies or toxicities and finally methods of mineral supplement formulation and administration for grazing ruminants.

These proceedings bring together reviews of research which should provide a useful reference for manufacturers of mineral mixtures, research scientists, teachers, students, extension specialists, farmers and others concerned with nutrition of grazing livestock in Latin America and other tropical regions of the world. It is hoped that these proceedings will be useful in documenting the current status in Latin America of minerals in ruminant nutrition and subsequently in stimulating additional productive research.

The proceedings of this symposium have previously been published in Portuguese and are now also available in English and Spanish. The English and Spanish editions have been updated with a photographic section illustrating mineral deficiencies and toxicities.

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Mineral Problems as Related to Tropical Climates

by
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Gainesville, Florida

I feel greatly honored to be invited to present the first paper on minerals at this symposium. It was easy to accept the assignment months ago, but my difficulties arose in trying to decide exactly what should be selected from the countless publications to illustrate the critical importance of mineral nutrition problems of grazing animals. This symposium was planned to summarize the present status of knowledge about the mineral elements which influence productivity of grazing ruminants in tropical areas and to stimulate critically needed research on unsolved problems which still greatly limit productivity. Everyone recognizes that an understanding of the specific areas where mineral deficiencies or excesses occur is necessary before producers can effectively and economically correct existing limitations. Hopefully, the discussions at this symposium will help to disseminate present knowledge and stimulate needed research to solve the remaining problems.

The primary usefulness of ruminants is that they contribute to man's food supply, not only directly as meat and milk but also to provide power to produce and transport food supplies. It has been estimated that ruminants in the developing countries (largely in the tropics) produce only 12% as much milk, 20% as much beef and veal and 57% as much sheep and goat meat per animal yearly as animals in developed countries. It is the low productivity per animal that accounts for the limited supplies of animal protein in the tropics and not shortage of animals. The developing countries have 70% of the world's cattle and water buffaloes, but they produce only 22% of the milk and 34% of the beef supplies. They also have 64% of the sheep and goats to produce 50% of the meat from these species. There is uncertainty about the relative importance of nutrition, genetic capacity of the animals, parasites and diseases, climatic stress and other factors have upon animal productivity in the widely diverse regions within the tropics. All are important; the failure of any one factor causes complete failure of the system. Thus, it is logical to consider that after critical diseases are controlled, providing any supplemental minerals needed is usually the easiest and cheapest way to maximize productivity of grazing ruminants.

If I may seek your indulgence, I would like to mention a few basic principles of which you are all at least as familiar as I am and which might be considered an imposition upon so elite an audience as this one, but which may be helpful to some less well informed people who may read the proceedings of this symposium.

Ruminants, like all other animals, must receive all of the essential dietary nutrients including water in optimum amounts (not only the mineral elements) to maintain health and to grow and reproduce at their potential levels. Climatic factors may modify the amounts of certain nutrients animals require and affect the responses to adequate diets, but possible differences in requirements have not been well-defined. The producer and researcher should recognize that the response to any supplement will depend upon whether or not other essential nutrients are adequately supplied and whether animal management practices will allow a response. For example, feeding mineral supplements to cattle will not increase growth if protein or energy is lacking.

The proof that a mineral element (or any nutrient) is essential in the diet depends upon feeding a diet low enough in that nutrient to cause structural or functional injury. Addition of the pure nutrient alone to the deficient diet must correct the deficiency signs and restore the animal to normal health. Some trace elements function either as constituents or as activators of enzymes, and they are needed in very minute amounts to sustain metabolic functions. Some elements can be recycled within the body so that the daily requirements are extremely small and long periods of time may be required to demonstrate a deficiency in animals, or the deficiency signs may be so mild or non-specific they cannot be easily recognized. Often too, there are multiple deficiencies which complicate accurate diagnosis. It is almost impossible to procure a diet for ruminants which is totally lacking in a specific mineral element. As a result, it is likely that trace elements not yet recognized as essential may later be proven to be important.

The Essential Mineral Elements

In Table 1 is listed the mineral elements which are presently considered to be essential in the diet and those which have caused toxicity in animals. Of these, Ca, P, Mg, Na, I, Fe, Cu, Co, Zn, Mn and Se are most likely to be deficient for ruminants, but a Ca deficiency has not been reported in ruminants grazing native grasses even without legumes, which are reliably high-calcium sources. While calcium deficiency can easily be produced in young growing animals and lactating dairy cows fed native forages supplemented with concentrates, the deficiency has not been reported in grazing beef cattle even during lactation. Potassium deficiency is not likely to occur in grazing ruminants because most forages are rich in this element. Details will be covered later in the symposium.

Of the trace elements, Cr, Si, V, Sn, and Ni have been shown to be essential for one or more small animal species and it is likely that they are essential for ruminants. However, deficiencies have not been produced in any ruminant and there is no information to suggest that these might cause practical problems. Toxicity of Pb, Cd, Hg and As are caused by animals eating lead paints, motor oil or discarded batteries, or from contaminated feeds or waste materials. While one should recognize the potential danger, the likelihood of problems arising among grazing ruminants is so small the matter is not considered in the symposium. The current knowledge about the essential mineral elements will be summarized in later papers.

Table 1

NUTRITIONAL CLASSIFICATION OF MINERAL ELEMENTS

Essential				Toxic	
Calcium	(Ca)	Manganese	(Mn)	Sodium	(Na)
Phosphorus	(P)	Zinc	(Zn)	Iodine	(I)
Magnesium	(Mg)	Selenium	(Se)	Copper	(Cu)
Potassium	(K)	Molybdenum	(Mo)	Cobalt	(Co)
Sodium	(Na)	Fluorine	(F)	Zinc	(Zn)
Chlorine	(Cl)	Chromium	(Cr)	Selenium	(Se)
Sulfur	(S)	Silicon	(Si)	Molybdenum	(Mo)
Iodine	(I)	Vanadium	(V)	Fluorine	(F)
Iron	(Fe)	Nickel	(Ni)	Lead	(Pb)
Copper	(Cu)	Tin	(Sn)	Cadmium	(Cd)
Cobalt	(Co)	Others?		Mercury	(Hg)
				Arsenic	(As)
				Others?	

Early Research on Minerals

While we are concerned in this conference with mineral deficiencies and toxicities of grazing ruminants, many basic discoveries about mineral requirements were made with birds, rats, dogs or people. A brief summary of some classical discoveries will be helpful in understanding methods for solving present problems.

The history of the development of knowledge about the essential nature of certain mineral elements is presented by McCollum (1956), while the more practical aspects of these discoveries were summarized by Maynard and Loosli (1962). One should recognize that only when methods were devised to identify and measure mineral elements in body tissues and feeds and to characterize responses to pure elements, was it possible to replace supposition with facts about the essential nature of any nutrient. Much of our earlier knowledge about nutrition resulted from systematic observations stimulated by a need to solve critical health problems with people and their domestic animals. Often a new scientific discovery has proven to be a confirmation of common beliefs of native people and an explanation of why the beliefs are true.

It seems likely that much information about mineral needs of animals gained by trial and error over centuries was never recorded and there is no way of learning what was practiced. French cites reports of views that the "fall of Thebes was hastened by heavy livestock mortalities caused by unidentified agents, when grazing apparently luxuriant pastures" (Underwood, 1966). Feeding "salts" to domestic animals can be traced to the time of Plutarch (40-120? A.D.). Virgil and Pliny (23-79 A.D.) recommended salts for milk production. There are many references to the feeding of salt in Britain after 1750 following land enclosure. In the early 1800s, mineral constituents of plants were shown to vary with soil type, stage of maturity of forages and these changes were considered to be important for animals, a view Boussingault later demonstrated to be true. Bone chewing by cattle was recorded in Africa in 1780 and in Paraguay in 1838, but the relation of osteophagia to phosphorus deficiency in cattle was not clarified until Theiler *et al.* (1924) of South Africa published their classical experiments showing that the dried grasses were critically low in phosphorus and that phosphorus supplements corrected bone chewing, overcame death losses from botulism and markedly increased growth rates and reproductive levels.

Phosphorus had been isolated from urine in 1669 by Brand and it was shown to be a constituent of bones by Gahn in 1748, along with calcium. In 1842, Chossat demonstrated that calcium was a necessary supplement to a cereal diet for bone development in birds. Many experiments were carried out in Europe and North America during the following 50 years on calcium and phosphorus metabolism and requirements as reviewed by Forbes and Keith (1914). After the importance of the Ca:P ration became recognized, as well as the actual levels of these elements in the diet and the discovery of vitamin D in 1922, it became possible to prevent or cure rickets, which had been a serious disease of children and young animals and birds produced in the winter in buildings to protect them from the cold, and which also prevented any exposure to sunlight. Rickets was never an important disease in the tropics because of natural ultraviolet irradiation of animals and food products.

It was reported in the early 1800s that in some areas of South America cattle regularly drank naturally mineralized waters and that health was impaired when this was not possible. I have been unable to learn which minerals were present in these waters. More recent studies have shown, however, that water may carry essential, as well as harmful amounts of mineral elements. Because of the high need and critical nature of water for animals as well as people, the matter is very important. The effective utilization of many areas is markedly limited by the lack of suitable water supplies. The research on nutrients and toxic substances in water has been reviewed by Shirley *et al.* (1974) and will be presented at this symposium. An excellent example of the usefulness of common practices relates to iodine in South America. In 1824, Alexander Humboldt described goiter in Colombia and stated that native Indians knew of a salt deposit that was an effective remedy, which was not true for other salt sources. A sample taken to France was shown by Boussingault to contain iodine, which was absent from the other salt. In 1831, Boussingault advised the Colombian Government to provide general distribution of the naturally iodized salt to the population. Iodine had been discovered

by Courtois in 1811 and nine years later he began prescribing it as a cure for goiter. Overdosages of iodine caused injury to some patients and its use was condemned by physicians. It was a hundred years later before the general use of iodized salt was started in the U.S.A. with medical authority support (McCollum, 1956).

One might expect that once we know the way to prevent something as simple to identify as goiter at a cost as low as a little iodized salt, this disease would quickly be eliminated, but goiter still exists among people and animals. What can we do about it?

Iron was shown to be present in blood by Menghini in 1747. Sydenham is credited with having treated anemia with iron solutions prepared by steeping steel filings in wine before 1680 but he did not know why it was effective. This process resulted in the formation of ferrous potassium tartrate. In 1867, Boussingault published data showing the iron content of a number of different animals and various food and beverages, since it was generally accepted by that date to be an essential element.

Except for iron and iodine, the trace elements were not studied until about 1926 when Leroy showed that magnesium increased the growth of mice. McCollum and associates reported in 1931 that magnesium deficiency caused tetany in rats and Duncan and Huffman observed similar signs in 1935 in calves fed milk as the only food. Low blood magnesium and death loss from grass tetany is a serious problem in lactating beef cows in some areas. Copper was shown to be essential for hemoglobin formation and iron utilization in rats by Hart and Elvehjem in 1928. Following this discovery, there was more than a decade of intensive research interest which resulted in the discovery of other essential elements. Sjollema reported copper deficiency in cattle and sheep in the Netherlands in 1933. Cobalt deficiency was first identified as the cause of a "wasting disease" and anemia in cattle and sheep in Australia in 1935 by Filmer and Underwood and Marston and Lines. Manganese stimulated growth of mice and reproduction of rats in studies by Kemerer and McCollum *et al.* in 1931, but its importance in cattle was not known until about three decades later. A similar situation existed with zinc, which was shown to be essential for growth and hair development of mice and rats in 1922, but its need by pigs was not shown until 1955 and for calves not until 1960.

Evidence that fluoride is essential is limited to recent reports showing that a deficiency causes impaired fertility in female mice and depressed growth in rats. Earlier tests demonstrated that traces in the drinking water (0.7 to 1.0 ppm) helps to prevent dental cavities in children, but 2.0 ppm or more causes mottling of the teeth enamel. Higher intakes (4 to 6 ppm in water) increases bone density and help to prevent osteoporosis and associated incidence of collapsed or distorted vertebrae in people over 55 years of age. There is also evidence that extra fluorine decreases the aorta calification often seen in low-fluorine areas. However, it is the toxicity of fluoride that is of greatest importance in ruminant nutrition (Shupe *et al.*, 1974).

Many of the essential mineral elements can have detrimental effects or cause toxicity if fed in sufficiently large amounts. The approximate requirement and harmful levels of the more toxic essential trace elements are shown in Table 2.

Table 2

REQUIREMENTS AND TOXICITIES OF TRACE MINERAL ELEMENTS

Element	Species	Requirement	Toxic level
		mg/kg ration	
Copper	Cattle	5-7	115
	Sheep	10	?
	Swine	6	250+
Cobalt	Cattle	0.05-0.07	60
	Sheep	0.08	120
	Horses	5-8	?
Iodine	Livestock	0.1	?
	Swine	0.2	?
Manganese	Cattle	16-25	2000
	Swine	10	4000
Zinc	Cattle	9	900->1200
	Sheep	18-22	1000
	Swine	50	2000
Selenium	Cattle	0.1	3-4
	Sheep	0.1	10
	Horses	7	5-40
	Swine	0.1	5-8

Advances in Analytical Methods

In 1937, Maynard listed only 12 mineral elements in his book, Animal Nutrition, as proven dietary essentials, (Ca, P, Na, K, Cl, S, Mg, Fe, I, Mn, Cu and Zn), several having been recently discovered. He stated "cobalt appears to be essential according to very recent work." He pointed out the commonly held view that in practice "most of them are supplied so abundantly in the commonly fed rations that no thought need be given to them." We now know that at least 6 of the above 12 are very often so deficient they must be supplemented to support optimal growth, reproduction or lactation of grazing ruminants. Furthermore, since that time eight additional trace mineral elements have been shown to be dietary essentials for some species of animals and two (Se, Mo) are important for grazing ruminants under some conditions.

I should like to mention again that knowledge about the need for mineral elements depended upon the development of methods for measuring the amounts in feeds and animal tissues and the availability of pure compounds to evaluate requirements. In the 1960s improved technical equipment and newer methods have made it possible to analyze many more samples for mineral elements and the accuracy has been greatly increased. In the industrial countries, surveys have been made to evaluate the mineral content of soils, food and feed crops and animal tissues. The areas where deficiencies and excesses of mineral elements exist have been determined so that corrective supplements can be used to maximize animal productivity and land utilization.

Some recent studies using modern techniques have been made in tropical countries to evaluate the status of mineral elements in soils and plants, and some animal studies have been reported. In 1950, de Alba cited the occurrence of phosphorus deficiency in northern Mexico, Venezuela, Colombia, Brazil, Argentina, Paraguay and Chile; cobalt deficiency in Brazil and Argentina, copper deficiency in Peru, Brazil and Argentina. Other summaries have also been published (McDowell, 1974; Mills, 1970; Russell and Duncan, 1956; Underwood, 1971; Van Niekerk, 1974).

Problems and Questions Needing Solutions

There is no doubt that there are many areas where mineral deficiencies limit productivity of grazing ruminants. We need to know what and where these are. Specific research is necessary before any deficiencies can be corrected in a reasonable and economic way. There is no justification for providing extra minerals unless they are really needed. They must be offered in such a way that they can be utilized to give economic returns.

There are a number of questions that should receive special attention in planning research, among which are the following. **Do the nutrient requirements of ruminants in the tropics differ from animals in the temperate zones?** It has been speculated that the requirement for sodium and other minerals lost in perspiration may be higher in hot dry areas, but there are no comparative data. There is evidence that genetic variation exists among breeds of sheep in the incidence of swayback and in copper metabolism and susceptibility to copper poisoning (Terrill, 1974). There are also significant genetic differences in blood concentrations of several mineral elements. Genetic-environmental interactions involving growth and energy utilization have been reported for sheep and cattle, but these probably do not modify mineral nutrition, except as would be expected from differences in feed utilization, growth rates, body size and levels of productivity. Until data are obtained to the contrary, it seems safe to assume that any differences in mineral requirements between tropical and temperate cattle and sheep are small.

What is the best and most economical way to provide the mineral supplements needed? Self-feeding minerals to grazing cattle and sheep to provide needed minerals or insurance against possible deficiencies is the common practice in the developed countries. The view that the body's need for a mineral will regulate the amount eaten has not been confirmed in controlled studies. Some animals eat very little or none of the free-choice minerals, while others eat several times more than needed. Economics in each situation should determine how the nutrient requirements will be met. Research should be carried out to define the specific needs in various locations to provide the basis for correct management decisions. Many other questions also need to be answered. This symposium will review the known information on mineral nutrition of ruminants in the tropics, define the unanswered questions and outline procedures for research which will obtain the critical information needed to increase the production of animal products.

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CLASSIFICATION AND DISTRIBUTION OF THE TROPICAL SOILS

by
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One defines the tropics as the area of land that is found between the Tropics of Cancer and Capricorn. There is only one soil characteristic that can be applied to this area which is the temperature of the soil profile at a determined depth throughout the year.

The variation in temperature at a depth of 50 cm is less than 5°C in the summer and winter which can be approximately 30°C at low altitudes and cold on the peaks of the intertropical mountains.

The greater part of the African continent, Central America, Northern Australia, and Southern Asia are found in this vast tropical area.

This paper will be addressed primarily to the tropical part of South America, not only because we know this area best but also because this is where studies of tropical soils have evolved in the last decades.

In the study of tropical soils, it has been established with a certain frequency that soil profiles situated in determined climatic zones, developed in the same hydrological situation and derived from the same parent material, have been laid down according to the stage of development.

A well known example is cited by Mohn and Van Baren, (1954) of the soils in the humid tropics of Java. These soils derived from volcanic ash are distinguished by the following stages: embryonic, juvenile, virile, senile and lateritic—names that specially refer to weathering stages of the parent material.

This paper will focus on the principal sequence of weathering or stages of soil development which occur in the vast tropical areas of Brazil, considering that up to a certain point, they are representative of soil formation sequences which occur in tropical regions, principally in Brazil and Africa.

Landscape Formation

One of the principal features of the oldest landscapes of Brazil is the presence of erosion surfaces at different altitudes (King, 1956) where the oldest surfaces are normally situated at the highest elevations.

The erosion surfaces that are observed in the landscape principally originated during the Quaternary and the Tertiary periods. The surfaces originating during the Tertiary period cover a vast area and many of them are well preserved such as the Brazilian Central Plateau with an average altitude of 750 m. The surfaces which originated during the Quaternary period are more common on the Atlantic coast and in the semi-arid region of the northeast. Erosive forces operated upon this original landscape during different periods, at diverse points and with different velocities such that many of the old surfaces were completely destroyed.

An ample time factor was utilized in the process which shaped the landscape and it produced greatly diverse geomorphic features.

For a comprehensive study of soils, regarding the distribution and classification, it is of great value to recognize the three large categories of landscapes (Bennema, 1962):

1 —old areas that reflect the original surfaces;
2 —areas with newer surfaces which form the more elevated parts of the landscape;
3 —never eroded surfaces which form the lower parts of the landscape.

In reality it is difficult to make a separation into 3 categories because they are an arbitrary division of a continuous process.

The majority of gently rolling plateaus belong to the first category of land surfaces. The principal erosive forces frequently occur on the periphery of the plateaus, producing a progressive dissection of the old surface which forms accentuated transformations in the relief. However, the dominant features continue from the original surfaces of the old landscapes.

—It has only traces of the primary aluminum-silicate minerals;
—It has more than 15% clay;
—It has diffuse or gradual transition between its subhorizons;
—It has less than 5% in volume which shows rock structure.

This definition is sufficiently generalized to include a number of latosols that differ among themselves as to:

a) the content of organic matter which can be extremely variable. In the hot equatorial region the aluminum horizon is usually thin, even in the dense equatorial jungle it rarely exceeds a thickness of 10 cm. In the higher altitudes

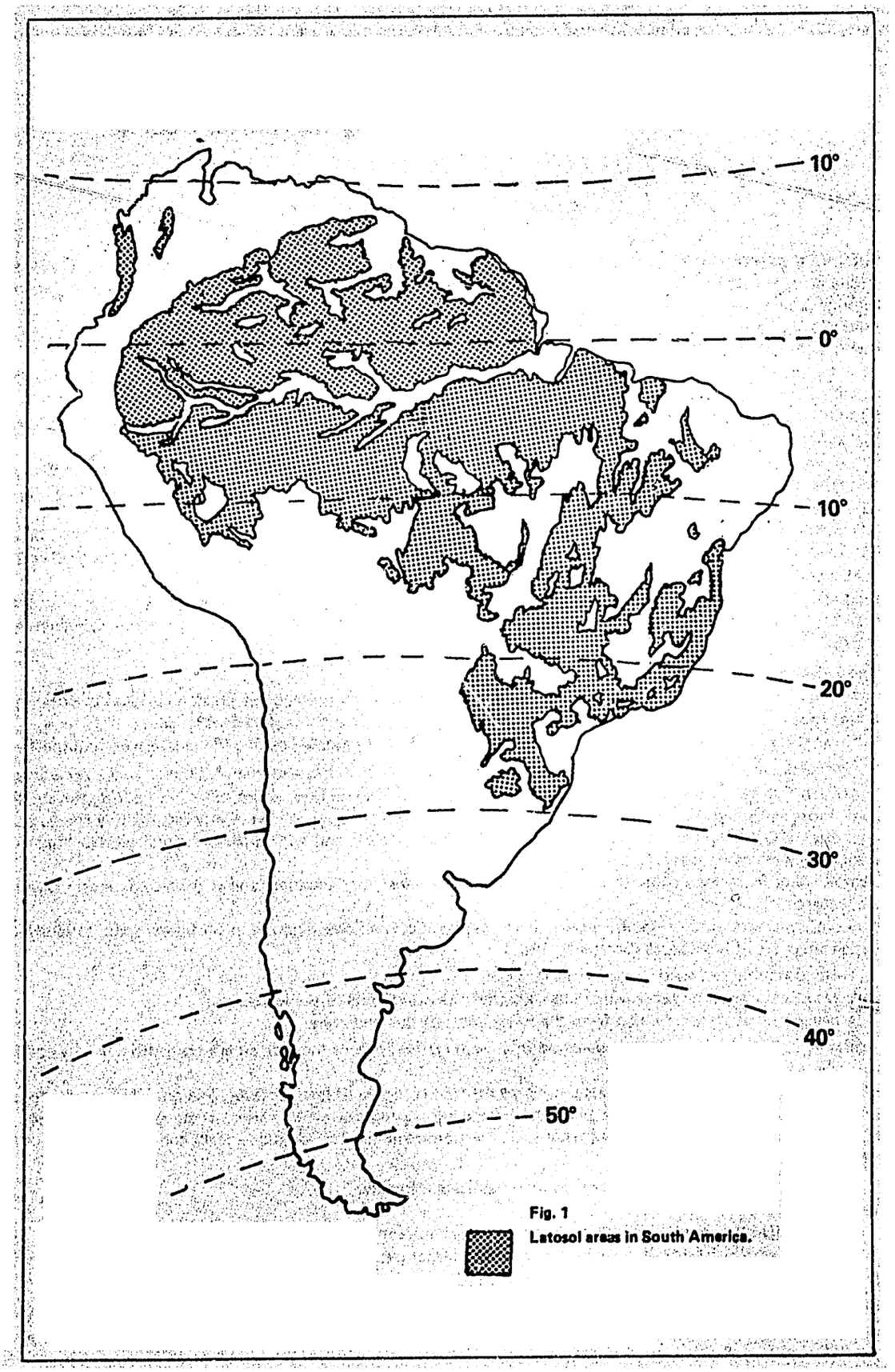


Fig. 1
Latosol areas in South America.

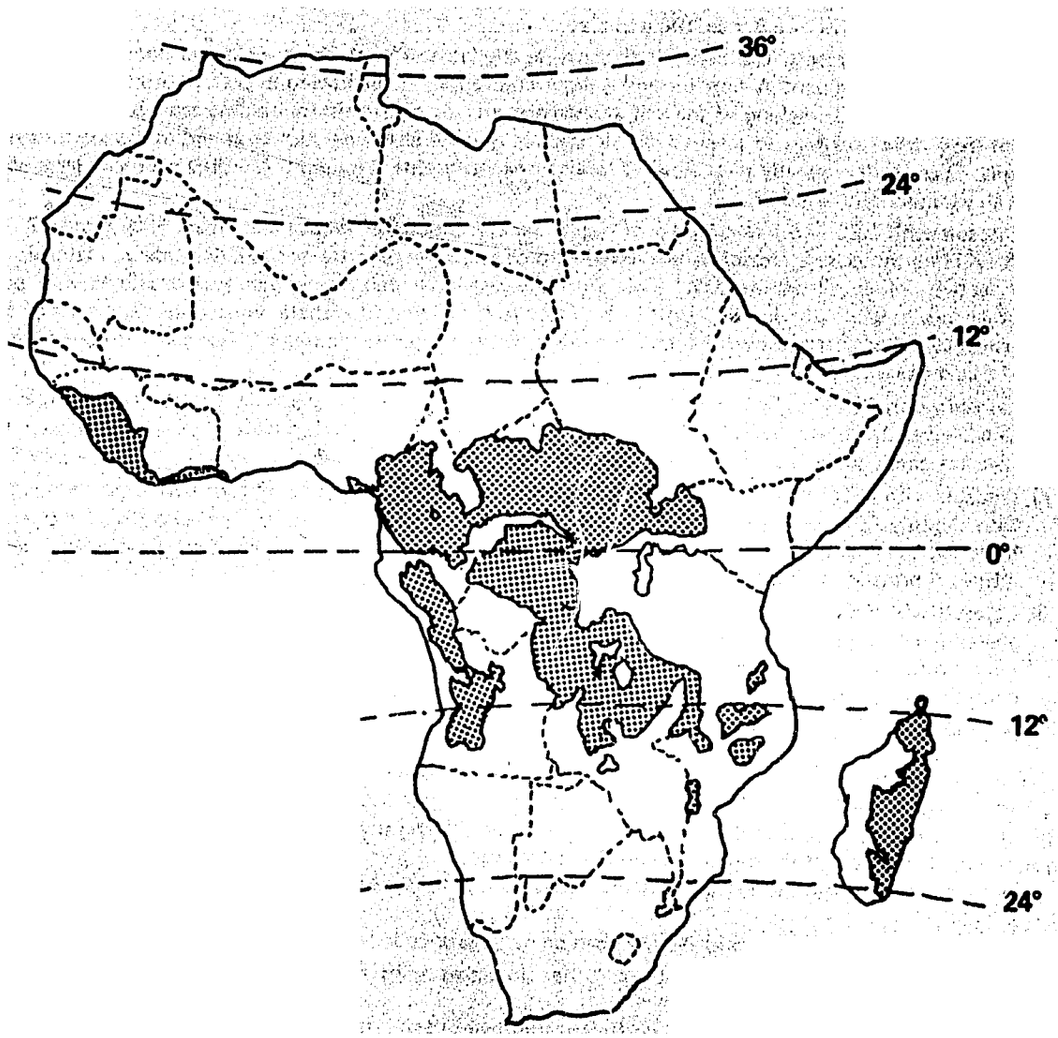


Fig. 2
Latosol areas in Africa

in which a colder tropical climate prevails the humus content is high and darker levels can cover extensive areas of latosols. Soils that contain high levels of iron oxide also have humus in considerable quantities.

b) the nature of the parent soil material can cause marked differences in the pedological properties even in heavily weathered sediments. This influence is reflected in the texture, color and iron oxide content of the soil. Latosols originated from eruptive basic rocks and have redder colors than those developed from acidic rocks which contain more quartz.

c) differences in the degree of the weathering of the soil material. The latosols are the most widespread in Brazil and Africa. Figures 1 and 2 (Wandeke, 1974) show the distribution of these soils in the South American and African continents.

The Brazilian classification of the latosols divided them as follows (Lemos, 1968):

1) Brown latosols of altitude;
2) Latosols with CEC > 6.5 meq/100 g of clay and PBS < 50% in the B2;
3. Latosols with CEC > 6.5 meq/100 g of clay and PBS > 50% in the B2;
4) Latosols with horizon A weak and high base saturation or base saturation that increases with the depth of B, attaining values greater than 50%.
5) Latosols with CEC < 6.5 meq/100 g of clay.

1) **Brown altitude latosols.** The intent is to separate the latosols of the high, cold and humid areas. They are characterized by prominent A horizon and yellow colorations or yellowing in the B horizon even with high levels of iron oxide. The cracking of the soil at entrance cuts, or high moisture holding capacity of samples which have not been dried previous to analysis can be used as specific characteristics as an aid to the identification of these soils. These soils normally have elevated levels of exchangeable aluminum. A united profile in large scale mapping is an example of this group.
2) Latosols with CEC > 6.5 meq/100 g of clay (after correcting for carbon) and PBS < 50% in the B2. The intent is to separate the class 2 latosols which have low base saturation and are not well developed as latosols as evidenced by activity of clays from the class 1 those with low base levels that are not very well developed as latosols, latosols which are hidden in cold wet zones and appear to be related to climatic conditions. The soils of this class are principally characterized by the high percentage of exchangeable aluminum. The soil, "Erechim", is an example of this soil class.
3) Latosols with CEC > 6.5 meq/100 g of clay and base saturation of > 50% in the B2. This includes the latosols which occur in the subhumid zone and have medium to high saturation base but excludes those latosols which have extremely low cation exchange capacity in the clay fraction.
4) Latosols with a diffuse A horizon (ochric) in addition, a high base saturation or base saturation which increases with depth and reaches values greater than 50%. The intent is to separate the latosols of the semi-arid zones from the latosols of the more humid zones. The predominant characteristic that distinguishes this soil is the diffuse A horizon and base saturations that are normally high.
5) Latosols with CEC < 6.5 meq/100 g of clay. These are normal latosols with a low clay activity that occur in vast areas in the humid and subhumid tropical regions. They may or may not be subject to the effects of the dry season but, neither the base saturation nor the clay activity, in the case of these latosols, is closely related to the climatic conditions under which they are found. In this particular situation the parent material and the topographic evolution is most important.

In soil landscape No. 1, the distribution of the latosols is related to the local features of topography. The degree, the form and the length of the slope are important factors in the distribution of soils, which acts in the control of the quantity of water that percolates through the soil, in the differential transport of the eroded material, leaching, dislocation and disposition of the mobile chemical constituents.

The following diagrams show topographic sequences and how they correspond with elements of the landscape (Rhue, 1960).

The variations of the topographic sequence can be distinguished in the field:

–topography shaped by denudation or other processes apart from the original formation, similar in lithologic character; and

–topography carved in two or more different lithological formations.

In this paper these new features still pertain to the previously mentioned landscape I category.

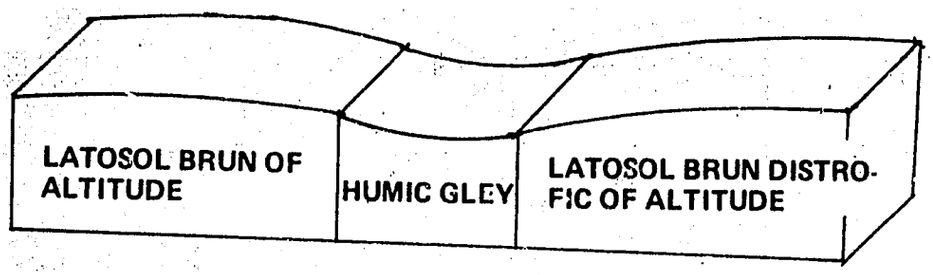
The landscape II category occupies higher elevations with old contour surfaces which form rivers in a mountainous topography. The rocks which constitute these areas are frequently more resistant to weathering.

The landscape III category is found in lower parts of the landscape and is related to the river systems which from erosion has formed the newest surfaces.

Soils of the Landscape

Landscape I (old surfaces with gently rolling to more accentuated topography) has a considerable covering of residual material varying in thickness and in an advanced stage of weathering.

Diagram of the topographic sequence of cold and humid areas—Class I Latosols.



pp - 1,500 to 2,000 mm.
alt. - 800 m.
Parent material - Basalt.
Veg. Araucaria forest with campos limpos

The soils that originate from this residual material are the Latosols of the Brazilian classification which corresponds to the Ferralsols of the FAO classification and the Oxisols of the American classification.

The class of latosols, created by the pedologists, in order to group the soils, are commonly found in the low latitudes and show properties specifically related with the genesis, geographic position and management practices. These soils occur principally in tropical climates and they cover vast areas with gentle rolling, well drained topography. These soils are intensely weathered and are associated with ancient geomorphic surfaces.

Latosols, as a general rule, are very deep soils with diffuse transition between horizons, very little strongly developed structure, very porous and very resistant to erosion.

Chemically and mineralogically they are composed of an almost complete decomposition of easily weathered parent material, with the clay fraction dominated by Kaolinite or sesquioxides.

The diagnostic horizon for this class of soils is called "Oxic Horizon" (FAO, USDA classification, 1970) or B latosols (Soils Commission, 1960) and exhibit the following principle characteristics:

- more than 30 cm thick;
- the cation exchange capacity of the fine soil fraction is 16 meq/100 g of clay or less by the ammonium acetate method at pH 7.

In areas in which the sediment mantle is not very thick or where the dissection of the plateau was more intense the appearance of Latosol Roxa and Terra Roxa structures are common on the river valleys.

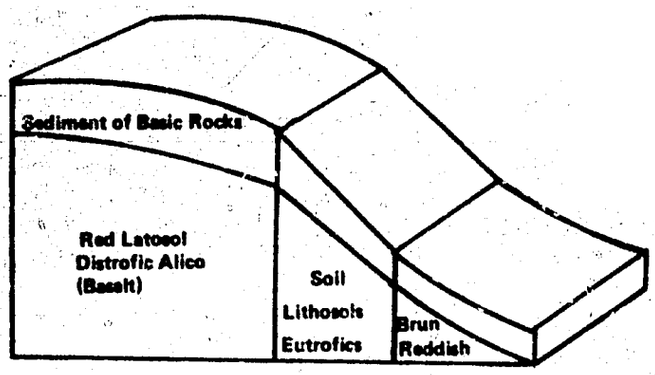
In areas in which the mantle is thick and is predominantly composed of quartz or sesquioxides, the dissection of the plateau by rivers does not normally modify the nature of the parent material. Erosion attacks the borders of the plateau and transports the material to the valleys, selecting soil particles during the process. The sands remain on the slopes and the clays are partially removed in suspension, which results in a soil sequence with accentuated characteristics of different texture and color.

The heaviest soils are observed in the highest parts; they are not dissected and have a red color and the more sandy soils are found on the lower parts of the slope or in the concave parts and are normally yellow in color.

In these topographic sequences it can be observed that besides the Latosols, the most dissected soils are those with different characteristics than the Latosols. These are soils that show textural B horizon according to the Brazilian classification that corresponds to the "argillic horizon" of the American classification and "argilluric horizon" of the FAO classification. These soils, litholic soils, Entisols, Inceptisols, are normally little developed and found in the more sloping sections of the relief while alluvial soils, vertisols, hydromorphic soils and alkaline soils are found in the lower parts of the slope.

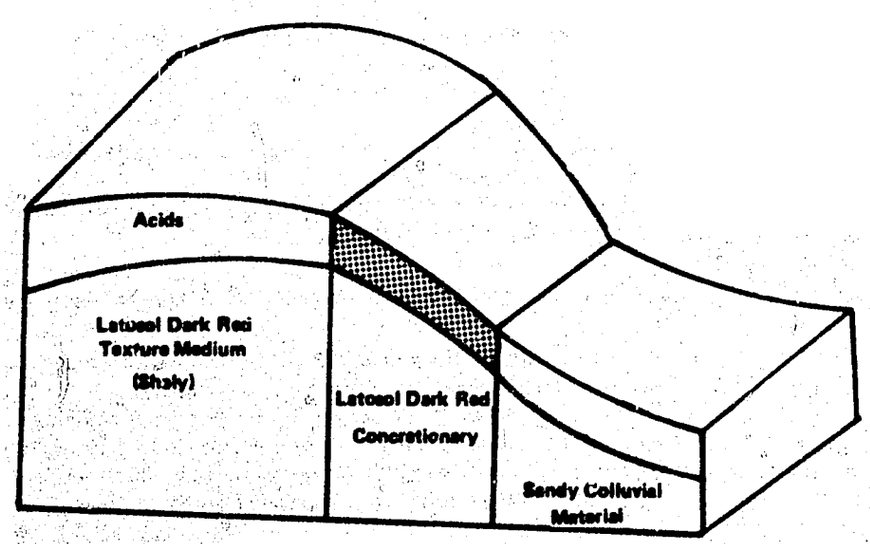
After the latosols the majority of the taxanomic classifications that occur in tropical Brazil show a textural B horizon. As a general rule this texture B horizon can be defined as having the following characteristics:

Diagram of topographic sequence in the areas of class 2 latosols.



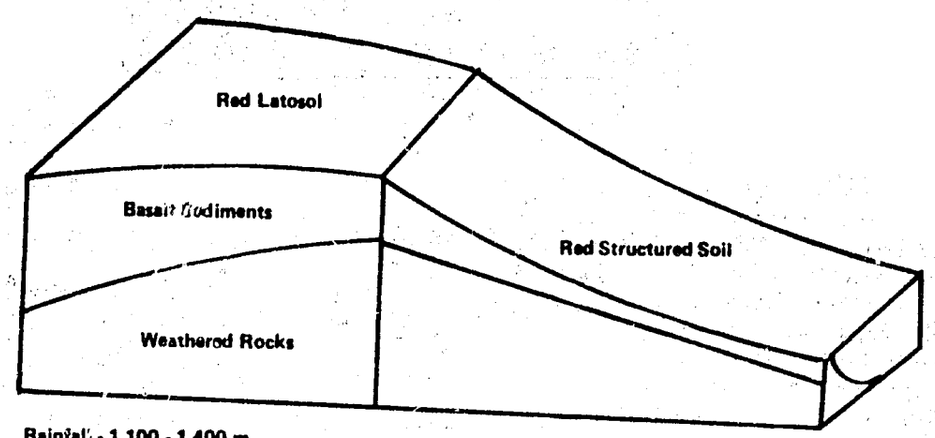
Rainfall - 1,500 to 2,000 mm.
Altitude - 700 to 200 m.
Parent material - Sediments of acid rocks.
Vegetation - Dry semideciduous forest.

Diagram of topographic sequence in the areas of class 3 latosols.

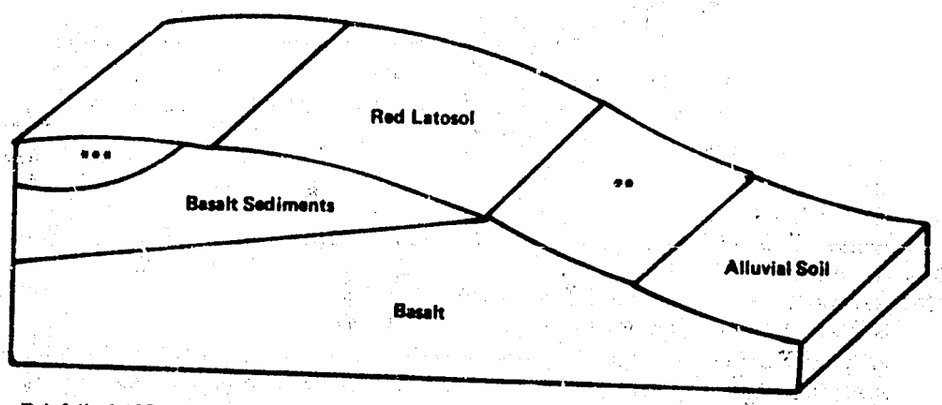


Rainfall - 800 mm.
Altitude - 750 - 400 m.
Parent material - Sediments of acid rocks.
Vegetation - Dry semideciduous forest.

Diagram of topographic sequences in the areas of class 5 latosols.



Rainfall - 1,100 - 1,400 m.
Altitude - 600 - 400 m.
Parent material - Basal sediments.
Vegetation - Mixed tropical forests



Rainfall - 1,100 - 1,300 mm.
Altitude - 600 - 400 m.
Parent material - Sandstone and basalt sediments.
Vegetation - Cerrado and mixed tropical forest.

*Red latosol dark texture medium without clay.
**Structured Terra Roxa.
***Sandstone sediment.

–the clay fraction is greater than 15%;
–it should have at least 1/10 the thickness of the sum of the superior horizons or more than 15 cm if the sum of the A and B horizon is greater than 150 cm;
–the textural ratio B:A is greater than 1:2 if the superficial horizon has more than 15 and less than 40% total clay; if it possesses more than 40% of what the B horizon should contain or at least 8% clay;
–the soils with high activity clay generally show clay values higher than 5%;
–the strongly developed structure has a tendency to be in angular or subangular blocks;
–the colloidal film that envelops the aggregates is always observed; and
–generally they show a distinct contrast between A, B and C horizons.

According to the criteria of the Brazilian classification the soils of texture B horizon were grouped according to the clay activity (the cation exchange capacity of more or less 24 meq/100 g per 100 g clay after correcting for carbon), the base saturation, the aluminum saturation, the type of A horizon and the parent material.

In landscape II (areas with young features which occupy the more elevated part of the relief) the mantle of sediments is much less. On the steeper slopes where rocks occur that are resistant to weathering, the mantle of sediments is practically absent and in these areas lithological soils predominate associated with outcroppings of rocks.

On the gentle slopes soils are more developed and they correspond to B horizon soils according to the Brazilian classification or "cambic horizon" of the American classification.

In landscape III, the younger eroded area forms the lower part of the general landscape which primarily occur in humid climates as Alluvial Soils, slightly humic gley, humic gley and hydromorphic laterite and yellow latosols in the terraces, in the semi-arid climate, there is a predominance of alluvial and alkaline soils.

Stages of Weathering

Frequency distribution of minerals in soils reflect climatic, biotic and topographic factors operating on the parent minerals as a function of time.

Jackson (1964) examined the basic geochemical and pedogeochemical principles controlling transformations of inherited clays in soils genesis during the Quaternary and considered the following stages of weathering:

Mild Desilication. This occurs in little weathered soils (intensity x time) and the results in the formation of intergrade or chloritic montmorillonite and vermiculite. Chloritized vermiculite is the most typical Quaternary clay transformation product under these conditions.

Intermediate Desilication (Kaolinization).This occurs in average weathered soils, predominately kaolinite, halloyste and allophane soils with small quantities of chloritized vermiculite and the presence of hematite and gibbsite. In these stage are found latosols of classes 1 and 2 plus the majority of soils with textural B horizon with clay of high activity.

Intensive Desilication (Laterization). Under conditions of intense leaching there is a loss of silicon and an enrichment of the clays in hydrous oxides of aluminum, titanium, iron and manganese and residues of titanium oxides. In the soils, crystalline oxides of iron (hematite) predominate along with gibbsite and kaolinite and the presence of chloritized vermiculite with mica. In this stage and under conditions of intense leaching most Latosols are found and soils with textural B horizon with clays of low activity.

If we utilize the terminology of Mohr and Van Baren, (1954) the majority of the latosols and the soils with textural B horizon belong to the senile stage. The difference in the development of landscape between Java, a geologically active region, and Brazil, a relatively stable region, explains why soils in the juvenile and virile stages rarely occur in Brazil.

GENERAL CHARACTERISTIC OF SOILS**

Units	Horizon	Color	Extr. Bases	Al^{+++}	CEC	Base Sat.	TiO_2 / Al_2O_3	TiO_2	Free Oxides	Am	Mix	Kao	Gi
Lat. Bruno de Altitude (Vacaria)	B	7.5YR416	0.54	5.17	7.75	7	1.95	3.33	15	21.6	17.3	58	0.8
Lat. Roxo Dist. Alico (Erexim)	B	2.5YR3/6	0.46	5.91	7.53	6	2.09	4.18	10.5	24.1	14.4	56.9	
Sololitolico Eutrofico (Charrua)	A	5YR3/2	19.07	0	21.70	89	3.07	2.96	3.3	22.68	9.6	46.72	1.4
Brunizem Avermelhado (Ciriaco)	B	2.5Y23/8	31.8	3.5	39.8	80	3.57	3.88	9.0	20.44	4.12	57.86	
Latosol Verm. Escuro Fase semi-arida	B	10R3/5	2.35	0.8	3.17	74	1.97	0.79					
Lat. Roxo	B	10R3/4	0.52	0	2.0	26	0.56	7.16	33	11.4	0.5	35	55
T. Roxa Estructurada	B	2.5YR3/4	8.93	0	11.25	53	2.13	4.32	23.5	29.8	15	52	8

**

Extr. Bases = Extractable bases, meq/100 g
Al^{+++} = Exchangeable aluminum, meq/100 g
CEC = Cation Exchange Capacity, meq/100 g
PBS = Percentage Base Saturation, %
TiO_2 = Oxigenated water

Am = Amorphous material
Mix = Mixed layer of gibbsite
Kao = Kaolinite
Gi = Gibbsite

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SOIL PROPERTIES THAT INFLUENCE MINERAL DEFICIENCIES OR TOXICITIES IN PLANTS AND ANIMALS

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Introduction

In a pasture-ruminant animal system, a major part of the animals requirements in terms of energy, protein, and vitamins can be satisfied by pasture. For this to be possible, it is necessary for the plants to have good soil and climate conditions for their development in order for them to produce high dry matter yields of good quality. Under this situation, the plants withdraw from the soil solution the essential elements N, P, K, Ca, Mg, S, Zn, Cu, Mo, Fe, Mn, B, and Cl, in quantities to satisfy their own requirements as well as satisfying many of the requirements of grazing livestock. Besides the essential elements, the plants withdraw Se, Co, I, Al, Si, etc., from the soil of which the first three are essential for ruminants.

In a given soil, absorption of the elements occurs in quantities proportional to its concentration in the soil solution when these are not excessive in relation to the capacity of absorption by the plants or when it does not cause them physiological disturbances. Therefore, in accordance with the requirements of the plant, elements with low, high, or excessively high concentrations in the soil solution will yield plants which will show a deficiency, sufficiency, or toxicity of the element in question. Obviously the variation from a deficiency or even an absolute absence through a toxicity is continuous. The deficiency or toxicity of an element provokes imbalances in the absorption of other elements and in both cases the growth of the plant is reduced. Lack of activity or undesirable activity of certain microorgamisms in the soil can also be the cause of deficiency or toxicity of some elements in plants.

In Latin America plants commonly suffer the consequences of phosphorus deficiency, while aluminum and often times manganese are primarily responsible for toxicity problems. Nitrogen deficiency in pasture grasses is also frequent. Other deficiencies found in pasture, associated with certain types of soils or soils that are intensely cultivated are K, Mg, S, and some micronutrients. Plants with deficiencies or toxicities are unhealthy and constitute pastures of low nutritive value for animals and often result in yields of dry matter lower than the genetic potential of the specie or variety. Even when animals ingest normal quantities from these pastures, they will often be deficient in minerals and other nutrients. Consequently, the quantity and quality of the nutrients produced in the pasture depends directly on the availability of the essential and nonessential elements which are available to the plant from the soil.

Availability of Elements to Plants

For a more adequate discussion of the properties of soils which affect the availability of elements to the plants, one must consider those factors which determine the concentration of minerals in the soil solution, as well as those which affect their movement in solution in the direction of the roots.

Elements are present in the soil in almost totally the solid phase, which form parts of organic compounds and minerals (E-solid). From the solid phase a small proportion is freed for the soil solution (E-solution), which in equilibrium is a complex between E-solid and E-solution. The elements in the soil solution move in the direction of the root surface (or vice versa), where they are absorbed and transported to the interior of the plant (E-plant). These relations can be diagramed as shown below:

$$\text{E-solid} \leftrightarrow \text{E-solution} \rightarrow \text{E-plant}$$

The process of the liberation of elements from the solid to the solution phase and later absorption by the plants is dynamic and whatever factor that affects it, even in part, will necessarily affect the absorption of the elements or its availability to the plants.

Factors that Affect the Relationship Between Elements in the Solid Phase and in Solution

The relationships maintained between elements in the solid phase and soil solution (E-solid ↔ E-solution) are a result of a great or small tendency of the elements to pass from the solid phase to the solution and vice versa. This tendency depends basically on the complex forces which link the elements in the solid compounds and on the composition of the soil solution. In the majority of the cases, only a small fraction of the total quantity of an element in the solid phase is in contact and, therefore, in equilibrium with the soil solution.

Factors that affect the relationships between E-solid and E-solution can be better visualized if they are treated in accordance with the laws of chemical equilibrium. For this, it is necessary to consider reactions of precipitation and solubilization, of cations and anions exchange, and of chemical adsorption and oxidation reduction. The activity of microorganisms should also be taken into consideration due to their role in oxidation-reduction reactions, decomposition of organic matter, and the availability of nitrogen and sulfur.

Precipitation and solubilization. The elements can react among themselves to form insoluble precipitates, in which the elements in the form of ions are distributed in the crystalline network in defined proportions and in a regular manner. Many minerals of the soil are compounds of this type and maintain an equilibrium with its ions in solution that can be defined quantitatively and qualitatively by the chemical equilibrium constant called solubility product. Similar reactions, however, in some cases very complex, as with clay, can also be considered for other minerals.

Table 1 shows the solubilization reactions of some minerals of importance in the soil.

Table 1

SOLUBILIZATION REACTIONS OF SOME MINERALS

No.	Mineral	Reaction
1	Calcite	$CaCo_3 + H_2O \leftrightarrow Ca^{2+} + 2OH^- + Co_2$
2	Gibbsite	$Al(OH)_3 \leftrightarrow Al^{3+} + 3OH^-$
3	Goethite	$FeOOH + H_2O \leftrightarrow Fe^{3+} + 3OH^-$
4	Hydroxyapatite	$Ca_5(PO_4)_3OH \leftrightarrow 5Ca^{2+} + 3PO^{3-} + OH^-$
5	Strengite	$FeH_2PO_4(OH)_2 \leftrightarrow Fe^{3+} + H_2PO_4^- + 2OH^-$
6	Variscite	$AlH_2PO_4(OH)_2 \leftrightarrow Al^{3+} + H_2PO_4^- + 2OH^-$

The reactions of Table 1 show that the pH is an important factor in the solubility of minerals. In the reactions to dissolve limestone, gibbsite, goethite, and hydroxyapatite more rapid solubility is obtained under conditions of low pH (low activity of OH^-). Consequently, the lower the pH, the greater the concentrations of Al^{3+}, Fe^{3+}, Ca^{++}, and phosphate in the soil solution. In conditions of low pH (pH 4 to 5), the concentration of Ca^{2+} and of phosphate in solution needs to be extremely high to maintain a constant solubility product. As these conditions are practically non-existent in acidic soils, the apatites completely dissolve in these soils. On the other hand, in apparent contradiction with reactions 5 and 6 in Table 1, strengite and variscite tend to dissolve more which increases the pH. This results because the ions Al^{3+} and Fe^{3+} have great affinity for OH^- and as its concentration increases raises the pH, hydroxides are formed with these metals. Consequently, there is decreased activity of the ions Al^{3+} and Fe^{3+} in the solution, which stimulates the displacement of the reactions to the right while increasing the solubility of the minerals. The pH also affects the solubility of many minerals by its action on the degree of protonation of anions of weak acids such as phosphoric acid, carbonic acid, etc.

Possible reactions in the formation of soluble complexes of di- and trivalent metals with organic radicals stimulate a greater solubility of minerals, increasing the total concentration of these metals in the solution. Conditions of high pH and of a high percentage of organic matter in the soil favors these reactions. The addition of soluble fertilizers to the soil can stimulate the precipitation of certain minerals in the regions adjacent to the fertilizer granules. These recently precipitated minerals principally the oxyhydroxides have an imperfect (amporphous) crystalline structure which makes them more soluble. The concentration of elements such as P, Al, Ca, etc., in the solutions of acid soils is generally more dependent on reactions of adsorption than on the solubility of minerals.

Exchange of cations and anions. The solid materials in the soil present positive or negative electrical charges on their surface. These charges can be permanent and constant with the pH, as negative charges of montmorillonites and vermiculites or charges which vary with the pH (charges dependent of the pH), like the charges of oxides and of organic matter. Increasing the pH of the soil by the addition of lime stimulates the increase of the negative charges on the surfaces of organic matter which can be represented by the reactions:

$$\boxed{R}\ \text{-COOH} + OH^- \leftrightarrow \boxed{R}\ \text{-COO}^- + H_2O$$

$$\boxed{Al}\ \text{-}OH_2^+ + 2OH^- \leftrightarrow \boxed{Al}\ \text{-}OH^- + 2H_2O$$

in which R and Al represent respectively, solid organic compounds, and Al or Fe from the mineral surface.

Increasing the pH from 4 to 6 in soils with high levels of oxides and organic matter increases the negative charges up to 100 percent or more.

In the majority of soils the surface charges are negative and for this reason the cations are adsorbed electrostatically to the surface. The adsorbed cations (Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+, and Al^{3+} principally) maintain themselves in equilibrium with those of the solution, in which a large quantity of an adsorbed cation corresponding to a large concentration in the solution. The anions Cl^-, No_3^-, and I^- are repelled by the negative surfaces and tend to remain in solution.

The proportion in which the cations are distributed in the solution and on the surfaces depends principally on the total proportion of each one in the system, on their total concentration in the solution, on the number of charges and origin and on the quantity of charges of the surface. This results from the fact that each adsorbed cation can be displaced by others in an exchange reaction as indicated below:

$$X\,Ca_{1/2}^{2+} + K^+ \leftrightarrow X^-K^+ + \tfrac{1}{2}Ca^{2+}$$

in which X^- represents a negative charge on the solid surface.

This reaction illustrates that as the concentration of a cation in solution increases, there is an increase in the concentration of all the others in the solution. The final equilibrium is dependent on the affinity of each cation for the charges on the surface, which is the equilibrium constant for each exchange reaction involved. The cations which are absorbed or in solution because of their properties to enter into exchange reactions are called exchangeable cations.

The order of affinity or force by which the cations are attracted by the charges on the solid surfaces of the soil is as follows: $Al^{3+} > Ca^{2+}, Mg^{2+} > K^+, NH_4^+ > Na$. Qualitative and quantitative changes in this order can be verified in accordance with the origin of surface charges and with the concentration of cations in solution. Thus, the charges originating from the organic matter attract more di- and trivalent cations, whereas the charges of vermiculite attract more K^+ and NH_4^+ when these are in low concentration in solution.

Increasing the pH by liming increases cation exchange capacity (CEC) of the soil. Therefore, for the distribution of the cations at the exchange points to remain in proportion to the total quantities in the system, adsorption of cations like K^+, Na^+, and NH_4^+ are stimulated. The result is a decreased concentration of these cations in the solution. Therefore, the total quantity of an exchangeable cation is not a good index of its availability to the plants (concentration in the solution). The effect of the number of charges (CEC) in the concentration of a cation in solution can be approximately compensated considering the percentage of the charges that are held by the cation (% of saturation). This is the objective of using percent saturation of CEC with Al and with K.

The absorption of cations by plants decreases the concentration in the soil solution. At the same time a portion of these cations is liberated from the sites of adsorption into the solution in an attempt to maintain the original equilibrium between adsorbed cations and those in solution. The decrease in cation concentration in the solution is less in soils with high pH, high levels of clay and high organic matter which provides high levels of exchangeable cations. The decrease in cation concentration, especially K, is large in sandy soils with low pH. In the first case the soils are said to have high cation buffering capacity while in the second there is low buffering capacity.

Chemical adsorption. Elements such as P, Mo, Se, S, Si, B, Zn, Cu, Co, Mn, Fe, Al, H, and others are able to link to other elements on the surface of the minerals and the organic matter, through bonds with high degrees of covalence which form compounds or complexes on the surface. This type of linkage is stronger than the electrovalent bonds due to the electrostatic adsorption of cations.

The elements P, Mo, Se, Si, and B are adsorbed in the form of anions (electron donors) which link themselves to Al and Fe on the surfaces of minerals in the soil. On the other hand, the elements Zn, Cu, Co, Mn, Fe, and Al are adsorbed in the form of cations (receptors of electrons) which link oxygen coordinates with Al and Fe on the mineral surfaces and to the carboxyls and other groups of the organic matter. In every case, a certain equilibrium is maintained between the adsorbed elements and those in solution. The addition of these elements to the soils in the soluble form increases its concentration in the solution and the quantity adsorbed. Phosphorus and copper are the anion and cation most strongly adsorbed by the soil. More than 99% of the P added to the soil in soluble form (super-phosphate) is normally retained by the solid phase. However, this does not indicate that all this P is lost to the plants, because a part of it remains in equilibrium with the solution and the concentration in solution is replenished when it is absorbed by the plants.

Some soil properties that affect the chemical adsorption and, consequently, the concentration of some elements in the soil solution can be deduced from the simplified reactions of Table 2.

Table 2

REACTIONS OF CHEMICAL ADSORPTION OF SOME SOIL ELEMENTS

No.	Elements	Reaction
1	P, Mo, Se, S	$\boxed{Al}\text{-}OH + H_2PO_4^- \leftrightarrow \boxed{Al}\text{-}H_2PO_4 + OH^-$
2	Si, B.	$\boxed{Al}\text{-}OH_2^+ \; H\,H_4SiO_4 \leftrightarrow \boxed{Al}\text{-}H_3SiO_4 + H^+ + H_2O$
3	Zn, Cu, Co, Mn, Al	$\boxed{Al}\text{-}OH + Zn^{++} \leftrightarrow \boxed{Al}\text{-}OZn^+ + H^+$
		$\boxed{R}\begin{matrix}COOH\\COOH\end{matrix} + Zn^{++} \leftrightarrow \boxed{R}\begin{matrix}COO\\COO\end{matrix}Zn + 2H^+$

The reactions of Table 2 show that increasing the pH of the soil stimulates the increase in the concentration of P, Mo, Se, and S in the solution of the soil; whereas, the concentration of Si, B, and of the cations in the solution diminishes with the increase in the pH. It should be emphasized that these reactions, as written, may not represent precisely the mechanism of adsorption; however, they are in accordance with pH effects generally observed.

At a given pH, the chemical adsorption due to the large number of adsorption sites is greater as the level of oxides and hydroxides of Fe and Al, clays and/or organic matter increases (this is true only for B and the cations). Consequently, after the addition of fertilizers the concentration of the elements in the solution, which are chemically adsorbed, will be greater in the soils of light texture and those low in organic matter. Nevertheless, in these soils, with the absorption by the plants, there is a greater decrease in the concentration of the elements in solution than in the clay soils and those with higher levels of organic matter. In the first instance, soils are said to have a low buffering capacity and in the second a high buffering capacity. Soils with high buffering capacity, in general, need heavier fertilization but lose their fertility more slowly than those soils with low buffering capacity.

Oxidation reduction. In soils with an excess of water, the air spaces between the soil particles are filled with water. Under these conditions there is a lack of free oxygen for the respiration of aerobic microorganisms and a population of anaerobic microorganisms is established. In order to oxidize and decompose the organic matter anaerobic microorganisms reduce the elements that can exist in more than one state of valence under normal conditions to the oxidation-reduction potential of the soil. The elements N, Mn, Fe, and S whose oxidation reduction reactions shown in Table 3 are of major importance.

Table 3
OXIDATION-REDUCTION REACTIONS OF SOME ELEMENTS

No.	Reaction
1	$2NO_2^- + 8H^+ + 6e^- \leftrightarrow N_2 + 4H_2O$
2	$NO_3^- + 2H^+ e^- \leftrightarrow NO_2^- + H_2O$
3	$MnO_2 + 4H^+ + 2e^- \leftrightarrow Mn^{2+} + 2H_2O$
4	$Fe(OH)_3 + 3H^+ + e^- \leftrightarrow Fe^{2+} + 3H_2O$
5	$SO_4^- + 10H^+ + 8e^- \leftrightarrow H_2S + 4H_2O$

Soon after flooding the soil a reduction of NO_3 to N_2 occurs, which is lost to the atmosphere (combination of reactions 1 and 2). At the same time an accumulation of NH_4^+ begins which originates from the decomposition of the organic matter. A reduction of Mn to Mn^{2+} and Fe to Fe^{2+} follows, which are soluble divalent compounds. Consequently, their concentrations in the soil solution increase to levels which are toxic to plants not adapted to the flooded soils. The concentration of Mn^{2+} and Fe^{2+} are generally higher in soils that have high levels of oxides-hydroxides of Mn and Fe and high levels of organic matter.

Drastic conditions of reduction, like those found in soils with high levels of easily decomposable organic matter, can result in the reduction of SO_4^{2-} to H_2S, which is toxic to plants.

Microbial activity. Microorganisms, specifically bacteria, have a fundamental role in the availability of N for plants, whether they fix it directly from the air or enhance the availability through the decomposition of nitrogenous organic compounds. Since the microorganisms live much like plants, they also require F, K, Ca, Mg, etc., for their nutrition, and their activity is generally greater in soils with high levels of these elements in solution.

The pH is a property of the soil that greatly affects the activity and type of microbic flora. As a general rule, microbial activity is much lower in very acid soils (pH 4 to 5) and is increased by the liming of these to a pH of 6 to 7. Consequently, liming acid soils increases the availability of N for plants because of greater availability of organic N and/or greater N_2 fixation by free or symbiotic bacteria. Greater and more efficient nodulation is generally observed in legumes when lime is added to acidic soils. In addition to N, the availability of S and up to a certain point B is closely linked to the microbic decomposition of organic matter.

Movement of Elements to Root Surfaces and Absorption

The roots absorb elements from the soil solution that enter into direct contact with their surfaces. In order to support continuous absorption by the roots, they grow into new regions which have nutrient solutions which can be translocated by the root surfaces. Three mechanisms are responsible for movement of elements to the surface of the roots: root interception, mass flow, and diffusion. The ability of the roots to absorb the elements in the solution adjacent to the surfaces may be difficult because of certain adverse soil conditions.

Root interception. As roots grown they occupy space formerly occupied by the soil solution and enter into contact with the elements which are present and thus absorb them. Data obtained with corn culture in relatively fertile soil, indicated that only the Ca requirement could be completely met by this mechanism. However, a significant portion of the plant requirements for Mg, Mn, and Zn can also be provided by root interception. The contribution of this mechanism to the absorption of nutrients is greater as the concentration of these in solution and the root system increases.

Mass flow. The soil solution moves in the direction of the root surface in order to replace the water lost in transpiration. This solution takes with it nutrients which can be absorbed by the roots upon contact. Approximate calculations have shown that in soils of high fertility this mechanism can furnish much more than the plant needs for Ca, Mg, Zn, Cu, and B. In these cases there is an accumulation of the elements close to the surface of the roots. Nevertheless, in soils in which the concentration is low in relation to the needs of the plant, this mechanism is insufficient for conducting necessary quantities of the elements to the root surfaces. This rarely occurs with a Ca due to its relatively high concentration in the solution, even in acidic soils.

When the requirements of the plants are not satisfied by root interception and mass flow, the elements move to the surfaces of the roots by diffusion.

Diffusion. This mechanism is indispensable for the expedient P and K nutrition of plants. In the solution next to the root surface, the concentrations of P and K are much lower than in the more remote solutions. In view of this concentration gradient, the phosphate ions and K^+ move by diffusion in the direction of root surfaces. This diffusive movement can be represented by the equation:

$$Q = ADH\,(Cs\text{-}Cr)/L$$

in which Q= quantity of the element that diffuses to the surface of the roots per unit of time; A= absorbent surface area of the roots; D= the coefficient of diffusion of the element in water (constant); H= fraction of the volume of the soil occupied by water (also includes a tortuosity factor); Cs= concentration of the element in solution at a distance L from the root surface; Cr= concentration of the element in the solution next to the root surface.

This equation does not exactly represent the situation in the soil; however, it clearly points out some of the properties of the soil that affect the diffusion of the elements to the roots surfaces. Thus an extensive root system composed of small roots provides a large area (A) for absorption of elements. In soils with a high content (H) of water (high levels of clay and organic matter) the quantity of the element that diffuses per unit of time up to the surface of the roots is greater than in soils with low water content (sandy). High concentration of elements in the soil solution (Cs) and the ability of the plant to absorb them rapidly resulting in a low Cr are factors that increase the absorption of P and K by plants. Soils with high buffering capacity of P and K have greater capacity to maintain a constant Cs than soils with a low buffering capacity. Consequently, the value of L tends to be less in those soils resulting in a greater absorption of P and K. In soils with low concentration of N, B, and other elements, diffusion can be the principal mechanism of movement to the root surfaces.

Absorption capacity of roots. The large or small capacity of roots to absorb elements is characterized by species and variety. However, some soil properties affect this ability. The presence of substances or elements in the soil solution that have toxic effects and interferes with the metabolism of plants affects the absorption of the elements. The most common cases of toxicity in the acidic soils of Latin America are due to high concentrations of Al^{3+} and Mn^{2+} in the solution. Liming of these soils to a pH of 5.5 or more eliminates the problem. Species and even varieties show great differences in the susceptibility to Al^{3+} and Mn^{2+} toxicity.

The roots of the plants adapted to well-drained soils need oxygen in the soil for their respiration. In soils with deficient aeration, root absorption of a large number of nutrients is greatly reduced. The absorption process of elements is related to the metabolic activity and it is affected by soil temperatures. Generally the absorption is slower in cooler soils.

Besides the required quantities of nutrient elements, it is necessary for them to be maintained in satisfactory proportions in the soil solution or to be appropriately balanced. If this does not take place, antagonistic effects can occur that cause a decrease in the absorption of one or more elements. One example is the antagonistic effect of K on the absorption of Mg where an increase in the concentration of K in solution causes a decrease in absorption and even a possible magnesium deficiency.

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METHODS OF ANALYZING SOIL FERTILITY

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Introduction

The theme of this paper is very diverse and it is difficult to approach it with the necessary depth that the material demands and that would be desirable in the short time that has been given to me. This subject is a segment of the program from the discipline—analysis of soil fertility, a course given at the graduate level, encompassing many class hours at the Federal University of Viçosa.

This preface is to justify the general approach that will be used on the subject. We will restrict ourselves to the basic principles of the analysis of soil fertility and we will superficially comment on the methodology used in the determination. To analyze signifies measuring, comparing, and determining the value of something. Therefore, the analysis of soil fertility means to measure its fertility, to compare it with a sample, and to determine its value.

At this level many difficulties begin to arise in the concept and in the definition of the basic principles of the analysis. When fertility of the soil is determined using the defined methodology, we encompass two very distinct stages. The first stage is the physical-chemical measurement of the characteristics of the soil and the second stage which is more difficult and complex, is the utilization of the parameters obtained in the first stage.

In this manner, the two stages are complimentary. On the other hand, the physical-chemical characteristics are measured in the area of soil fertility, so that this information can be used to alter some parameters of vegetative growth. There is no significance in saying that a soil has a 8 ppm phosphorus unless this information permits other interpretations, for example:

(a) What quantity of phosphate fertilizer added to the soil is needed for maximum vegetative production? (b) Do the plants which grow in this soil have an adequate level of the element? (c) With this level in the soil, will there be sufficient forage production to support a certain number of cattle per hectare? Certainly many other investigations will have to be made.

How do the two distinct stages make up a program of soil fertility evaluation? To quantify the fertility and to adequately use that quantity involves the study of two systems: the soil system and the vegetative system. These two systems are very dynamic and this dynamism is associated with the interaction of many other variables which makes the analysis of soil fertility a vital and challenging subject.

The need to study these two systems is implicit in the very concept of soil fertility which is the capacity of soil to give essential elements to plants. The relationship can be seen from a study of these two systems.

The relationship of the two systems, using the example of the movement of element M can be seen in figure 1.

Figure 1

Diagram showing relationship between the soil and plant systems, according to Gunary and Sutton (1957).

K_1

M-Soil $\rightleftarrows$ Soil solution (near the soil surface)

K_2

Diffusion

$\downarrow$

M - soil solution (near the roots)

$K_3\downarrow$ $\uparrow K_4$

M - Plant

When we study the relationship between the two systems (soil and plant system), we are forced to restrict the study in such a manner that under specified conditions it is necessary to observe the effect of one element in particular.

This restriction frequently brings on other difficulties. One of them refers to the soil itself. In the soil system we emphasize the study of a defined quantity of soil which is located near the roots and where they are numerous. However, the development of the roots was or will be affected by the physical-chemical properties of each layer of soil (Jackson, 1967). Table 1 shows the absorption of phosphorus by grasses and other species at different depths.

Another difficulty frequently encountered in the analysis of soil fertility is with regard to plant association, an area of great interest to Animal Science.

When a single species is studied the difficulties are not small, but difficulties are increased when studying different species and even cultivars within a species. There are many interpretations that can be made from the evaluation of data from one specie in particular. The recommendation that is made for one specie consequently spreads its supremacy over another, "the capacity of one specie is more or less proportional to its productivity," excluding the Montgomery effect, Bergh (1969).

Table 1

RELATIVE PHOSPHORUS ABSORPTION AND ROOT DEVELOPMENT AT DIFFERENT DEPTHS

Depth (cm)	Phosphorus Grasses	% Other Species	Roots Grasses	% Other Species
0-25	70	64	81	66
25-50	19	23	14	27
50-75	11	13	5	7

Source: Nye (1969).

We will discuss the soil system for it is the main objective of this paper. The analysis of the soil system can be accomplished by using chemical and/or biological methods.

In the first group, the analysis is made by means of a chemical agent that, after being activated in the soil system, extracts a liquid component in which the element is determined.

In the second group, the plant substitutes for the chemical extraction. The analysis is made from production in field trials and greenhouses, from the visible symptoms or by the analysis of the total or specific parts of the plant.

Soil and plant analysis do not offer the same parameters, but this paper will give an idea when chemical methods and biological methods are used to analyze the soil system.

Chemical Methods

Soil System

The soil system can be analyzed using only the liquid phase or the solid phase, but it is more accurate to study the interaction between the two phases.

When the plant absorbs a quantity of an element from the liquid phase of the soil, there is an immediate need to replace it from the solid phase. If the solid phase contains a sufficient quantity of the element and the constant K_1 is greater than K_2 (figure 1) there is the possibility of replacement of the absorbed quantity. It is important for the level of the element in the liquid phase to remain constant so that it can be renewed numerous times during the plant cycle. In some situations, this level can be up to 0.001 ppm of P, with the level being renewed about 500 times during the growing cycle of a plant, Seatz and Stanberry (1963).

The scheme, represented by figure 1, suggests that the total quantity of the elements which can exist in the solid state depends on the retention capacity of the soil. Likewise, the larger the value of K_1, the larger the quantity that can be retained and the larger the quantity that can pass to the liquid phase. This passage depends on (1) the rate at which these elements transfer from the solid phase into the soil solution, (2) the rate at which the plant removes elements from the soil solution, (3) the length of the diffusion path, (4) the diffusivity of the ion, (5) the magnitude of M (solid) and the reaction rate constants, (6) climatic factors such as rainfall and temperature which affect both ionic and biological processes, and (7) the history of the soil sample (Fried and Broeshart, 1967).

At this level one already has some idea of how to analyze for the element M in the soil. When the soils have the same absorption capacity, the analysis can be made exclusively on the quantity of M in the liquid phase. When the absorption capacity of the soils are different three parameters are needed: the quantity of the absorbed element that can be transferred by the soil solution, the quantity existing in the soil solution, and the velocity of the transference from the solid phase to the liquid.

The first of these parameters is called the capacity factor (Q) and the second is the intensity factor (I). As it is not always possible to know beforehand the value of Q, it is necessary to calculate the value of Q/I which signifies the buffering capacity of the soil, Bache and Rogers (1970), Barrow *et al.* (1965), Beckett and White (1964), Khasawneh (1971), Le Mare (1960), Rama Moorthy and Subramanian (1960), Weber and Mattingly (1970), White and Beckett (1964).

Analysis of the Capacity Factor

Besides the definition already given, the capacity factor can also be thought of as reserves of the element M that can be transferred from the soil solution during plant growth, Fried and Broeshart (1967). This capacity can be determined by using selected chemical extractors which are chosen to conform to the type of element which is being analyzed.

For the analysis of nitrogen, the quantification of the capacity factor is more difficult because it depends on the microbial activity of the soil and the surrounding factors which regulate this factor. In addition to these difficulties, is a fact that in the last stage of transformation the form of N is in the $N\text{-}NO_3$ form which is easily leached from the soil. The analysis of the nitrogen capacity by its rate of availability and by the initial analysis of inorganic N was reported by Dahnke and Vasey (1973).

In order to relate the nitrogen in the soil to the plant correlation, studies are made using, as a dependent variable, the nitrogen absorbed by the plant or the response of this to the application of a nitrogen source.

In the case of phosphorus the problem is more complex because of the extremely dynamic behavior of this element in the soil and of the physical-chemical characteristics of the soil which infuence its behavior. For each form of phosphorus existing in the soil one extractor is used which implies that the form is related to the extraction. Table 2 shows an experiment with latosols conducted in the state of Minas Gerais, Bahia Filho and Braga (1975). The data obtained are correlated with the quantity of absorbed phosphorus or with the plant response which is similar to the case of nitrogen.

For the elements potassium, calcium, magnesium, and others, the analysis of the capacity factor signifies the measurement of the exchangeable quantity of these elements as well as the capacity for replacing these elements. In the case of potassium the Q factor was obtained with the use of ammonium acetate 1N, pH=7.0. Values obtained were correlated with the absorption of potassium by the plant with other extractors of available potassium (Braga, 1972). The capacity of potassium liberation has been evaluated by means of chemical extractors or through successive crops depending on the forms that exist in the soil.

The analysis of the micronutrients is particularly difficult because of the small quantities and because of the small amount of existing knowledge on the behavior of the micronutrients in the soil, especially in reference to the interactions that are present with other elements and with the characteristics of the soil environment.

Analysis of the Intensity Factor

The intensity factor is the active quantity in soil solution. Its measurement presents a series of difficulties principally because of the variation in the degree of soil moisture.

This difficulty motivated the soil investigators to use two basic methods: one measures the concentration of the element under normal moisture conditions and the other uses elevated moisture conditions. Each of these approaches require variations in techniques. The most common method uses $CaCl_2$ in concentrations that vary from 0.01 to 0.0001 M.

The results are expressed in terms of the potential of the element. The Deckie-Huckel equation is used in the calculation which indicates the difference in free energy between two elements $pH_2PO_4^-$½pCa, common in scientific experiments.

Table 2

EXISTING RELATIONSHIP BETWEEN EXTRACTORS AND INORGANIC FORMS OF PHOSPHORUS IN LATOSOLS IN THE STATE OF MINAS GERAIS

Extractor	Source of Variation	df	M.S.	R^2	Regression Equation
Bray 1	P-Al	1	1,175.00**	0.9603	$Y=0.3383+0.1131^{**}X_{Al}$
	P-Al and P-Fe	2	594.57**	0.9727	$Y=0.0374+0.0896^{**}X_{Al}+0.0225^{*}X_{Fe}$
	P-Fe after extracting P-Al	1	14.14*	0.0124	
	P-Al, P-Fe, and P-Red	3	396.40**	0.9720	
	P-Red after extracting P-Al, P-Fe	1	0.04 n.s.	0.0000	
	P-Al, P-Fe, P-Red, P-Ca	4	297.30**	0.9720	
	P-Ca after extracting P-Al, P-Fe, P-Red	1	0.01 n.s.	0.0000	
IAC	P-Fe	1	278.40**	0.5836	$Y=1.7006+0.0465^{**}X_{Fe}$
	P-Fe and P-Al	2	149.56**	0.6270	
	P-Al after extracting P-Fe	1	20.72 n.s.	0.0434	
	P-Fe, P-Al, P-Red	3	103.92**	0.6535	
	P-Red after extracting P-Al, P-Fe	1	12.66 n.s.	0.0265	
	P-Fe, P-Al, P-Red and P-Ca	4	84.84**	0.7113	
	P-Ca after extracting P-Fe, P-Al, P-Red	1	27.59 n.s.	0.0578	
Mehlich	P-Al	1	374.61**	0.9544	$Y=-0.4825+0.0639^{**}X_{Al}$
	P-Al and P-Fe	2	187.86**	0.9573	
	P-Fe after extracting P-Al	1	1.12 n.s.	0.0029	
	P-Al, P-Fe, P-Red	3	125.39**	0.9585	
	P-Red after extracting P-Al, P-Fe	1	0.45 n.s.	0.0012	
	P-Al, P-Fe, P-Red and P-Ca	4	94.11**	0.9591	
	P-Ca after extracting P-Al, P-Fe, P-Red	1	0.25 n.s.	0.0006	
Olsen	P-Al	1	438.09**	0.9377	$Y=0.9253+0.0691^{**}X_{Al}$
	P-Al and P-Fe	2	220.77**	0.9451	
	P-Fe after extracting P-Al	1	3.44 n.s.	0.0074	
	P-Al, P-Fe and P-Ca	3	148.15**	0.9513	
	P-Ca after extracting P-Al, P-Fe	1	2.91 n.s.	0.0062	
	P-Al, P-Fe, P-Ca and P-Red	4	111.77**	0.9570	
	P-Red after extracting P-Al, P-Fe, P-Ca	1	2.63 n.s.	0.0057	

n.s. — Not significant
* — Significant at 5% level
** — Significant at 1% level

Analysis of the Renewal Velocity of the Element in the Liquid Phase

The analysis of the Constants K_1 and K_2 are very important (figure 1) for measuring the renewal capacity of the element in the soil.

The following techniques are used:

1. Successive extraction of the element that will permit evaluation, by partial quantities obtained and the renewal of the quantity in the liquid soil phase.
2. Isotopic exchange technique.

For some soils this parameter has already been quantified.

The velocity of renewal in Bridger, Caribou, and Nibley soils is estimated at 13-16 lb. of P/acre/hour. This velocity is about 250 times greater than that of plant absorption (Fried and Broeshart, 1967).

The "available" Form

The "available" forms previously defined are not the ones most frequently measured in soil and analysis. When establishing a program of soil analysis, it is necessary that the information obtained in the laboratory be rapid and available to the user as quickly as possible. The use of existing methods does not result in the determinations of factor capacities and intensities. The necessity of having a soil parameter rapidly has motivated investigators and Bray (1948) developed a methodology which was widely recognized. This technique used an extractor which resulted in data that was correlated with plant characteristics. After having obtained significant coefficient of correlation values, the parameter obtained with the extractor would measure the "available" quantity of the element in the soil.

The determination of the quantity of the element "available" does not indicate a chemical form nor does it indicate the dynamic character of the soil-plant relationship in the soil neither does it measure the intensity and capacity factors of the soil. There is not a specific relationship between the form of the element in the soil (cause) and a reflection of this quantity in the plant (effect).

Based on this philosophy, many extractors for the same element can be used. Obviously, in some cases, the extractor defines the chemical form as well as the "available" quantity. It is also possible that the quantity of the chemical form is not the "available" quantity.

Thomas and Peaslee (1973) studied the extractors for phosphorus and recommended that the extractors should possess certain important characteristics.

These important characteristics are valid for extractors of other essential elements and they are outlined as follows:

The extractor should:

1. rapidly dissolve or reabsorb P from the soil with the same intensity for up to 30 minutes,
2. maintain the organic matter and the flocculated soil clays,
3. avoid reprecipitation of the dissolved P and/or hydrolyze the organic P,
4. does not contain excessive amounts of salts, buffers or ions that would interfere in analytical determinations,
5. produce extracts that contain significant quantities of other nutrients as well as P,
6. be easy to prepare, store and use.

The use of extractors of "availability" give an indication of the soil fertility. There have been some failures with the use of this methodology. Some of these failures result because:

1. the plants differ in the elemental needs for their growth,
2. full plant development depends on a perfect balance of elements in the soil,
3. the quantities of the elements needed to satisfy the plants requirements differ according to the stage of development, but the total quantities of elements may be the same,
4. the quantity absorbed by the plant depends on the quantity present in the soil solution, its form, the replacement of the element in the liquid soil phase, its availability, and absorption.

Biological Methods

From the previous explanations, it appears the characteristics of the soil system—the capacity factor and the intensity factor—cannot be evaluated separately using the plant as the extractor. The growth of plants in the soil is a result of the interactions of these two factors rather than a single one. Plant behavior resembles that of the chemical extractors which measure the available quantities.

If the major objective is animal development, the analysis of fertility can be more simple and one needs to know only the percentage of the elements in the plants that will be absorbed. In this case, one more variable, the animal, is introduced.

The analysis can be made by the total quantity absorbed by the animal which depends on the quantity that this animal can absorb and on the level of the element in the plant.

A soil may be fertile for growing calves but it may be of average or low fertility for lactating cows. This is because minimal quantities of minerals are required by each animal as well as different quantities that can be absorbed by class of animal.

Need for Research

Methods of measuring soil fertility which will reflect nutrients available to the plant is a complex area of soil science because many factors interfere with plant absorption of elements from the soil.

In spite of the progress that has already been made in this area, there is still much to do. There is the need to better understand the behavior of the elements in tropical soils, to study the kinetics of the reactions, to understand the interaction between the solid phase and the liquid phase and to adapt this knowledge to native species, or those well adapted to our conditions. There is the need for research and for much research.

This is an excellent opportunity to make an appeal to the animal scientists who are present here in the sense of helping the soil investigators in the solution to common problems. We need your help.

Consider the soil in your research. Conduct research to seek explanations for unconfirmed hypotheses. Use more than one method for analysis and evaluation. Develop and conduct multidisciplinary research and solicit the constant assistance of soil scientists.

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TECHNIQUES OF SOIL SAMPLING AND ANALYSES

by

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General Consideration

In general, soil productivity is taken as synonymous with fertility. This concept, however, is completely erroneous. Fertility is related to the soil capacity in furnishing nutrients to plants; productivity is a broad concept meaning fertility itself and other soil characteristics such as texture, structure, porosity, water availability and also soil depth.

Relative to the importance of this evaluation, it is enough to consider that fertility may play an important role on soil productivity, it is possible of being modified, with relative ease, through fertilizers and liming, just the contrary of physical characteristics, that can not be modified.

Evolution of Analytical Methods

The use of chemical analysis of soil for the determination of its fertility was started in 1840 by Liebig (Wutke, 1922; Coelho & Verlengia, 1973) when he published his work on mineral nutrition of plants. Since then, great progress was accomplished relative to the development of new chemical methods to evaluate soil fertility through the use of strong or weak acids as extracting solutions, which were designed to reproduce the extracting capacity of nutrients by the roots. However, due to lack of knowledge of soil phenomena as well as of plant physiology, such analyses were of little help relative to the true soil relationships. New findings were developed mainly on a single point of view, on the balance between the amount of extracted nutrients by plants and those determined on the soil by conventional extracting methods that did not take in account all colloidal phenomena of soil and the dynamics of these elements.

With the evolution of knowledge of plant nutrition and of the characteristics of soil, colloidal complex, particularly those related with absorption and ion exchange, the methods of analysis to evaluate fertility were improved. Although research has developed in this direction, obviously not all problems have been solved.

With knowledge of the forms of availability of all nutrients to the plants, research was directed to the methodology that could permit a correct evaluation of these forms in the soil. At the present time having by basic principle knowledge of chemical form of the elements that must be analyzed, the relationship existing among them and the physical-chemical characteristics of soil, this according to Catani *et al.*, 1955; Catani, Kupper and Fitts (Wutke, 1972), the methods became as much as possible non-conventionals. The data obtained are independent of the nature of reagents, what is valid mainly to the determination of exchangeable cations.

Results must be reproducible; if a sample of soil is analyzed several times, the same result must be obtained. Laboratory technique is as important as reagents. The reagent-soil relationship, the method and shaking time or the contact with soil must be the same. But with exception to phosphorus, that may present very different results according to the solvent solution as well as the solvent procedure used, the results are comparable among them.

Some of the most important objectives of soil analysis are (Coelho & Verlengia, 1973):

a) Soil grouping in classes to define types of fertilization and liming.
b) Predicting the probability of obtaining a profitable reaction according to the nutrients furnished to the plant.
c) Helping to evaluate soil productivity.
d) To determine specific soil conditions that could be improved by adding some corrective, or cultural practices.

Of those analyses to evaluate soil fertility, generally the following are done (Pipaemg, 1972):

Available Phosphorus - P - results in ppm, solvent used: H_2SO_4 0.25 N plus HCl 0.05N, ratio 10 ml soil/100 ml solvent, shaking for 5 minutes, ascorbic acid method by colorimetry.

Available Potassium - K^+ results in ppm, solvent used H_2SO_4 0.025 N^+ HCl 0.05N, ratio 10 ml soil/100 ml solvent; flame photometric method.

Exchangeable Aluminum: Al^{+++} results in mg/100 ml of soil; solvent used KCl 1N; ratio 10 ml soil/100 ml solvent, shaking for 5 minutes; titration with NaOH 0.025N using bromothymol blue as indicator.

Calcium + Magnesium Exchangeable: Ca + Mg, results in mg/100 ml of soil; solvent used KCl 1N; ratio 10 ml soil/100 ml solvent, shaking for 5 minutes, complexometric method with EDTA 0.025N, using eriochrome black as indicator.

Water pH: pH; ratio 1:2.5 (soil/water), shaking with rod, resting for 30 to 60 minutes; potentiometric reading.

Other analyses such as organic matter, nitrogen, hydrogen; "S" Value (base number); "T" Value (soil exchange capacity); "V" Value (% base saturation) and granulometric analysis, may be done when necessary.

SAMPLING

The greatest source of error in soil analysis is field sampling. Most of the time this affects the analytical results. To evaluate the importance of this operation, it is enough to remember that the size of the sample sent to the laboratory is small, approximately 500 g. Only a small amount of it is used for distinct and diverse analysis. This 500 g of soil represent, many times, large areas of many hectares, and for this reason great care must be employed in sampling be well collected.

It has been verified in Brazil and in several other countries that the most convenient way of soil sampling is taking a composite sample, that results from mixing several other single samples. According to Catani (1955) on an area of 5 to 7 hectares of a uniform soil relative to topography, color, texture, management cultivation, erosion degrees, and other characteristics, around 25 to 35 samples must be collected on a zigzag line. These samples must be mixed, homogenized and formed into composite sample. In an area of 3 to 5 hectares, the composite sample must be made of 20 simple samples, and in areas smaller than 3 hectares the composite sample must be made of 15 simple samples.

From the composite sample, once well homogenized, around 500 g is sent to the laboratory. It must be well packed to resist transportation and be well identified. With the sample, soil information on the soil must also be sent which will help interpreting chemical results and will permit a better recommendation of fertilization and of liming.

The depth of a soil sample must be equal to that of plowing (20 cm) for the majority of crops. For permanent crops, with more developed root system, it is possible to collect, separately, samples between 20 - 40 cm (Malavolta, 1967) and relative to sampling time, mainly annual crops, it must be at the end of harvesting.

SOIL PREPARATION

Once the sample arrives at the laboratory for analysis, the procedure established by the National Program of Soil Fertility is the following:

Arriving at the laboratory, the sample is identified and dried at 50 to 60°C or distributed over paper and dried in the shade if necessary. It is ground and screened using screen of 2 mm mesh, transferred to plastic bag and sent to the laboratory. This sample is called "fine soil air dried" (FSAD). After completion of the analysis, the sample is kept in the laboratory for a period of time and eventually discarded.

Extraction

Extraction of available phosphorus and potassium, calcium + magnesium and exchangeable aluminum takes an initial short period of soil shaking with the extractor. Mechanical shaking for a period of time helps assume the standardize extraction.

Volume instead of soil weight is used in these analyzes. The volume of sample is made using a "measuring device" that permits soil transfer to convenient flasks for the analytical procedure.

The extraction is made with eleven samples at once, as follows:

Eleven erlenmeyer flasks of 125 ml fixed on a metal rack constitute one unit for handling. These racks are numbered. The samples are measured and transferred into erlenmeyer flasks. Simultaneously the extracting solution is added to each erlenmeyer flask by an automatic pipette. Pipetting is rapidly completed using a vacuum pump.

Each "rack" containing the soil and extracting solution is placed in a mechanical shaker for 5 minutes. After shaking the mixture is allowed to stand overnight to obtain complete sedimentation of soil particles and a clear extract.

Chemical Determination

Convenient aliquots are taken from the extracts for analyses.

Phosphorus determination is made by a colorimetric method. Potassium is analyzed by flame photometry. Calcium and magnesium are determined by EDTA titration 0.025 N and aluminum by titration with NaOH 0.025 N; pH determination is potentiometrically done on water extract. The ratio soil/water is a 1:2.5 and extraction is shaking for one minute and 1 - 3 hours of resting.

General Levels of Soil Fertility

The soil fertility levels and its interpretation by the Official Laboratory of Minas Gerais are presented in Table 1. Interpretation is based essentially on a chemical point of view, although being a good starting point for these studies, does not permit more than the establishment of general levels of fertility. For quantitative recommendation of fertilization, experimental field data is required.

According to the fertility level, the analyzed soil is classified as in low and high averages. A soil is of high fertility when it contains a high level of nutrients sufficient to maintain the development and production of crops without fertilizer. It is low in fertility when one or more nutrients are insufficient and fertilization is required. A soil is average in fertility when it contains an intermediate content of one or more nutrients and needs to receive an average quantity of fertilizer.

Table 1

LEVELS OF SOIL FERTILITY IN A mg/100 ml OF DRIED SOIL AND ITS INTERPRETATION (Pipaemg, 1972)

Analyzed Element	Levels	Interpretation
Exchangeable Aluminum e. mg/100 ml	0.0 to 0.3	Low
	0.4 to 1.0	Average
	Greater than 1.0	High
Exchangeable Calcium + Magnesium	0.0 to 2.0	Low
	2.1 to 5.0	Average
	Greater than 5.0	High
Available Phosphorus ppm of P	0.0 to 10	Low
	11 to 30	Average
	Greater than 30	High
Available Potassium ppm of K	0.0 to 60	Low
	61 to 120	Average
	Greater than 120	High
pH	Less than 5.0	High Acidity
	5.0 to 5.9	Average Acidity
	6.0 to 6.9	Low Acidity
	7.0	Neutral
	7.1 to 7.8	Low Alkalinity
	Greater than 7.8	High Alkalinity

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LABORATORY SAMPLE PREPARATION AND ANALYSIS OF ANIMAL TISSUES

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INTRODUCTION

The rapid growth in analytical methods has provided powerful tools for mineral research, particularly, in relation to the microelements. These developments, however, may have disadvantages when the techniques and their limitations are not well understood. Therefore, it is necessary, to appreciate the limitations with regard to the techniques and the correct interpretation of the results. In determining mineral concentrations in animal tissues, the precision and accuracy needed are important factors to be taken into consideration. In addition, the quantitative determination of minerals in animal tissues requires good sampling procedures, appropriate sample preparation and application of suitable analytical techniques.

To determine mineral concentrations in tissues the following aspects should be considered:

Use of more than one method of analysis.

Two or more analytical procedures may be used to test an analytical method and may include different sample preparation and digestion or destruction of the organic matter. For organic matter destruction three procedures may be compared; wet digestion, dry ashing at low temperatures and dry ashing at high temperatures.

The final element determination may be done using several techniques such as:

Atomic absorption spectrophotometry
Spectrofluorometry
X Rays
Neutron activation, etc.

This criterion may warn the researcher of errors occurring in each technique.

Use of certified standards.

The use of animal tissue certified standards is necessary in any laboratory. These standards may be obtained by analyzing them by two different analytical methods including different procedures of organic matter destruction or oxidation. The standards should be similar or have approximately the same chemical and physical composition as the samples that will be compared. Even so, not all matrix effects will be eliminated.

Contamination

Accidental contamination of the sample during collection, preparation and element determination is a source of error that the analyst should avoid; particularly, when determining microelements.

SAMPLE COLLECTION

No matter how accurate the analysis, the values obtained can be no better than the sample collected. Minerals in biological samples are often found in different forms each with characteristic biochemical and analytical properties. In order to obtain relevant information on mineral concentrations the tissue or organ selected for analysis should reflect a deficiency or excess, or it should be physiologically related to the disease of interest. Therefore, knowledge on mineral metabolism and mode of action is of great value in selecting appropriate tissues. Organs or tissues may be selected based on the following aspects:

a) Tissues in which minerals function as local regulators. These tissues maintain homeostasis regulating absorption and excretion of an element or its synthesis in a biologically active molecule. The thyroid regulates iodine in the active form and indicates its organic level.

b) Tissues in which minerals have an essential function. In these tissues minerals are necessary for normal physiological function. Among these minerals are iron, important in hemoglobin, and zinc in the enzyme carbonic anhydrase. Both elements are found in liver, muscle and pancreas and analysis of these tissues may indicate the nutritional level of the minerals in the animal.

c) Tissues that have an important function in mineral transport, storage and excretion. These are tissues that constitute body fluids including urine, bone cortex and marrow. Serum and plasma are the most commonly used tissues for analysis. Urine analysis is complicated by its high salt concentration and also the variation in volume voided per day. Matrix interferences are common in urine analysis. Nevertheless, urine is good sampling material to study the metabolism of some microelements. A reduction of the normal levels of a microelement in organs that store it may often indicate a deficiency before clinical signs appear. Therefore, an iron deficiency may be detected in the bone marrow, liver and other organs or tissues that are part of the reticulo-endothelial system.

d) Tissues or organs that accumulate minerals with an excessive exposure. The kidney, lungs, nails, hair and the corneous part of the skin immobilize minerals. All these tissues may be used to determine a microelement deficiency or chronic intoxication.

Hair is often used for the determination of copper, zinc and chromium because it is easily obtained. After collection it may be difficult to take a representative sample of bone, hair and skin tissues for analysis. Hair may be cut in small pieces with scissors and a representative sample taken after mixing the pieces.

Skin may be dried and cut in small pieces with a scalpel. Bone may be cut in small fragments and ground. Stainless steel or porcelain tools should be used to prevent contamination. Contamination may also occur during storage of the samples. Glass containers with polyethylene caps must be clean for storage of liquid samples. Solid samples are usually stored in polyethylene bags (i.e. "Whirl-Pak" Nasco, Fort Atkinson, WI 53538).

Sample Preparation

Sample preparation for analysis depends on the analytical technique used. Many methods require oxidation of the organic matter and solubilization of the residues. The two most used methods for destruction of the organic matter are wet digestion and dry ashing.

a) **Wet digestion.** This procedure is used in many laboratories. The samples are usually digested in beakers with nitric and perchloric acid on a hot plate. Standard and blank solutions are prepared following the same procedure as with samples. High digestion temperatures may result in mineral losses; particularly, in the case of volatile elements such as, arsenic, selenium and mercury. The pH of the final solution should also be considered since the mineral of interest may be precipitated; for instance, iron is precipitated when the pH is over 3.0.

Samples with a high fat content should be predigested with nitric acid to prevent sample losses due to violent reactions of perchloric acid with fat.

All materials used in the analysis must go through a rigorous cleaning procedure. Wash labware with a low-phosphate detergent, rinse with deionized water two times, rinse with a 6N hydrochloric acid solution and finally with deionized water three times. Dry glass and plastic-ware may be placed in plastic bags and stored in a dust-free area.

All reagents used should be of the best quality and highest purity grade. Standard solutions should also have high purity grades and certified concentrations.

b) **Dry ashing.** In this procedure the sample is ashed in a furnace and is satisfactory for the determination of calcium, phosphorus, magnesium in bone or copper, iron, zinc, molybdenum, manganese in several tissues such as muscle, liver, pancreas, skin, hair, etc.

Care should be exercised with the temperatures used for the ashing process since losses may occur due to mineral volatilization and element adsorption in the walls of the crucible. Ashing temperature and time used will depend on the element of interest and it is important to control both of the factors.

c) **Analytical techniques.** The analytical method of choice will depend on the element to be determined.

Analyses are performed in our laboratory by atomic absorption spectrophotometry using the flame or graphite furnace. Minerals usually studied in tissues include calcium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, phosphorus, potassium and zinc. Recently, we have obtained excellent results using the graphite furnace for the determination of selenium.

Elements present in tissues at levels below the instrument detection limits may be chelated with ammonium pyrrolidine dithiocarbamate (APDC), 1% solution, at the appropriate pH and extracted with methyl isobutyl ketone (MIBK).

Element determination by atomic absorption spectrophotometry requires a light source for each element to be determined, pressure and flow regulators for fuel and oxidant gases, a burner, nebulizer, a monochromator and electronic detectors that provide readouts in absorbance or concentration units.

The technique of atomic absorption spectrophotometry utilizes the radiation of an external light source. Generally, hollow cathode lamps or electrodeless discharge lamps, in which the cathode is constructed of the element to be determined, are used as a light or energy source. The emitted light is directed through a flame into which the liquid sample to be analyzed is aspirated. Atoms in the flame which are chemically unbound and in their minimum energy state absorb the light at certain wavelength lines. A monochromator is used to isolate the line or wavelength of interest from the remainder of the emitted radiations. Electronic detectors measure the changes in the amount of light or energy which has passed through the flame. Signals coming from the detectors may be expanded and appear, according to instrumentation, either as percent absorption, as absorbance units, as direct readout in concentration units, or as discrete peaks on a stripchart recorder. The degree of absorption is proportional to the concentration of the element in the aspirated sample.

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MINERAL COMPOSITION OF GRASSES AND TROPICAL LEGUMINOUS FORAGES

by

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From the animal nutrition viewpoint, 8 macroelements–N, P, K, Ca, Mg, S, Na, Cl and 8 microelements–Zn, Mn, I, Co, Cu, Fe, Mo and Se are recognized as being important, and the presence of these minerals in feed is necessary for the animal's metabolic processes. Forages, the principal feed of herbivores, is commonly deficient in Na and Cl. Also phosphorus is a mineral element quite often found in critical levels in pastures and its deficiency has been verified in herds in Minas Gerais (Menicucci Sobrinho, 1943) and São Paulo (Villares and Silva, 1956). The occurrence of symptoms of cobalt deficiency in animals was found in São Paulo (Correia, 1957)), Ceará (Damaso and Tokarnia, 1961) and Minas Gerais (Magalhães, 1949). Megale (1949) reported the occurrence of iodine deficiency symptoms in the state of Minas Gerais. In determining the levels of P, Ca and Co on farms in the municipality of Teofilo Otoni, Minas Gerais, Pereira *et al.* (1971) stated that the majority of pasture samples were P deficient, while some samples showed evidence of being deficient in Co. While these authors found satisfactory levels of Cu in the samples of forages, Teixeira *et al.* (1971) verified critical levels of Cu, but not Co, plus generally low levels of P in pasture samples of 2-3 farms studied in Morrinhos, Goiás.

The mineral composition of forages varies according to many factors; among those are the age of plant, the soil and fertilization , differences among species and varieties, seasons of the year and the cutting intervals.

Age of the Plant: This is an important factor in affecting the chemical composition as well as the overall nutritive value of forages. The levels of N, P and K decrease with the advance of age and/or growth of the plant (Table 1). Table 1 shows the effect of dilution of these nutrients in the vegetative dry matter, whose production follows a sigmoidal curve as a function of the weather. To this generally accepted theory of dilution are other factors such as a diminishing capacity of the plant to absorb nutrients from the soil and variation in the stem: leaf ratios.

Some nutrients like N, P and K are very mobile within the plant, translocating themselves from the oldest tissues to the newest ones; whereas, elements such as Ca, Mg, Zn and Fe are relatively immobile, being concentrated in the oldest tissues and in the stem. This differential distribution of the elements in the diverse vegetal tissue would explain the accentuated decrease in the levels of N, P and K with the growth of the plant which is accompanied by the change in the stem: leaf ratio.

It is often observed that decrease in the levels of N and K with the growth of the plant is more accentuated in poor soils; such an event might be attenuated with the practice of more liberal and divided fertilization during the period of plant growth. Yet in a study of guinea grass, application of 25 kg of N and K per hectare in the forms of ammonium sulfate and potassium chloride, respectively, at the ages of 0, 28 and 56 days did not substantially alter the levels of those elements in the plant samples collected at the ages of 14, 28, 42, 56, 70 and 84 days.

While it is known that the leguminous forages show less variation in their nutritive value during their vegetative development, this does not displace the data that states this fact in relation to the tropical leguminous plants.

Table 1

VARIATION OF THE MINERAL COMPOSITION WITH THE AGE OF PLANTS

Grass	Age Days	Composition of Dry Matter N %	P %	K %	Ca %	Mg %	Zn ppm	Mn ppm
Guinea grass* (*Panicum maximum*)	14	2.96	0.18	2.24	0.41	0.28	38	–
	28	2.40	0.14	2.33	0.34	0.23	34	–
	42	1.81	0.13	2.80	0.34	0.20	36	–
	56	1.55	0.10	2.64	0.34	0.17	32	–
	70	1.26	0.08	2.53	0.31	0.14	32	–
Molasses grass* (*Melinis minutiflora*)	14	2.88	0.20	2.3	0.28	0.25	116	178
	28	2.54	0.18	2.3	0.27	0.25	135	106
	42	2.18	0.18	2.2	0.27	0.25	71	73
	56	1.47	0.06	2.0	0.20	0.20	73	62
	70	1.34	0.05	1.7	0.20	.18	97	136
Elephant grass** (*Pennisetum purpureum*)	28	–	0.33	2.38	0.61	0.42	40	138
	84	–	0.15	1.20	0.38	0.28	28	111
	140	–	0.11	0.34	0.43	0.36	33	128
Pangola grass** (*Digitaria decumbens*)	28	–	0.16	1.32	0.56	0.39	35	192
	84	–	0.11	0.74	0.50	0.38	22	188
	140	–	0.12	0.37	0.66	0.39	31	317
Jaragua grass*** (*Hyparrhenia rufa*)	28	–	0.28	1.68	0.40	0.46	51	–
	56	–	0.17	0.63	0.20	0.36	30	–
	84	–	0.11	0.57	0.23	0.58	37	–

* Unpublished data (Gomide and Obeid; Ruiz and Gomide).
** Gomide *et al.* (1969).
*** Nascimiento *et al.* (1976).

Soil and Fertilization. Soil is the source of all mineral elements found in plants. The capacity of the soil to supply the mineral elements to the plants depends on such factors as the soil material origin, the reaction of the soil (pH), the texture and state of growth (less with inclement weather). While clay and organic soils are rich in potassium, the sandy soils are frequently deficient in this mineral. Very acidic or very basic soils are poor in available phosphorus; although they contain great quantities of total phosphorus in the forms of iron phosphates and aluminum and tricalcic phosphates, respectively.

Gomide *et al.* (1974) studied composition of grasses in "cerrado" sandy areas poor in K (12 ppm), P (2 ppm), Ca (0.4 mEq/100 g) and Mg (0.1 mEq/100 g) and reported the following levels: 0.07 and 0.08% P; 1.05 and 1.78% K; 0.09 and 0.14% Ca and 0.09 and 0.10% Mg for *Tripsacum laxum* and the Napier variety of *Pennisetum purpureum*, respectively, when cut at a height of 1.50–1.80 m and when receiving 50 kg of ammonium sulfate and 33 kg KCl/hectare/cutting plus a fertilizer in the furrow with 30 t of corral manure and 500 kg of Araxá fertilizer per hectare. It is an example in which the levels of P, Ca and Mg are extremely low as a consequence of the deficiency of some elements of the soil. Values that are also low (0.08% P, 0.14% Ca and 0.10% Mg) are stated by Andrade (1972) for the Mineiro variety of *Pennisetum purpureum*, cultivated in "cerrado" areas. Yet in a "cerrado" soil showing 36 ppm of available K, 2 ppm of available P plus 1.4 mEq Ca and 0.6 mEq Mg/100 g, the following mineral compositions were found in varieties of elephant grass and their respective hybrids with *Pennisetum glaucum* 23 A (Table 2).

Table 2

MINERAL COMPOSITION OF VARIETIES OF *PENNISETUM PURPUREUM* AND ITS HYBRIDS WITH *PENNISETUM GLAUCUM* 23 A*

	N (% DM)	P (% DM)	K (% DM)	Ca (% DM)	Mg (% DM)	Zn (% DM)
Mineiro	1.66	0.15	2.06	0.28	0.13	30
Napier	1.49	0.14	2.13	0.36	0.08	41
Mercker	1.41	0.13	2.16	0.35	0.11	36
Mineiro x 23A	1.52	0.13	2.12	0.34	0.15	37
Napier x 23A	1.58	0.12	2.22	0.32	0.15	37
Mercker x 23A	1.52	0.14	1.92	0.34	0.13	42

*Unpublished data (Gomide, Christmas and Obeid).

These results reveal higher values of calcium and magnesium as a consequence of the large availability of these elements in the soil, since the criteria for cutting grains was the same. This means that the cutting is always made when the plants attain a height of 1.80 m. The highest levels of P and K occur from the application of triple superphosphate (200 kg/hectare) in the furrow plus simple superphosphate (612 kg/hectare) broadcast plus KCl (60 kg/ha/cutting).

Zúniga (1966) found effects of NPK fertilization on the mineral composition (Table 3) of a series of grass forages, cultivated in sandy loam soils near Viçosa. In this study, the grasses were cut at the beginning of flowering and the levels of P and K found were considered satisfactory.

Table 3

LEVELS OF P, K, Ca, Zn, B AND Co IN GRASSES WHICH WERE CUT AT THE BEGINNING OF FLOWERING*

	P (% DM)	K (% DM)	Ca (% DM)	Zn (ppm DM)	B (ppm DM)	Co (ppm DM)
Elephant grass "Napier" *(Pennisetum purpureum)*	0.18	1.91	0.27	33	4	0.89
Elephant grass "Mercker" *(Pennisetum purpureum)*	0.17	1.86	0.29	35	4	0.78
Guatemala grass *(Tripsacum laxum)*	0.15	1.55	0.14	19	3	0.73
Imperial grass *(Axonopus scoparius)*	0.15	1.33	0.46	42	5	0.83
Guinea grass *(Panicum maximum)*	0.18	1.77	0.35	36	5	1.00
Paragrass *(Panicum purpurascens)*	0.14	1.43	0.41	29	4	0.95
Pangola grass *(Digitaria decumbens)*	0.14	1.39	0.36	31	4	0.63

*Adapted from Zúniga (1966).

Average values for calcium and magnesium, found by Gomide *et al.* (1969) in different grasses cultivated in sandy soils which contained 2.5 mEq of Ca + Mg/100 g of soil were molasses grass 0.43% Ca and 0.38% Mg; *Pennisetum purpureum* (Napier variety) 0.43% Ca and 0.34% Mg; *Melinis minutiflora* 0.64% Ca and 0.38% Mg and *Panicum maximum* 0.70% Ca and 0.48% Mg.

Thus the mineral level of forage depends on the type of soil and its fertility. The fertilization of grasses and legumes is a practice capable of increasing the mineral level of these plants. However, there are frequently cases in which the plants do not respond to fertilization, that is the mineral composition is not increased and, at times, the inverse reaction occurs. Andrade (1972) showed little or no effect from organic or chemical fertilization (Table 4) on the Mineiro variety elephant grass that had been cultivated in a "cerrado" pasture that was poor in K (36 ppm), P (1 ppm), and Ca + Mg (0.9 mEq /100 g).

Table 4

EFFECT OF ORGANIC AND CHEMICAL FERTILIZATION ON THE MINERAL COMPOSITION OF ELEPHANT GRASS (MINEIRO VARIETY)*

	N (% DM)	P (% DM)	K (% DM)	Ca (% DM)	Mg (% DM)	Cu (% DM)	Zn (% DM)	Mn (% DM)
Control	1.29^{a}	0.08^{a}	2.8^{a}	0.14^{a}	0.10^{a}	17	21^{b}	137^{a}
Araxá phosphate (1)	1.32^{a}	0.10^{b}	3.1^{b}	0.15^{a}	0.11^{ab}	22	19^{ab}	135^{a}
Corral manure (2)	1.33^{a}	0.14^{c}	3.1^{b}	0.15^{a}	0.12^{b}	18	18^{a}	130^{a}
NPK (3)	1.56^{b}	0.10^{b}	3.2^{b}	0.16^{a}	0.11^{a}	21	21^{b}	160^{b}

*Andrade (1972).
(1) 500 kg/ha
(2) 30 t/ha
(3) 600 kg/ha of Araxá in the furrow + 270 kg of ammonium sulfate and 80 kg of KCl/ha/cutting.
a, b, c ($P<0.05$).

These figures show that, in spite of some significant differences, fertilization did not result in a marked increase in the mineral levels of the majority of the plants. Similar results are being observed in experiments in Viçosa with *Melinis minutiflora* and in CEPET (Capinopolis) with grass that is fertilized with 100 kg of simple superphosphate/hectare in the planting furrow and 25 kg of N and K/hectare broadcast on the soil surface. The results that were obtained are as follows, respectively, for fertilized and non-fertilized: *Melinis minutiflora* cut at 28 days of age 2.54 and 2.61% N; 0.18 and 0.15% P; 2.3 and 2.2% K, 0.27 and 0.24% Ca, 0.25 and 0.24% Mg; 135 and 128 ppm Zn and 106 and 135 ppm Mn. The results obtained for *Panicum maximum*, respectively, for fertilized and non-fertilized, cut at 28 days of age as follows: 2.40 and 2.38% N; 0.14 and 0.15% P; 2.33 and 2.41% K; 0.34 and 0.45% Ca; 0.23 and 0.29% Mg and 34 and 32 ppm Zn.

In Nhecolandia, in the Pantanal of Mato Grasso in sandy areas, with the pH = 6.2; 7 ppm P; 38 ppm K and 1.3 mEq of Ca + Mg/100 g of soil, the results of the fertilization of NPK on the mineral composition of native and introduced grasses (Table 5) are available.

Panicum repens, Cenchrus ciliaris, Melinis minutiflora, Panicum maximum showed high levels of phosphorus when not fertilized, also the same was true for the level of magnesium from first 2 grasses, while the levels of K, Ca, Zn and Cu were not affected by the fertilization but there was a slight increase in the level of nitrogen of 5 of the 6 species studied.

Table 5

EFFECT OF THE FERTILIZER NPK ON THE MINERAL COMPOSITION OF NATIVE AND INTRODUCED GRASSES OF NHECOLANDIA*

	Fertilization NPK%**	Compositon of Dry Matter							
		N %	P %	K %	Ca %	Mg %	Zn ppm	Cu ppm	Mn ppm
Torpedo grass	+	1.09	0.17	1.4	0.16	0.14	21	6	198
(Panicum repens)	–	0.96	0.21	1.6	0.18	0.17	22	6	242
Tio Pedro grass	+	0.86	0.17	1.1	0.48	0.17	26	7	550
(Paspalum convexum)	–	0.67	0.23	1.2	0.51	0.24	25	6	506
Buffel grass	+	0.96	0.19	1.5	0.22	0.12	22	6	152
(Cenchrus Ciliaris)	–	0.91	0.24	1.5	0.21	0.13	25	5	147
Pangola grass	+	0.64	0.19	1.4	0.27	0.09	19	4	298
(Digitaria decumbens)	–	0.69	0.26	1.4	0.30	0.10	18	4	230
Sheep grass	+	0.98	0.25	1.6	0.25	0.22	30	6	208
(Brachiaria decumbens)	–	0.83	0.25	1.7	0.16	0.20	24	5	158
Guinea grass	+	1.06	0.18	1.8	0.31	0.22	36	6	273
(Panicum maximum)	–	0.90	0.22	1.7	0.30	0.22	30	5	260

*Adapted from Santos (1973).
**Simple superphosphate 500 kg/ha; ammonium sulfate and potassium chloride respectively, 250 and 50 kg/ha/cutting.

Some results of experiments of the fertilization of tropical legume have shown increases, principally in the levels of phosphorus and potassium. The results of a study on the effect of the liming and fertilization of the perennials soybean (*Glicine javanica*) in a dark red latosol of medium texture, containing 5 ppm P, 30 ppm K and 2.5 mEq of Ca + Mg/100 g is shown in Table 6 (Tardin, 1971). The results of this study are shown in Table 6.

The levels of calcareus calcite studied were 0, 2 and 4 t/ha while the fertilizer phosphorus-potassium consisted in the application of 500 kg of simple superphosphate plus 80 kg of KCl/hectare in the furrow. Liming tends to raise the levels of calcium and reduce the levels of magnesium of the perennial soybean; however, these differences were not significant. The levels of phosphorus and potassium were raised by the phosphorus-potassium fertilizer which favorably affected the production of dry matter, almost tripling it. On the other hand, fertilization with phosphorus and potassium resulted in a decrease in the levels of crude protein, calcium and magnesium in the legumes.

In a factorial experiment (2^4) of the fertilization of siratro (*Phaseolus macropdilium*) in a "cerrado" area, dark red eutrophic latosol, the application of calcium (1.5 t/ha), simple superphosphate (1500 kg/ha), potassium chloride (200

Table 6

EFFECT OF THE LIMING AND FERTILIZATION (PK) ON THE MINERAL COMPOSITION OF THE PERENNIAL SOYBEAN

Liming (t/ha)	Fertilization PK	Mineral Composition				
		P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)
0	+	0.14[a]	1.96[a]	0.80	0.32	101[a]
	–	0.11[b]	1.44[b]	0.86	0.44	112[a]
2	+	0.14[a]	2.05[a]	0.85	0.33	100[a]
	–	0.11[b]	1.52[b]	1.04	0.42	104[a]
4	+	0.13	1.53[a]	0.94	0.47	92[a]
	–	0.11	1.25[b]	1.00	0.45	93[a]
Average	+	0.14	1.85	0.86	0.37	98
	–	0.11	1.40	0.97	0.44	103

*Tardin (1971).

[a,b]Means bearing different superscripts are significantly different ($P < .05$).

kg/ha/cutting) and FTE-Br-10 (30 kg/ha) was studied. The following figures are the levels obtained from the average of the 8 treatments that contain the experimental factor in relation to the remaining 8 treatments: **Superphosphate:** 0.28 x 0.18% P; **Calcium:** 0.63 x 0.63% Ca and 0.33 x 0.31 Mg; **Potassium chloride:** 1.35 x 0.92% K; **FTE*:** 30 x 28 ppm Zn; 31 x 32 ppm Cu, 1.14 x 0.93 ppm Mo and 0.26 x 0.22 ppm Co. In the absence of fertilization the siratro showed the following composition: 2.48% N; 0.17% P; 0.67% K; 0.62% Ca; 0.30% Mg, 35 ppm Zn, 88 ppm Mn, 37 ppm Cu, 1.37 ppm Mo and 0.14 ppm Co.

Heavy fertilization with simple super-phosphate raises the level of P, while the application of KCl raises the level of K in legumes. Apparently, the application of FTE does not affect the level of the micronutrients Zn, Mn, Cu, Co and Mo in the siratro.

From the examination of the results, it can be concluded that in the majority of cases, fertilization has not greatly altered the mineral composition of tropical forages. the explanation for this fact is due, apparently, to several reasons:

a) **Insufficient quantities of fertilizers applied.** From the point of view of fertility, a soil is considered rich in P and K when it contains above 30 and 120 ppm, respectively, in an available form. The application of 100 kg of simple superphosphate/hectare and its incorporation into a layer of 20 cm of soil would correspond to an increase in fertility of only 4.4 ppm of P. Similarly, the application of 125 kg of KCl/hectare would represent the incorporation of only 38 ppm of K.

b) **Dilution of the fertilization applied in the larger quantity of dry matter produced.** The primary effect of fertilization is to increase the forage output, accelerating the growth of the plant. Results from diverse pasture studies show that fertilization results more frequently in an increase in the carrying capacity of the pasture and the production of meat or milk/hectare than in an increase in production per animal. This fact, valid for tropical forages as well as temperate forages, is more applicable to the former, when one considers more plant growth and condition of soils that are less fertile and more subject to seepage. Under these conditions, the fertilizing element would concentrate itself in the vegetative portion only when applied in quantities that exceed the capacity of the plant to augment its forage yield, which would be conditions of liberal fertilizer application.

c) **Harm caused by uneven distribution of the fertilizer.**

d) **Inefficient absorption of the fertilizers.** The application of fertilizers after the cutting is the time in which the root system enters into a regeneration phase (Oswald *et al.*, 1959 and Scott, 1956). Naturally, the effect of dilution of nutrients from the fertilizers is more accentuated in relation to elements not contained in the applied fertilizer. For example, the application of simple superphosphate, while stimulating the growth of the plant, can result in the reduction of the levels of elements like N, K, Ca and Mg (Table 6).

On the other hand, liming, which alters the reaction of the soil, frequently affects the levels of some micronutrients in the plant by affecting the availability of these in the soil. This means that, in general, liming reduces the availability of Mn, Zn, Fe, Al, B and Co but increases the availability of Mo, Se and P.

Differences among species and varieties. Results presented indicate that there are certain differences in mineral composition among forage species. It is necessary to make comparisons that refer to the species studied in the same experiment to prevent the superimposing of effects of other factors like the type of soil, fertilization levels and management.

*FTE is a trace element fertilizer.

The data of Table 3 indicate that *Pennisetum purpureum* and *Panicum maximum* are richer in K while *Axonopus* scoparius and *Digitaria decumbens* show lower values. On the other hand, higher levels of Ca are observed in *Axonopus scoparius, Panicum purpurascens, Digitaria decumbens* and *Panicum maximum.* Differences in the mineral composition among other species are evident from an examination of Table 5 in relation to the grasses *Paspalum convexum, Cenchrus ciliaris, Digitaria decumbens, Brachiaria decumbens* under conditions of fertilization. *Paspalum convexum* has the highest levels of Ca and Mn while *Brachiaria decumbens* seems to have the lowest level of P and Mg. Of these 4 grasses, *Digitaria decumbens* has the lowest amount of N.

Gomide *et al.* (1974) reported the mineral composition of varieties of *Pennisetum purpureum* and *Tripsacum laxum.* An adaptation of this data (Table 7), comparing the Taiwan and Napier varieties of *Pennisetum purpureum* with *Tripsacum laxum* demonstrates the superiority of the former concerning its levels of N, K and Ca, not showing, however, the differences as to the levels of Zn and Mn.

In an experiment of fertilization and combination of pasture with Jaragua grass conducted in CEPET, Cadinopolis, the results (Table 8) indicate high concentrations of N, K, Ca and Mg in legumes in relation to *Hyparrhenia rufa.*

Table 7

MINERAL COMPOSITION OF GUATEMALA GRASS *(TRIPSACUM LAXUM)* AND OF VARIETIES OF ELEPHANT GRASS *(PENNISETUM PURPUREUM)**

Grasses	Composition of Dry Matter							
	N %	P %	K %	Ca %	Mg %	Zn ppm	Mn ppm	Cu ppm
Pennisetum purpureum, (Taiwan)	1.18[a]	0.10[a]	2.03[a]	0.12[a]	0.13[a]	19[a]	179[a]	24[a]
Pennisetum purpureum, (Napier)	1.14[a]	0.08[b]	1.78[a]	0.14[a]	0.10[b]	17[a]	226[a]	18[b]
Tripsacum laxum	0.78[b]	0.07[b]	1.05[b]	0.09[b]	0.09[b]	12[a]	230[a]	16[b]

*Adapted from Gomide *et al.* (1974).

[a,b]Means bearing different superscripts are significantly different ($P < .05$).

Legumes high in N, Ca and Mg in relation to grasses is a common observation. In the present case, legumes are richer in K. Normally, grasses have higher levels of K than legumes. The roots of dicotyledons have a greater capacity to change the absorbed cations, with preference toward divalent cations; while grasses, having a smaller capacity to change cations in their root systems, preferentially accumulate monovalent cations. This can be determined not so much by an elevated level of K in the siratro, centrosema or perennial soybean but an exceptionally low level of K in the *Hyparrhenia rufa*, a fact that would merit investigation. Evidence resulting from another experiment (Table 1) supports this observation of abnormally low levels of K in *Hyparrhenia rufa.*

High levels of N in legumes, commonly attributed to symbiotic fixation, would possibly explain the low rate of growth of these plants.

Table 8

MINERAL COMPOSITION OF LEGUMES AND JARAGUA GRASS *(HYPARRHENIA RUFA)*, COMBINED*

	Composition of Dry Matter					
	N %	P %	K %	Ca %	Mg %	Zn ppm
Centrosema *(Centrosema pubescens)*	2.50	0.10	1.34	1.36	0.24	40
Siratro *(Phaseollus macroptillium)*	2.24	0.09	1.66	1.13	0.30	41
Perennial soybean *(Glycine javanica)*	2.45	0.10	2.06	1.29	0.28	52
Jaragua grass *(Hyparrhenia rufa)*	0.86	0.14	0.61	0.47	0.14	48

*Unpublished data (Gomide and Obeid).

The data does not show great differences between legumes, centrosema, siratro and perennial soybeans. The siratro has a smaller concentration of N and the centrosema has a smaller concentration of K.

Season of the year and succession of growings. Seasonal factors like light, temperature and rain could justify certain variations in the chemical composition of forage during the year. Yet in a study of this type it is necessary to avoid possible superimposing of effects that are due to the differences in the age, and/or development of the plant. It is necessary also to consider the composition of the plant collected at different times of the year but with the same age (days) or the same development (height). Table 9 shows the results of a study underway in CEPET concerning non-fertilized *Panicum maximum* at 28 days of age. The first growth began with germination on December 6, 1974, the

second growth began with the cutting when it had grown 20 cm on January 3, the third growth began with 1 cutting at a height of 20 cm on January 31, and the fourth growth began on Febuary 28 under the same conditions. In this study it was necessary to prevent, through sprinkler irrigation, possible plant damage due to drought. An examination of the data of Table 9 shows a progressive decrease in the levels of N, Ca and Mg while the levels of K and Zn vary erratically. The behavior of K levels is abnormal but in a cutting experiment the levels of this element frequently fall with the succession of cuttings. Considering the below average levels of K (65 ppm) the observation perhaps is suggestive of a soil with great ability to supply K.

Table 9

VARIATION OF MINERAL COMPOSITION OF GUINEA GRASS *(PANICUM MAXIMUM)* WITH INCREASING PLANT GROWTH*

Growth	Cuttings	Mineral Composition of Dry Matter					
		N	P	K	Ca	Mg	Zn
Order	Date	%	%	%	%	%	ppm
No. 1	1-3-74	3.36	0.18	2.14	0.53	0.28	38
No. 2	1-31-74	2.38	0.15	2.41	0.45	0.29	32
No. 3	2-28-74	2.22	0.13	2.46	0.32	0.18	35
No. 4	3-28-74	2.11	0.14	2.80	0.28	0.16	30

*Unpublished data (Gomide and Obeid).

Gomide *et al.* (1974) in studies with varieties of *Pennisetum purpureum* in sandy soils in a cerrado area of the Mineiro Triangle, verified that while the levels of N and K decreased progressively with the succession of cuttings, the levels of P, Mg, Cu and Zn varied erratically after showing a decrease from the first to the second cuttings. The levels of Ca and Mn did not show any definite tendency (Table 10). The high levels of N and K observed in samples of the first cutting were attributed to the contribution of the manure applied in the furrow. Since, in this experiment the grass received fertilization of 50 kg of ammonium sulfate and 33 kg of KCl/ha after each cutting, it is concluded that the fertilization that was applied was not sufficient to sustain the levels of N and K for the elephant grass cut at a height of 1.8 m. On the other hand, there is evidence of the low ability of the soil to supply K where the experiment occurred.

Table 10

VARIATION, WITH THE SUCCESSION OF CUTTINGS ON THE AVERAGE MINERAL COMPOSITION OF 4 VARIETIES OF *PENNISETUM PURPUREUM**

		Growth					
		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
N	(% DM)	2.14	1.06	1.06	0.85	0.75	0.64
P	(% DM)	0.16	0.06	0.08	0.07	0.07	0.10
K	(% DM)	4.52	1.20	1.44	1.11	0.71	0.86
Ca	(% DM)	0.14	0.13	0.12	0.13	0.14	0.14
Mg	(% DM)	0.12	0.08	0.09	0.10	0.11	0.11
Zn	(ppm DM)	28	13	13	15	12	16
Mn	(ppm DM)	176	226	181	222	257	2[illegible]4
Cu	(ppm DM)	31	18	18	19	15	17

*Gomide *et al.* (1974).

Different results (Table 11) were observed in an experiment involving 4 varieties of *Pennisetum purpureum* and their 8 hybrids with *Pennisetum glaucum*. The soil had a higher fertility level and a more liberal application of fertilizers (350 kg ammonium sulfate and 60 kg potassium chloride/hectare/cutting plus 612 kg of simple superphosphate/hectare). A progressive decline was observed in the levels of N and P as well as a decline in the levels of Ca in the last 2 cuttings. The levels of N, P, K, Ca and Zn shown in Table 11 are superior to those shown in Table 10 which is a result of the larger quantity of fertilizers used. The decline in the level of potassium also decreased with the succession of cuttings.

Table 11

AVERAGE MINERAL COMPOSITION OF 4 VARIETIES OF ELEPHANT GRASS *(PENNISETUM PURPUREUM)* AND HYBRIDS WITH 2 VARIETIES OF *(PENNISETUM GLAUCUM**

		Growth			
		No. 1	No. 2	No. 3	No. 5
N	(% DM)	1.84	1.39	1.42	0.88
P	(% DM)	0.19	0.16	0.11	0.12
K	(% DM)	3.76	1.60	1.30	1.91
Ca	(% DM)	0.42	0.44	0.24	0.28
Mg	(% DM)	0.12	0.16	0.12	0.12
Zn	(ppm DM)	38	41	–	29

*Unpublished data (Gomide, Christmas and Obeid).

The data presented show the necessity of replacement fertilizations to maintain the mineral composition of the forages when the forage is used as green chop, hay or silage. Yet, the possible variations in the mineral composition of grazed forages with a succession of grazings during the growing period should not show great decrease since the animals excrete a large part of the ingested nitrogen, phosphorus and potassium in the feces and urine.

Summary and Conclusions

The mineral composition of tropical grasses and tropical forage legumes is discussed as to their variation in function with various factors including age of the plant, fertility and type of soil, season, succession of cuttings plus the difference between species and varieties. With increase in growth and advance in age of the plant, the levels of N, P and K decrease. This is principally due to an effect of dilution of the mineral elements in a great quantity of dry matter that is produced and accumulated. Exceptionally low levels of P, K, Ca and Mg were related to varieties of elephant grass that were cultivated in sandy cerrado soil; moreover, the levels of P found in the majority of cases are low indicating the low fertility of the soils in relation to this element. Fertilizers in the normally recommended levels have not improved the mineral composition of tropical grasses and, in the majority of cases, have resulted in the decrease in the levels of several elements, principally those not contained in the fertilizer that was used.

The differences in mineral composition among species was not greatly different except in some cases like the low level of K in Jaragua grass and different levels of N and K between elephant grass and Guatemala grass. The higher levels of N, Ca and Mg in legumes compared to grasses was also evident in the case of tropical forages.

With relation to tropical forage legumes there is a need to study the variation of the mineral composition as the plant develops.

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WATER AS A SOURCE OF MINERALS

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Extensive analyses of water have demonstrated the presence of all the known essential dietary minerals for farm animals. This is due largely to the so-called universal solvent property of water. Streams, rivers, lakes, impoundments and groundwaters are the primary sources of water for livestock. Such properties as acidity or alkalinity, hardness, color, turbidity, biological oxygen demand, chemical oxygen demand, taste and odor detract sometimes from its quality for livestock uses.

Water Requirements of Farm Animals

The water percentage in an animal's body cannot change appreciably without severe consequences to the animal. Water is excreted in urine, feces, sweat, evaporated from the lungs and skin, and is in such products as milk and eggs. The amount of urine excreted daily varies with work intensity, external temperature, feed and water consumption and other factors. Adolph (1933) determined that a standard for water intake of animals is 1 ml per kcal of heat produced. This expression of water requirement includes the increased needs associated with activity. Cattle are an exception to this rule due to the large amount of water in their feces. They require 1.29 to 2.05 ml per kcal of heat production.

Practical measurements of water consumed voluntarily under various specified conditions have demonstrated that the various classes of livestock and poultry in temperate climates have a wide range of intake as presented in Table 1 (N.A.S., 1974).

Table 1
WATER CONSUMPTION OF ADULT LIVESTOCK OF MEDIUM WEIGHT IN A TEMPERATE CLIMATE

Animal	Liters/day
Beef cattle	26-66
Dairy cattle	38-110
Horses	30-45
Swine	11-19
Sheep and goats	4-15
Chickens	0.2-0.4
Turkeys	0.4-0.6

Availability of Nutrient Elements of Water

The availability of nutrient minerals in water solution is generally believed to be as much as occurs with solid feeds or dry mineral mixes. When radioactive salts of phosphorus-32 and calcium-45 were dissolved in water and administered to steers as a drench, the calcium and phosphorus were absorbed at levels equivalent to when the isotopes had been incorporated in forages from fertilizer (Shirley *et al.*, 1951, 1957). Chapman *et al.* (1962) reported that when 12 g of dry copper sulfate was given daily to steers in a gelatin capsule for 12 months no ill effects occurred; but when this quantity was in aqueous solution as a drench, two treated steers died within 65 days. Many studies with nutrient mineral isotopes in water solution have demonstrated them to be readily absorbed, deposited in the tissues and excreted by animals that consume them.

Concentrations of Nutrient Elements in Water

In the United States (N.A.S., 1972, 1974) concentration values of most mineral elements in surface waters determined in the period 1967-1969 were accumulated in STORET (Systems for Technical Data, 1971). The mean, maximum and minimum concentrations of the common nutrient elements are tabulated in Table 2.

Table 2

COMPOSITION OF UNITED STATES SURFACE WATER, 1957-1969 (COLLECTED AT 140 STATIONS)

Substance	Mean	Maximum	Minimum	Number of Determinations
Phosphorus (mg/liter)	0.087	5.0	0.0001	1,729
Calcium (mg/liter)	57.1	173.0	11.0	510
Magnesium (mg/liter)	14.3	137.0	8.5	1,143
Sodium (mg/liter)	55.1	7,500.0	0.2	1,801
Potassium (mg/liter)	4.3	370.0	0.06	1,304
Chloride (mg/liter)	478.0	19,000.0	0.0	37,355
Sulfate (mg/liter)	135.9	3,383.0	0.0	30,229
Copper (μg/liter)	13.8	280.0	0.8	1,871
Iron (μg/liter)	43.9	4,600.0	0.10	1,836
Manganese (μg/liter)	29.4	3,230.0	0.20	1,818
Zinc (μg/liter)	51.8	1,183.0	1.0	1,833
Selenium (μg/liter)	0.016	1.0	0.01	234
Iodine (μg/liter)	46.1	336.0	4.0	15
Cobalt (μg/liter)	1.0	5.0	0	720

In Table 3 is presented the average intake of drinking water expressed in liters per day for various farm animals. Under the names of the nutrient elements three columns of values are given for illustrative purposes. One column expresses the Naional Research Council (1968a, b, 1970, 1971a) daily requirement; the second column gives the approximate average percentage of that daily requirement in the water consumed per day; and the third column gives the maximum percentage that the daily water intake would supply at the highest concentration of the element reported. At minimum concentrations of nutrient elements there were generally less than one percent of the requirements in the daily intake. These minimum values are not reported.

Table 3

MEAN AND MAXIMUM PERCENTAGES OF DAILY REQUIREMENTS OF NUTRIENT ELEMENTS IN THE DRINKING WATER OF LIVESTOCK

Animal	Water Intake[a] (liters)	Req. Daily[b] (g)	Mean (%)	Max. (%)	Req. Daily (g)	Mean (%)	Max. (%)	Req. Daily (g)	Mean (%)	Max. (%)
		NaCl[c]			Calcium			Phosphorus		
Beef cattle (450 kg)										
Nursing cow	60	25	34	4,560	28	12	37	22	<1	1
Finishing steer	60	24	35	4,760	21	16	49	21	<1	1
Dairy cattle (450 kg)										
Lactating cow	90	66	19	2,600	76	7	21	58	<1	1
Growing heifer	60	21	40	5,430	15	23	68	16	<1	2
Sheep										
Lactating ewe (64 kg)	6	13	7	870	7	5	15	5	<1	1
Fattening lamb (45 kg)	4	10	6	760	3	8	23	3	<1	1
Swine										
Fattening (60-100 kg)	8	4	28	3,800	17	3	8	14	<1	<1
Lactating sows (200-250 kg)	14	28	7	950	33	2	7	22	<1	<1

Table 3 (continued)

Animal	Water Intake[a] (liters)	Req. Daily[b] (g)	Mean (%)	Max. (%)	Req. Daily (g)	Mean (%)	Max. (%)	Req. Daily (g)	Mean (%)	Max. (%)
		Magnesium			Potassium			Sulfur		
Beef cattle (450 kg)										
Nursing cow	60	14	6	59	90	<1	24	10	27	683
Finishing steer	60	9	10	91	70	<1	31	9	29	719
Dairy cattle (450 kg)										
Lactating cow	90	14	9	88	99	<1	34	20	20	507
Growing heifer	60	9	10	91	70	<1	32	10	27	676
Sheep										
Lactating ewe (64 kg)	6	1.5	6	68	–	–	–	3	11	270
Fattening lamb (45 kg)	4	1.1	5	68	–	–	–	2	10	250
Swine										
Fattening (60-100 kg)	8	1.0	11	110	9	<1	33	–	–	–
Lactating sows (200-250 kg)	14	2.2	9	90	14	<1	37	–	–	–

		Cobalt (mg)	(%)	(%)	Manganese (mg)	(%)	(%)	Selenium (mg)	(%)	(%)
Beef cattle (450 kg)										
Nursing cow	60	0.74	8	40	49	4	395	0.74	1	8
Finishing steer	60	0.71	8	40	47	4	412	0.71	1	8
Dairy cattle (450 kg)										
Lactating cow	90	1.4	6	32	100	3	290	2.0	1	5
Growing heifer	60	0.7	9	43	50	4	388	1.0	1	6
Sheep										
Lactating ewe (64 kg)	6	0.18	3	16	–	–	–	0.1	1	6
Fattening lamb (45 kg)	4	0.13	3	15	–	–	–	0.1	1	4
Swine										
Fattening (60-100 kg)	8	–	–	–	66	<1	29	0.33	1	2
Lactating sows (200-250 kg)	14	–	–	–	110	<1	18	0.55	1	3

Table 3 (continued)

Animal	Water Intake[a] (liters)	Req. Daily[b] (mg)	Mean (%)	Max. (%)	Req. Daily (mg)	Mean (%)	Max. (%)	Req. Daily (mg)	Mean (%)	Max. (%)
		Iron			**Zinc**					
Beef cattle (450 kg)										
Nursing cow	60	0.99	<1	28	0.15	2	47	–	–	–
Finishing steer	60	0.94	<1	29	0.14	2	51	–	–	–
Dairy cattle (450 kg)										
Lactating cow	90	2.00	<1	21	0.86	1	12	–	–	–
Growing heifer	60	1.00	<1	28	0.43	1	16	–	–	–
Sheep										
Lactating ewe (64 kg)	6	–	–	–	0.25	1	3	–	–	–
Fattening lamb (45 kg)	4	–	–	–	0.18	1	3	–	–	–
Swine										
Fattening (60-100 kg)	8	0.26	<1	14	0.17	<1	5	–	–	–
Lactating sows (200-250 kg)	14	0.44	<1	15	0.28	<1	6	–	–	–
		Iodine			**Copper**					
Beef cattle (450 kg)										
Nursing cow	60	1.7	163	1,180	73	1	21	–	–	–
Finishing steer	60	1.6	173	1,260	75	1	22	–	–	–
Dairy cattle (450 kg)										
Lactating cow	90	5.1	81	593	160	1	16	–	–	–
Growing heifer	60	1.6	173	1,260	80	1	21	–	–	–
Sheep										
Lactating ewes (64 kg)	6	1.0	28	202	13	1	13	–	–	–
Fattening lamb (45 kg)	4	0.8	23	168	9	1	12	–	–	–
Swine										
Fattening (60-100 kg)	8	–	–	–	20	1	11	–	–	–
Lactating sows (200-250 kg)	14	–	–	–	33	1	12	–	–	–

[a]See discussion on water consumption for sources of these values.
[b]Sources of values generally are the NAS-NRC bulletins on nutrient requirements of various species of livestock (1968a,b, 1970, 1971a).
[c]Based on sodium values for water.

Salinity in Livestock Drinking Water

Saline waters are usually found in arid areas and where seawater contaminates ground water. Ions commonly found in saline water are sodium, calcium, magnesium, chloride, bicarbonate and sulfate. Overall, it is evident form the literature that recommendations of salt concentrations in water that can be tolerated by the various species of domestic animals will vary with the kind, age, sex, lactation, exercise or work intensity, climatic conditions, type of diet and moisture content, salt in the diet, and chance for adaptation to total salt intake. Taking these factors into consideration the National Academy of Science (1974) presented guidelines as given in Table 4 for use of saline waters consumed by domestic animals.

Table 4

A GUIDE TO THE USE OF SALINE WATERS FOR LIVESTOCK AND POULTRY

Total Soluble Salts Content of Waters (mg/liter)	Comment
Less than 1,000	These waters have a relatively low level of salinity and should present no serious burden to any class of livestock or poultry.
1,000–2,999	These waters should be satisfactory for all classes of livestock and poultry. They may cause temporary and mild diarrhea, but should not affect their health or performance.
3,000–4,999	These waters should be satisfactory for livestock. They are poor waters for poultry, often causing watery feces and (at the higher levels of salinity) increased mortality and decreased growth, especially in turkeys.
5,000–6,999	These waters can be used with reasonable safety for dairy and beef cattle, sheep, swine, and horses. It may be well to avoid the use of those approaching the higher levels for pregnant or lactating animals. They are not acceptable waters for poultry.
7,000–10,000	These waters are unfit for poultry and probably for swine. Considerable risk may exist in using them for pregnant or lactating cows, horses, sheep and the young of these species.
More than 10,000	The risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

Toxic Elements and Substances in Drinking Water

Only limited information is available on experimentally determined toxic levels of substances in water for domestic animals. It is necessary to use good judgement when applying information in the literature to practical problems. No single level of potentially toxic substances can be accepted as dangerous in all situations. Short-term intakes of a toxic substance may have no effects; while consumption over the long-term may be hazardous. Young and healthy animals may react differently from mature or unthrifty ones. Intakes of toxic materials that may cause no effect on growth, milk production or reproduction may cause subcellular damage that may lead to greater susceptibility to disease. Finally, elements or substances in water that may not be toxic to the livestock consuming them may accumulate in meat, milk, or eggs at concentrations that are objectionable or harmful to people that eat them.

Many common elements occurring in water seldom offer any problems to domestic animals as they do not occur at high levels or because they are toxic only in excessive concentrations. Examples of these elements are aluminum, iron, boron, cobalt, copper, chromium, iodine, molybdenum, manganese and zinc. None of these elements tend to accumulate in milk, eggs or meat. However, elements such as mercury, lead, and cadmium do occur occasionally in drinking water at toxic levels to animals and accumulate in milk, eggs and meat at concentrations that make these foods unfit for human consumption.

The National Academy of Science (1974) presented the data in Table 5 summarizing the available research information on potentially toxic elements in water for livestock and poultry. The summary statements on the various elements can only serve as a guideline in evaluating the safety of a given level of the element in the drinking water of domestic animals.

Substances such as arsenic, cadmium, fluoride, lead, mercury, nitrate, nitrite and selenium may justify some additional discussion beyond the summary statements given in Table 5.

Arsenic has long been known for its toxicity and has been accused of being a carcinogen. Frost (1967) refuted this accusation and pointed out there was no evidence that 10 ppm of the element is toxic to any animal. McKee and Wolf (1963) recommended 1.0 mg/liter in drinking water as the upper limit for livestock.

Cadmium has been found in groundwater contaminated with electroplating wastes at 3.2 mg/liter and at 1,000 mg/liter in mine water (McKee and Wolf, 1963). Surface water rarely exceeded 10 μg cadmium per liter (Durum *et al.*, 1971). Rats that drank water containing 50 mg/liter of cadmium as $CdCl_2$ during 320 days had stunted growth and approximately a 50% decrease in hemoglobin (Decker *et al.*, 1958). Lambs given a choice of water that contained 0, 3, 5, 8, 12 and 15 μg/liter of cadmium as $CdCl_2$ consumed significantly more of the water that contained 12 μg/liter than the control water (Doyle and Pfender, 1974).

Fluoride has been reported in some groundwater to be as high as 15 mg/liter (Clarke and Clarke, 1967). Chronic fluoride poisoning of livestock has been observed at this level (Underwood, 1971). Mottling of the teeth without other physiological effects has been reported (N.A.S., 1974) in animals consuming water that contained 2 mg fluoride/liter.

Lead is tolerated better by pigs than by cattle (Link and Pansinger, 1966). Eight pigs consumed 11 to 66 mg/kg body weight of elemental lead in their feed without acute toxicity. Hammond and Aronson (1964) suggested that a chronically toxic daily dose of lead for cattle was 5 to 7 mg/kg body weight. They reported that lead tends to accumulate in tissues and was transferred to milk at hazardous levels for humans. The reviewers of lead in our environment (N.R.C., 1972b) concluded there was no evidence of a trend to greater concentrations of the element in natural waters.

Table 5

SUMMARY OF EFFECTS OF TOXIC LEVELS OF ELEMENTS AND SUBSTANCES IN WATER FOR LIVESTOCK, POULTRY, AND EXPERIMENTAL ANIMALS

Element	Concentration	Species	Effects
Antimony (Sb)	5 mg/liter	mice	decreased growth and longevity of females
Arsenic (As) (see discussion in text)	5 mg/liter	mice	survived through three generations
	1 mg/liter	guinea pigs	increased thyroidal colloid
Barium (Ba)	2 mg/liter	man	probably not toxic
Boron (B)	2 mg/liter	lambs	stated to be excessive
Cadmium (Cd) (see discussion in text)	10 mg/liter	mice	second generation didn't survive
	0.5 mg/liter	dogs	tissue concentration in proportion to intake
Calcium (Ca) (see section on nutrients)			
Chloride (Cl) (see section on salinity)			
Chromium (Cr)	25 mg Cr^{6+}/liter	rats	decreased water intake; 9 times more present in tissue than when Cr^{3+} substituted
	5 mg/liter	livestock	not affected adversely
Cobalt (Co)	1.1 mg/day/kg body weight in drench	calves	symptoms similar to Co deficiency
	160 mg/day in drench	sheep	depressed appetite; weight losses
Copper (Cu) (see discussion in text)	12 g $CuSo_4 \cdot 5H_2O$/day in drench	steers	body weight decrease; fatal in 65 days
Cyanide (CN)	103 mg HCN/liter	cows and ducks	fatal
Fluoride (F) (see discussion in text)	100 mg/liter	calves	decreased feed intake, growth and Ca absorption; bones decalcified
	11.8 mg/liter	cattle	mottled teeth
	20 mg/liter	sheep	decreased health; severe teeth mottling
Iodide (I) (no published data for toxicity in water, approximately same as in feed)			
Iron (Fe)	17 mg/liter	cattle	in pasture irrigation water scouring; decreased milk production and body weight
Lead (Pb) (see discussion in text)	100 mg/liter	calf	died after 4 months of drinking $Pb(NO_3)_2$
	25 mg/liter	rats and mice	reproduction ceases in second generation
Manganese (Mn)	500 mg/liter	cattle	reduced liver Fe but no toxicity
Mercury (Hg) (see discussion in text)	75-300 mg/liter	man	fatal
	30 μg/liter	man	readily absorbed into tissue
Molybdenum (Mo)	10 mg/liter	mice	3rd generation failed to survive
Nickel (Ni)	5 mg/liter	rats	reduced litter size through three generations
Nitrate (NO_3) (see discussion in text)	300 mg N/liter	sheep	no detrimental effect
	300 mg N/liter	pigs	no effect on weight gain or reproduction during two gestation periods
	90 mg N/liter	cattle	no observed harm with range cattle

Table 5 (continued)

Element	Concentration	Species	Effects
	300 mg N/liter	chicks	no effect on feed and water intake and growth
Nitrite (NO_2) (see discussion in text)	200 mg N/liter	chicks	decreased growth and liver vitamin A
	200 mg N/liter	laying hens	no effect on egg production and quality
	20 mg N/liter	rats	decrease life span slightly over 3 generations
Potassium (K); excesses not likely to occur in water; see section on nutrients.			
Selenium (Se) (see discussion in text)			
Se^{4+}	2-3 mg/liter	rats	decreased growth and early death of males
Se^{6+}	3 mg/liter	mice	third generation failed to survive
Sulfate (see discussion in text)			
S as SO_4^-	100 mg/liter	cattle	lost weight; decreased water intake 35%, feed intake by 30%
Vanadium (V)	5 mg/liter	mice and rats	no effect on longevity
Zinc (Zn)	675 mg/liter	human	emetic
	2,320 mg/liter	hens	decreased water intake; egg production stopped after 3 days; weight loss

Mercury is usually low in surface waters (Durum *et al.*, 1971) due to the tendency of the soluble inorganic element to be absorbed in sediment. However, biological methylation (N.A.S., 1974) slowly removes mercury from sediment as methylmercury. In this form it may be absorbed from drinking water by animals, accumulates in body tissues and is more toxic. Indirect poisoning by mercury retained in animal tissues and later consumed has been observed in man eating pork (Curley *et al.*, 1971) and fish (Uchida *et al.*, 1961). While mercury in water may not be of much concern for the health of livestock, the role of livestock as concentrators of mercury for man's diet needs consideration.

Nitrate may occur at hazardous levels in areas of septic tanks and high concentrations of domestic animals (N.R.C., 1972a). Nitrite in water was not correlated with livestock production nor with heavy fertilizer application except sand point wells in river flood plains (N.A.S., 1974). Beneath feedlots soil contains nitrogen and bacteria at depths of approximately 5 to 9 meters in some cases. Below this level the soil is generally sterile and the nitrate may be released at some point downstream.

Selenium is not likely to occur in potable water at levels that are toxic to livestock; and the role of selenium as a nutrient as well as a toxicant was recently summarized (N.R.C., 1971b).

Toxic algae: Cattle, sheep and poultry have been affected by accumulations of certain blue-green algae in lake waters (Fitch *et al.*, 1934). Corham (1960) recognized six species of algae as potential sources of livestock poisoning. Predeath symptoms have not been described in livestock poisonings and post mortem examination is of no help in diagnosis of algal poisoning (Fitch *et al.*, 1934). It can be concluded that water with heavy algal growth should best be avoided by livestock (N.A.S., 1974).

Pesticides: The use of pesticides presents a potential danger to livestock. They may enter water from soil runoff, accidental spills, direct application, rainfall and faulty disposal procedures (N.A.S., 1974). Schwartz *et al.* (1973) reported that 16 common pesticides did not effect rumen microbe digestion of dry matter and cell wall constituents *in vitro* when at levels below 100 ppm in the medium. Maximum concentrations of these pesticides in drinking waters have been found to be considerably below the LD_{50} doses for mammals, which indicates that the health of livestock is not threatened. However, their meat and products may be contaminated too much for human use (N.A.S., 1974).

Summary

Hardness, dissolved salts, color, turbidity, biological and chemical oxygen demand, taste and odor have been pointed out as important properties of drinking water. The nutrient mineral requirements and amounts supplied in drinking water for beef and dairy cattle, sheep and swine have been summarized.

Potentially toxic substances in the drinking water were summarized in regard to their effect in reproduction, growth, longevity and build-up in milk, eggs and edible tissues where data were available. Elements such as cobalt, copper, chromium, iron, manganese, molybdenum, iodide and zinc seldom cause problems in the drinking water of livestock.

Arsenic, nitrate and selenium while potentially hazardous have limited danger to livestock. Lead, mercury and cadmium due to their build-up in tissues and products of animal production to hazardous levels were discussed. The effects of high concentrations of various salts in saline waters were discussed in regard to tolerance of various classes of livestock. Only one toxin has been identified in toxic blue-green algae. Sudden decomposition of algal blooms often precedes livestock poisoning. Effects of pesticides in drinking water on animals and their products were discussed.

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CALCIUM, PHOSPHORUS AND FLUORINE IN ANIMAL NUTRITION

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Mineral elements make up only 4 to 6 percent of the body of a vertebrate animal, but because of their diverse roles in the body processes, they are important in the entire field of nutritional biochemistry. The major or macro mineral elements essential for physiological processes in animals are calcium, phosphorus, potassium, sulfur, sodium, chlorine and magnesium. The required minor or trace elements are iron, zinc, copper, iodine, manganese and cobalt. The list of essential elements is now usually expanded to include molybdenum, selenium and fluorine.

In addition to the elements known to be required by livestock, an animal's body may contain as many as 20 to 30 additional different elements. Most of these are believed to be acquired merely by the process of accumulation in bones and other tissues due to their contamination or presence in the feedstuffs eaten by animals. There is growing evidence, however, that such elements as aluminum, silicon, vanadium, chromium and others will be found essential to biochemical processes in animal nutrition. For example, zinc, thought to be a contaminant only a very few years ago, is now known to be essential. Minerals play a unique role in nutrition because they furnish no energy or protein, but yet they are essential for the utilization of energy and protein and for the biosynthesis of essential nutrients.

Much more emphasis is being placed on mineral fortification of feeds today than ever before. Some of the major factors which have brought about this increased need of mineral fortification in animal diets are:

1) Changes in methods of processing feedstuffs.
2) Increased milk production levels in dairy cattle.
3) The advent of high energy feeds.
4) Greater genetic potential in today's livestock.
5) A greater use of synthetic ingredients and less use of animal by-products which were good sources of mineral elements.
6) The use of computers that place increasing pressure on mineral levels.
7) Crop fertilization practices.
8) The complex interaction of the various mineral elements.

Calcium and phosphorus are vitally concerned with not only bone development, growth, and productivity, but with essentially all important metabolic processes. These two elements are very closely related—to the extent that a deficiency or an over-abundance of one may very likely interfere with the proper utilization of the other. It is important, therefore, that rations be formulated, or free-choice minerals be provided in a manner that will insure optimum amounts of these two elements if they are to be most effective.

The term "optimum Calcium and Phosphorus nutrition" takes several points for granted: (1) that all animals will receive adequate amounts of calcium, phosphorus, and other mineral elements in their rations, (2) that the minerals are in forms that are biologically useful to animals, (3) that the elements are present at levels that are compatible with other minerals to provide proper ratios, and (4) that vitamins, protein, energy, and other nutrients are provided in sufficient quantity so that minerals may be efficiently utilized.

It may seem strange that research continues at such a rapid pace on calcium and phosphorus requirements and interactions for animals, since these elements have been studied rather extensively for the last 60 years. The answer is, of course, that little of our information remains unchanged. Every time a new factor is found, or when a new nutritional fact is discovered, it becomes necessary to re-establish the requirements for calcium and phosphorus, as well as for most other nutrients.

Calcium

Calcium is the most abundant mineral element found in the animal body with about 99 percent of the calcium found in the bones and teeth and the remaining 1 percent widely distributed in various soft tissues of the body. On a total basis, immature cattle contain about 1.6% of calcium and mature cattle about 1 percent (Smith, 1965).

Calcium plays an important role in a wide variety of essential functions in body metabolism (Beeson *et al.*, 1975). A few of the most important functions of calcium are as follows:

1. Essential for bones formation and maintenance.
2. Important in teeth development and maintenance.
3. Required for normal blood clotting. Calcium must be present for prothrombin to form thrombin. Thrombin reacts with fibrinogen to form the blood clot, fibrin.
4. Necessary for contraction of skeletal, cardiac and smooth muscle.
5. Enhances transmission of nerve impulses to maintain normal neuro-muscular excitability.
6. Important in the regulation of the heartbeat along with potassium and sodium ions.
7. Calcium can act either as an activator or stabilizer of enzymes.
8. Calcium has been shown to be necessary for the secretion of a number of hormones and hormone-releasing factors.
9. Essential for normal milk secretion.

There are many factors which influence the utilization and metabolism of calcium in the animal body. Some of the more important factors which affect calcium utilization in cattle are as follows:

1. Adequate levels of calcium and phosphorus to meet the daily requirement.
2. Ratio of calcium to phosphorus.
3. Proper level of vitamin D_2 or D_3. In the absence of vitamin D, calcium absorption and utilization are decreased.
4. Parathyroid hormone regulates the level of calcium in the blood.
5. Thyrocalcitonin from the thyroid gland has a depressing effect on blood calcium by decreasing calcium absorption and reduction in mobilization of calcium from the bone.
6. Biological availability of calcium varies from different feed sources.
7. Age of the animal. Young cattle use calcium more efficiently than mature cattle.

Clinical symptoms of a calcium deficiency characterized by rickets and osteomalacia do not occur too frequently in cattle because of the long period that calves are on milk and the high-roughage diets that are ordinarily fed to pregnant and lactating cows. A calcium deficiency occurs most frequently in beef animals on high-energy grain rations and is manifested by decreased gain, poor digestibility of nutrients, low blood calcium, brittle bones and in some cases tetany.

Rickets is an abnormal metabolism or calcification of the bones in young growing calves which may be caused by a deficiency of calcium, phosphorus or vitamin D. Calcium and phosphorus are not deposited in the organic cartilaginous matrix in sufficient quantities to develop a strong, dense bone. Calcium and/or phosphorus content of the blood is

lowered and there is an increase of phosphatase in the plasma. In a specific calcium deficiency, the blood calcium is lowered more than the blood phosphorus although both may be involved due to their close interrelationship. For clarity, the terms low-calcium rickets or low-phosphorus rickets should be used. Gross symptoms of rickets are manifested by swollen tender joints, enlargement of ends of bones, beading of ribs, arched back and stiffness of legs. Prolonged cases of rickets will result in structural abnormalities such as buckled knees, bowed legs and crooked fore or hind legs. The weight of the body and tension of the growing muscles pull the weakened, soft bones out of shape.

Osteomalacia is a term which describes a decrease in the mineral content of adult bone which is due to a lack of adequate calcium and/or phosphorus in the diet. Even when bone is mature and stops growing, there is a continuous mobilization of calcium and phosphorus which must be replaced to prevent weakening of the bone structure. During pregnancy and lactation which are periods of high calcium and phorphorus demands, there is a depletion of the mineral content of bone and the calcium and phosphorus must be replaced during non-pregnancy and dry periods in cows. A continual depletion of the calcium and phosphorus content of adult bone will lead to weak and brittle bones which may break accidentally under external pressure.

Phosphorus

Phosphorus contributes about 1% of the total weight of an animal's body, but unlike calcium, only about 80% of the total quantity is found in the bones. But because of this magnitude, it is a very important function in bone formation. The remaining 20% is distributed throughout the body in every living cell, and performs a host of functions. It is involved in almost all, if not all, metabolic reactions (Church, 1971).

From a metabolic point of view, phosphorus is probably the most versatile of the mineral nutrients. In addition to its important contribution to the skeletal tissues, phosphorus occupies a very important role in various aspects of absorption and energy metabolism. Carbohydrates such as glucose are absorbed through the intestinal mucosal tissues as phosphorylated compounds. Phospholipids are believed to be the chief means by which fatty acids are transported throughout the body. Phosphorylated compounds such as glucose-6-phosphate and triose-phosphate are vital intermediates to the glycolysis scheme of energy metabolism. Energy transfer occurs by way of high-energy phosphate bonds found in such compounds as adenosine triphosphate and creatine phosphate. Phosphorus is also found in nucleic acids present in the cells. Other functions include those such as buffering activity and formation of soluble complexes with cations. Obviously, phosphorus is involved in a host of functions vital to life.

In ruminant animals phosphorus is an extremely important element for the proper metabolism and health of the rumen microflora. For ruminants, then, two phosphorus requirements must actually be considered—one for the animal itself and one for rumen microorganisms.

Phosphorus deficiency appears to be a wide-spread problem throughout the world. Most of the forage that ruminants consume is little more than adequate in phosphorus content and weathered, leached forage is nearly always borderline or deficient in phosphorus. Consequently, phosphorus is usually one of the most limiting of the mineral nutrients for ruminants in many situations.

Usually, the first evidence of phosphorus deficiency is a drop in plasma inorganic phosphorus below the normal levels (4-6 mg/100 ml for adults; 6-8 mg/100 ml for young animals). Plasma phosphatase values increase. The mineral content of the bones becomes depleted and the bones become fragile. Another result of a phosphorus deficiency is that the joints become stiff, lameness may develop and fractures may occur.

Anorexia (reduced appetite) is the first clinical symptom of phosphorus deficiency, but it is not specific for a phosphorus deficiency, of course. Most animals develop pica (a depraved appetite) in which case they will chew and ingest articles such as rocks, dirt, wood, bones, or hair. Pica is not specific for phosphorus either, since it may occur with a Na or K deficiency. Less drastic deficiencies result in a listless appearance and a dull, dry hair coat. A phosphorus deficiency may also interfere with the utilization of vitamin A and, in young, growing animals, teeth as well as bones will be less dense and less completely mineralized.

Gain or milk production will be reduced in phosphorus-deficient animals; fertility is apt to be reduced in females (Morrow, 1969; Jakovac *et al.*, 1968). Both of these papers indicate that fertility of dairy cows was markedly reduced when deficient in phosphorus. Supplementation with phosphorus resulted in prompt recovery of blood phosphorus levels and a restoration of normal fertility.

Problems associated with phosphorus deficiency in range cattle include:

1. Lowered conception rates and smaller calf crops.
2. More difficult calving.
3. Lowered milk supply and a consequent lowered weaning weight of calves.
4. Reduced growth and size at a given age.
5. Poor appearance.

Other phosphorus deficiency symptoms include: loss of body fluids, poor feed efficiency, lowered resistance to infectious diseases, and low phosphorus rickets.

As a matter of interest, some common sources of supplemental Ca and P are shown here:

COMMON SOURCES OF CALCIUM AND PHOSPHORUS

Source	Percentage of Element	
	Ca	P
Limestone	38	–
Calcite grit	34	–
Oyster shell	38	–
Calcium sulfate	23	–
Dicalcium phosphate	24 – 26	18 – 22
Dicalcium-Monocalcium phosphates	16 – 23	18.5 – 23
Defluorinated phosphate	30 – 36	14 – 18
Bone meal, steamed	23 – 26	8 – 18
Fish meal, all types	2 – 14	2 – 7
Fish meal, menhaden	4.5 – 7.5	1 – 4.5
Meat and bone scraps	9 – 14	3 – 7.5
Meat meal	1 – 14	0.5 – 9
Ammonium phosphates	–	20 – 24
Sodium phosphates	–	20 – 25

Biological Availability

Biological availability studies make up a large share of the research that is being reported on calcium and phosphorus nutrition. This is to be expected, however, in view of the critical role that these two elements play in animal feeds. Furthermore, phosphorus certainly is not the least expensive item in a feed formula. Therefore, it is important in the formulation of feeds to ensure that the proper levels of biologically available calcium and phosphorus are provided for the various ages and classes of livestock, keeping in mind the costs for optimum performance. A summary of these studies is presented in the paper on biological availability of major mineral elements which is included in this proceedings.

Calcium to Phosphorus Ratio

It has been known for over 50 years that an interrelationship exists between calcium and phosphorus. The desirable calcium phosphorus ratio has been defined as one lying between 2:1 and 1:2; however, a large number of nutritionists have for years believed that adequate nutrition is possible outside these limits. In fact, reports are found in the literature that ratios as wide as 4, 5 and even 7 calcium to 1 phosphorus, have not produced noticeable ill effects in ruminants. In spite of these beliefs and reports, the calcium to phosphorus ratios recommended for the various species of livestock by the National Research Council are narrow—more nearly a 1:1 ratio.

For young calves and growing stock, the NRC recommends a calcium to phosphorus ratio of about 1.4 parts calcium to 1 part phosphorus. As cattle grow older and their skeletons are more developed, the calcium requirement is reduced slightly while the phosphorus demand increases. This is due to larger body size as about 20% of the phosphorus is located in the body tissues and fluids. It is recommended by the NRC that mature animals have a 1.1 to 1 calcium to phosphorus ratio in their daily ration. With cows nursing calves the ratio should approximate 1.3 parts calcium to 1 part phosphorus, due to the heavy lactation demand on calcium.

One interesting and important area is the relationship of calcium and phosphorus to Milk Fever. Over the years, no single disease in dairy cattle has drawn so much continuous interest as milk fever, and for good reason. As productivity in herds is increased, the incidence of milk fever tends to increase. It is a metabolic disorder that can have serious economic consequences and be disastrous if not properly handled.

As early as 1925 (Little and Wright), it was proposed that milk fever resulted from a rapid loss of calcium from the blood stream to the mammary glands due probably to parathyroid dysfunction. In 1954 Boda and Cole at the University of California were able to prevent milk fever from developing by feeding dairy cattle a very low calcium, high phosphorus ration for approximately one month before parturition. They speculated that their technique was successful because the low calcium, high phosphorus ration placed a strong demand on the parathyroid gland to keep it active so that at calving time sufficient amounts of the regulating hormone would be available to mobilize calcium rapidly enough to satisfy the demands of the mammary gland and also to maintain adequate blood levels of calcium.

Dr. G. H. Stott of the University of Arizona showed that complete parathyroidectomy of lactating and parturient dairy cows did not bring on milk fever, thus exploding the parathyroid hormone deficiency theory. Data now indicates that the parathyroid gland is active in affected cows, but part of the problem appears to be due to the production and possibly the sudden release of thyrocalcitonin from the thyroid gland (Care, 1969). This hormone acts to depress blood calcium. At any rate, the affected cow has a severe metabolic deficiency of calcium and, usually, phosphorus.

It has been confirmed by several workers (Goings *et al.*, 1973; Boda *et al.*, 1954; Wiggers *et al.*, 1975) that the feeding of rations with a low calcium-high phosphorus ratio (1:1 to 1:3) with adequate phosphorus to preparturient cows will prevent milk fever most of the time.

Requirements for Calcium and Phosphorus

Beef Cattle. The recommended phosphorus content of the rations of beef cattle appear to be gradually increasing whereas calcium levels have not changed appreciably. This is especially true of fattening cattle in feedlots.

Range cattle in certain areas depend heavily on native vegetation for a large share of their phosphorus and calcium needs. In many types of vegetation the calcium level will remain relatively high throughout the year, but phosphorus may be easily leached out, and by mid-winter as much as 85% of the phosphorus content may be lost. In addition to the lowered phosphorus content of these plants, the phosphorus remaining in mature, weathered forage is usually not as well utilized because much of it is bound in the phytin form.

Publications have also pointed out the importance of considering the phosphorus requirements of the microflora in the rumen if maximum gains and feed efficiencies are to be obtained. A healthy, efficiently functioning rumen is one of the keys to the efficient feeding of ruminants.

Suggested levels of calcium and phosphorus for various classes and weights of beef cattle are shown here. NRC recommendations are also presented:

CALCIUM AND PHOSPHORUS LEVELS EXPRESSED AS PERCENT OF RATION DRY MATTER FOR BEEF CATTLE

NRC—Revised 1970

	% Phosphorus		% Calcium	
	Initial	Final	Initial	Final
Fattening Calves	0.43	0.22	0.60	0.22
Fattening Yearlings	0.28	0.22	0.40	0.23
Fattening 2-year olds	0.22	0.22	0.29	0.22
Wintering Pregnant Heifers and Cows	0.18	0.18	0.18	0.16
Growing Heifers and Steers	0.43	0.18	0.60	0.18
Cows Nursing Calves	0.23	0.22	0.29	0.27
Bulls	0.21	0.18	0.29	0.18

VALUES COMMONLY USED IN COMMERCIAL BEEF FEEDS

	% Phosphorus	% Calcium
Growing Beef Calves	0.40	0.60
Fattening Calves	0.35	0.45
Feedlot Cattle (High Energy)	0.30-0.35	0.40-0.45
Lactating Cows and Heifers	0.30	0.35

Dairy Cattle. Dairy cattle should be provided relatively high levels of phosphorus on a continuous basis because of, a) the relatively high endogenous loss in the feces, b) the relatively low true absorption of phosphorus, c) and the relatively high level of phosphorus in milk. Regardless of the dietary supply of phosphorus, its concentration in milk remains quite constant. Therefore, if adequate dietary levels are not provided, the milk yield will shrink to that volume which can be secreted from the amount of phosphorus the cow can obtain from her diet and bone stores.

Unlike that for calcium, there is no direct mobilizing mechanism for phosphorus. Since these two elements are combined in bone, the mobilization of calcium as a result of the parathyroid glands is accompanied by the incidental mobilization of phosphorus. Because of this and except during early lactation when calcium is being mobilized very actively, the cow depends on a meal-to-meal supply of phosphorus. Even though the bones stores of phosphorus are large, an inadequate supply may lead quickly to biochemical and structural disturbances.

CALCIUM AND PHOSPHORUS LEVELS EXPRESSED AS PERCENT OF RATION DRY MATTER FOR DAIRY HEIFERS AND BULLS

NRC—Revised 1971

	% Phosphorus		% Calcium	
	Initial	Final	Initial	Final
Growing Dairy Heifers	0.42	0.26	0.55	0.34
Growing Dairy Bulls	0.37	0.18	0.48	0.24

CALCIUM AND PHOSPHORUS REQUIREMENTS OF DAIRY COWS
(NRC Revised 1971)

Body Weight Kg	Calcium (g/day)	Calcium (%)	Phosphorus (g/day)	Phosphorus (%)
Maintenance of Mature Cows				
350	14	.30	11	.23
400	17	.30	13	.23
450	18	.30	14	.23
500	20	.30	15	.23
550	21	.30	16	.23
600	22	.29	17	.23
650	23	.29	18	.22
700	25	.29	19	.22
750	26	.29	20	.22
800	27	.28	21	.22
Maintenance and Pregnancy (Last 2 to 3 Months of Gestation)				
450	26	.33	20	.25
550	31	.33	24	.26
700	39	.34	30	.26
Lactation (Added to Requirements for Growth or Maintenance)*				
	% Fat	(g/Kg Milk)	(g/Kg Milk)	
	3.0	2.5	1.8	
	4.0	2.7	2.0	
	5.0	2.9	2.2	

*Add to figures for growth rather than maintenance if heifers are still growing.

Complete dairy feeds are becoming more commonplace and there is interest in the levels of calcium and phosphorus required to adequately balance these rations for high producing cows. Based on the 1971 Revised NRC values, a 550 Kg non-pregnant cow milking 45.5 Kg of 4% fat milk per day would need to consume 127 grams of calcium and 95 grams of phosphorus daily. If she consumes 20.5 Kg of dry total ration containing 0.72% calcium and 0.54% phosphorus (Ca:P 1.3:1) she will just meet NRC standards.

Fluorine

An excellent review of the effects of fluoride in animals has been published by the National Research Council (1974). Animals normally ingest low levels of fluoride without adverse effects. Fluoride in small amounts may be beneficial and appear to be essential in some species. When excessive amounts are assimilated, adverse effects are induced. The fluorine levels of common uncontaminated feed materials are too low to constitute a fluorine hazard to livestock. The ingestion of toxic or potentially toxic amounts of fluorine by farm animals occurs most commonly under the following circumstances:

a. In areas where the drinking water is naturally high in fluoride this is known as indemic fluorosis and usually results in chronic rather than acute fluorine intoxication.
b. When the animal's diet is supplemented with fluorine bearing minerals as a source of extra calcium and phosphorus.
c. In restricted areas adjacent to industrial plants or mines which result in the omission of fluorine fumes or fluoride dust which contaminate the soil and the herbage and water consumed by the animals.

Changes in the teeth are the earliest evidence of the ingestion by livestock of fluorine in amounts in excess of the capacity of the body for prompt elimination. Mild dental fluorosis of itself may be of negligible economic importance but it is probable that it is qualitatively indicative of undesirable metabolic disarrangement.

An animal offered a fluorine containing ration has four ways of trying to keep the fluorine out of the blood and soft tissues. Some of the fluorine ingested will be unabsorbed and voided in the feces—some will be filtered out by the kidneys and eliminated in the urine—some will be synthesized in the bone and tooth tissues and finally through reduced food consumption, the animal can reduce its fluorine intake. Other than the effect on the teeth then, the first symtoms of excessive fluorine intake is reduced appetite or feed intake. It follows then, that along with this lowered feed intake, a reduction in body weight gain and progressively poor physical condition results.

Fluorine is a "accumulative poison" and for this reason, it is not only the level of ingestion but the time period over which the ingestion takes place that is important. This is especially true as we look at some of the chronic affects. The ingestion of toxic amounts of fluorides for an extended period will result in the development of bone lesions. This, in

some cases, results in a general thickening of bones and when examined closely, they appear chalky white on the surface and very rough and porous as compared with a normal hard smooth bone. Animals suffering from fluoride toxicity usually exhibit generalized stiffness and lameness. This is probably attributable to the fact that as the condition advances there is calcification on the ligaments, especially at the point of attachment to the bones.

There are specie differences with regards to resistance to fluoride toxicity. Swine and poultry are more resistant to fluoride toxicity than most other animals. The order of tolerance is as follows with the least tolerant species listed first:

Dairy Cow
Beef Cow
Sheep
Swine
Chickens
Turkeys

Factors that influence fluoride toxicity in animals include:

- amount of fluoride ingested,
- duration of ingestion,
- fluctuations in fluoride intake with time,
- solubility of fluoride ingested,
- species of animal involved,
- age at time of ingestion,
- general level of nutrition,
- stress factors, and
- individual biologic response.

A summary table of tolerable dietary fluorine levels for the various animal species is attached.

The North American feed industry and organizations (Association of American Feed Control Officials) which control the industry have set up certain standards relating to fluorine in animal feeds. Section 7 of the Uniform State Feed Bill (AAFCO, 1975) states that: a commercial feed shall be deemed to be adulterated: (a)(1) if it bears or contains any "poisonous or deleterious substance" which may render it injurious to health... For the purpose of Section 7(a)(1) of the Uniform Feed Bill, the terms "poisonous or deleterious substances" include but are not limited to the following:

1. Fluorine and any mineral or mineral mixture which is to be used directly for the feeding of domestic animals and in which the fluorine exceeds 0.30% for cattle; 0.35% for sheep; 0.45% for swine; and 0.60% for poultry.
2. Fluorine bearing ingredients when used in amounts that they raise the fluorine content of the total ration above the following amounts:

   0.009% for cattle; 0.01% for sheep; 0.014% for swine; and 0.035% for poultry.

SUGGESTED FLUORINE TOLERANCES FOR ANIMALS[a]

(These levels are based on the assumption that the animals receive an otherwise adequate diet.)

Animal	Tolerance Level (NRC) (Diet F ppm)	Definitely Unsafe (Diet F ppm)
Breeding Animals		
Beef or dairy calves[b]	—	40 and above
Beef or dairy heifers[c]	30-40	50 and above
Mature beef or dairy cattle[d]	40-50	60 and above
Ewes	60	70 and above
Horses	40-60	80 and above
Sows	100-150	160 and above
Laying hens	400	440 and above
Growing dogs	50-100	120 and above
Animals to be Slaughtered		
Beef or dairy calves[b]	35	65 and above
Beef or dairy heifers[c]	50	80 and above
Growing chickens (broilers)	300	340 and above
Mature beef or dairy cows[d]	100	120 and above
Feeder lambs	150	170 and above
Finishing pigs	150	200 and above

[a]The values presented assume the ingestion of a soluble fluoride, such as NaF. When the fluoride in the ration is present in the form of dicalcium phosphate, these tolerances may be increased by approximately 50%.

[b]Calves up to 4 months of age.

[c]Heifers 4 months to 2 years of age.

[d]Cattle 3 years of age or older.

In addition, as part of specific definitions, the term "defluorinated" cannot be used as the part of the name of any product containing more than one part of fluorine to one hundred parts of phosphorus. Quality feed phosphates meet this restriction.

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SODIUM AND CHLORINE REQUIREMENTS OF RUMINANTS

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The value of common salt (NaCl) for man and his animals undoubtedly was recognized before recorded history. The earliest records list salt as an important item of trade along with spices and clothing. The strong craving for salt exhibited by grazing animals under most natural conditions could not have gone unnoticed by the earliest herders. It appears, however, that only in the present century has the detailed role of salt been recognized.

Sodium and Chlorine are Essential Elements

Sodium and chlorine, along with potassium, function in maintaining osmotic pressure, regulating acid-base equilibrium and controlling water metabolism in the body tissues. They help control the passage of nutrients into the cells and waste products out. Sodium occurs largely in the extracellular fluids and it makes up 93% of the bases of the blood serum, but is not present in the blood cells. Chlorine is found both within the cells and in body fluids. The gastric secretion contains chlorine as HCl and in the form of salts.

Sodium and chlorine (NaCl) are dietary essential elements. Animals need to receive a regular supply in the diet because there is limited body storage capacity, any excess consumed being rapidly excreted in the urine. Salt is also lost in the perspiration. When the animal is deprived of NaCl it is able to conserve the limited body reserves by largely eliminating urinary losses. Even after prolonged severe deficiency neither blood levels of NaCl nor the amounts secreted in the milk decrease. Thus lactating animals suffer most from the lack of salt in the diet.

Babcock (1905) was apparently the first to report the effects of salt (NaCl) deprivation on lactating dairy cows. After 2 to 3 weeks without salt, cows exhibited an abnormal appetite for it, but up to a year elapsed before any ill effect on health was noted. Eventually there was loss of appetite, unthriftiness and marked decline in body weight and milk yield. These signs occurred first in high producers, and breakdown was seen most frequently at calving or shortly after at the peak of milk flow. Feeding produced rapid recovery.

Smith and Aines (1959) repeated and expanded the study with higher producing dairy cows. They found that the sodium and chlorine levels in the blood remained unchanged in cows receiving no salt, but the urine content dropped almost to zero within a month. The sodium and chlorine of milk remained unchanged. Highest producing cows showed symptoms first and continued to secrete milk until they actually died of the deficiency, while others ceased lactating and gradually improved in condition even without receiving salt. Some of these were rebred, conceived and produced normal calves, but broke down again at the next calving. The calves were all normal at birth. The primary deficiency was shown to be sodium (Na). Feeding NaCl or Na_2CO_3 effected rapid recovery, but potassium chloride (KCl) did not bring about improvement.

In a later study (Kemp and Geurink, 1966) high producing black and white cows became sodium deficient in about 4 months on a diet of hay and concentrates with 0.05% sodium with adequate chlorine in the dry matter. Sodium excretion in the urine was 10 to 26g per day before depletion and this fell to 0.19 to 0.50g. Sodium in the saliva and rumen fluid declined and potassium levels increased. After 2 months sodium reserve in the rumen had fallen from about 200 to 100g and clinical signs were noted, including reduced feed intake and milk yield and salt hunger. Cows fed 38g supplemental sodium excreted 2.5 to 3.0g daily. Deficiency did not appear when the saliva contained more than 3g sodium and less than 0.5g potassium per liter, while serious deficiency appeared with sodium less than 1.5g and potassium more than 2.5g per liter of saliva.

Even though it has been known for some 200 years that HCl is present in gastric juice and that chlorine is critical for maintaining acid-base equilibrium in body fluids and thus is an essential dietary element, the experimental rat is the only animal in which a deficiency has been produced. A recognized chlorine deficiency has not been reported in ruminants even though many forages are very low in chlorine.

In Southern Africa du Toit *et al.* (1934) suggested there was little chance of chlorine deficiency occurring, but that sodium deficiency might limit performance in the dry season when herbage was mature. Smith and Aines (1959) confirmed this view in showing that sodium alone without chlorine will correct the deficiency in salt deprived cows. Thus it appears that the requirement for chlorine is lower than for sodium or that the body is able to conserve and recycle chlorine much more efficiently than sodium. Sodium is the principle limiting element supplied by salt and not chlorine.

Supplemental Salt for Ruminants

It is now recognized that sodium deficiency can greatly decrease productivity of beef cattle. The deficiency is best characterized by a decline in sodium concentration in the saliva and urine and an increase in the potassium levels in these fluids. Murphy and Connell (1970) reported a simple method of collecting saliva for analyses which has proved useful in determining the sodium requirements of animals and distinguishing between a simple lack of salt and other limitations to production.

Earlier studies measured animal performance as to the only indicator of the necessity to add supplements. After reviewing the published research it is clear why many questions remain about the desirability of providing supplemental salt for grazing ruminants especially in the tropics. Du Toit *et al.* (1934) suggest the growth requirements of cattle could be met by forage containing 0.02% Na and 0.07% Cl in the dry matter. Suitable forage should contain 0.15% Na and 0.19% Cl. In Nigeria, Anderson observed that pica symptoms in cattle grazing forage containing 0.26% Na in the dry matter were cured by feeding more NaCl. He suggested the salt requirements of cattle were increased in hot semiarid countries (Rhodes, 1956).

Tests in Rhodesia (Husband, 1933, 1938) showed that feeding salt alone, salt and iron, or salt, iron and bonemeal resulted in improvement in appetite and general condition of cows grazing native or fertilized pastures and the suckling calves grew faster suggesting increased milk yields. In contrast Murray and Romyn (1936) observed no effect from supplements of salt, bonemeal of dicalcium phosphate in preventing weight loss in the dry season or increasing rainy season gains of growing cattle in Southern Rhodesia, but feeding as little as 0.12 Kg of digestible protein to supplement the low-protein dry-season forage improved performance.

Rhodes (1956) reviewed some of the early observations in Africa on feeding mineral supplements to cattle and reported the results of his research in Rhodesia. Yearling steers studied over a 3-year period gained more weight during the dry seasons on a supplement of peanut meal (0.68 Kg/day) than on cornmeal, salt or bonemeal. During the rainy season, salt stimulated growth the most. A combination of protein in the dry season and minerals throughout the year tested in a second study with weanling steers resulted in appreciably greater gains than either supplement alone. However, the response to minerals alone was greater than to peanut meal. In a third trial, Africander type native cattle showed no response to salt supplements, in contrast to the results in the first two tests using European breeds of cattle. High temperature was not a problem in these studies carried out in the higher elevations of Rhodesia.

Walker (1957) studied the effects of supplements of salt or protein during the dry seasons over a 4-year growing period in Northern Rhodesia at an altitude of about 1000 meters using 135 Kg native weaned steers 6 to 7 months old. The 6 to 7 months dry season occurs between March and November and the crude protein content of the natural forages declines from 4.5% to 0.68% during this period. The control steers (Table 1) provided only native grazing gained weight during the rainy season, but failed to gain and generally lost weight during the dry season. The group fed orally 28g of salt per day throughout the year gained more rapidly than the controls in the rainy season on flush pasture and maintained body weight during the dry season. Skeletal growth continued throughout the year. Feeding 0.68 Kg of peanut meal per day did not improve weight gains above the control steers but skeletal growth occurred and protein plus salt was only slightly better than salt alone. Feeding 57g salt per day was excessive since those steers performed only slightly better than the controls on grazing alone. Note that the steers were about 5 years old before reaching 500 Kg with the supplements and the controls would have needed at least another year to reach that weight.

This very slow growth is still typical of many of the cattle produced in tropical Africa today. While feeding salt is beneficial and French (1955) stated that sodium was the most needed nutrient, cattle really need more and better quality feed throughout the year except during the early rainy season, to allow satisfactory growth and reproduction.

Recent experiments have used new chemical methods to relate the sodium content of forages and saliva of cattle to their responses to supplements in Australia.

Playne (1970) surveyed the sodium content of eight grass and legume pasture species in the Townsville, Australia district. Several common pasture species contained < 0.05% Na in the dry matter. It was concluded that sodium deficiency symptoms could occur in grazing stock under certain conditions.

Table 1

EFFECTS OF SUPPLEMENTS ON GROWTH OF STEERS

Year and Season		Live weights, end of season, Kg		
		Control	28g Salt	Peanut meal + Salt
1952	Initial	132	131	131
1953	Rainy	197	220	224
	Dry	204	232	232
1954	Rainy	297	322	330
	Dry	286	313	326
1955	Rainy	371	422	428
	Dry	356	397	429
1956	Slaughter	424	501	516
	Total gain	292	370	385

Murphy and Plasto (1973) reported that Hereford cattle became salt deficient while grazing native pasture on the eastern Darling Downs, Queensland, Australia. Feeding NaCl free choice increased weight gain of cows from 0.14 to 0.25 Kg per day and gain of the suckling calves from 0.62 for the deficient group to 0.77 Kg per day for the salt supplemented group. Saliva sodium and potassium were 60.2 and 71.7 mequiv./liter for the deficient vs 139.1 and 7.4 mequiv./liter, for the salt-fed cows. Blood and milk sodium and potassium levels were not altered, but urinary levels were changed by the treatments.

Gartner and Murphy (1974) observed that steers and cows with calves grazing *Panicum maximum* (Coloniao) pastures (sodium concentration of 0.18%) or *Cynodon dactylon/Paspalum dilatatum* (0.115 to 0.7% sodium) in Queensland, for 72 days did not exhibit any differences in performance, even though on Coloniao saliva sodium declined markedly and potassium increased. The values remained at normal levels on the *Cynodon/Paspalum* grazing. The sodium content of the milk did not change the suckling calves made normal gains. The short grazing trial and the weight losses by cows and steers may explain the failure to show deficiency signs even though the Coloniao was too low to meet the sodium needs for equilibrium.

Sodium Requirements of Cattle

Smith and Aines (1959) calculated that lactating cows need about 30g NaCl (21g Na) per day for the production of 20 Kg of milk. They fed 15 or 60g NaCl per day and the feed contained 8 to 15g per day, so the cows on 15g NaCl were getting 14 to 20g Na and those on 60g NaCl were getting 32 to 39g Na. The lower level was inadequate for best responses.

Steers fed an all-sorghum grain diet deficient in sodium (0.033% or 0.13g/day) gained less than steers receiving 0.06% (3.1g/day) or larger amounts (up to 0.2%, 11.4g/day). The sodium requirement was not more than 0.06% of the dry matter or 3.1g/day for the 300 Kg steers studied, based on feed intakes, weight gain, and concentration of sodium and potassium in parotid saliva and rumen fluid. Urinary sodium excretion rose as the intake was increased (Morris and Gartner, 1971). The results are illustrated in Table 2.

Table 2

RESPONSES OF STEERS FED AN ALL-SORGHUM DIET AND DIFFERENT SODIUM INTAKES

		Sodium Intake			
	g/day	0.13	3.1	6.0	11.4
	% DM	0.003	0.06	0.11	0.2
Feed intake	Kg/day	4.50	5.54	5.31	5.69
Daily gain	Kg/day	0.59	0.93	0.89	0.97
Final weight	Kg	311	341	340	356
Saliva	Na	60.4	152.2	144.7	145.8
m-eq./L	K	80.8	7.1	7.0	7.4
Rumen fluid	Na	51	120	126	122
m-eq./L	K	48	24	27	23
Urine	Na	2.8	12.9	22.0	38.8
m-eq./L	K	38.[illegible]	40.8	39.7	60.1

Morris and Murphy (1972) depleted beef calves of sodium reserves on a sorghum grain-soybean meal diet, then fed graded levels of sodium bicarbonate to study performance during 52 days repletion. From a consideration of feed intake, body weight gain, and salivary concentration of sodium and potassium it was concluded that for 80 to 110 Kg calves gaining 0.6 Kg per day the minimum sodium requirement was about 2.3g per day, 1.2g was clearly deficient and and 3.4g per day is probably more than adequate.

Sodium Requirement of Sheep

Morris and Peterson (1975) utilized the Na:K ratio of parotid saliva to estimate the sodium requirements of lactating ewes. The basal diet of rice straw, sorghum grain, soybean meal, minerals and vitamins contained 0.016% sodium and 1.1% potassium. It was supplemented with sodium bicarbonate at levels to supply from 0 to 2290 mg of Na per Kg of dry matter. A level of 870 mg/Kg of diet dry matter was considered adequate. Level of sodium supplementation did not affect sodium or potassium concentrations in the ewe's milk (19.8 ± 1.2 and 26.9 ± 0.7 meq/1, resp.). McClymont *et al.* (1957) reported mg/kg diet (0.9 g Na/day).

Hagsten and Perry (1975) depleted lambs on a low-sodium diet (0.012% Na) for several months until daily gains declined from about 0.3 kg to <0.1 kg. Plasma sodium did not decline appreciably during depletion nor increase during repletion, but remained at about 3300 ppm. Urinary excretion declined to a low level after 3 weeks depletion. Repletion by oral administration of salt solution which supplied sodium at 0.08% or more of the dry matter consumed caused large urinary excretion. In another study these researchers utilized daily drenching of lambs fed a salt-low diet to estimate that the salt requirement for growth was 0.38% of the dry matter. In a feedlot study the sodium chloride requirement was 0.39%. On this basis, the sodium requirement would be 0.10% of the dry matter intake of growing lambs. Low salt intakes decreased feed efficiency 26%.

Sodium Requirements of Goats

Schellner (1972) studied the effect of two levels of sodium (0.31g/Kg vs 1.74g/Kg dry feed) on growth, reproduction and lactation of goats. Deficiency appeared 4 to 6 weeks after the goats were started on the low-sodium diet. They included persistent licking, restlessness, dull shaggy hair, poor growth and intake of feed and marked emaciation during lactation. After 224 days, the deficient goats weighed 80% as much as those supplemented. They ate an average of 6% less feed per day and required 18.5% more feed per unit of gain. There was no effect on reproduction, but milk yields and the sodium content of milk and hair were depressed, but not in the liver or whole body of new born kids. Clearly, the low level of sodium (0.31g/Kg or 0.031%) was deficient while the higher level studied (0.174%) was fully adequate.

Sodium and Chloride Content of Feeds

The amount of supplemental salt needed varies with the amounts in the feeds and water animals consume. Only recently have systematic surveys been attempted to measure the sodium content of forages and only very limited areas have been studied to date. In contrast to most temperate countries, the cost is high for delivering common salt to the areas where cattle are produced in tropical countries and the expense may not be justified unless there is a substantial response. Water may also be a good source of sodium.

The University of Florida summarized the available analyses of Latin American feeds. Of 2615 forage samples, only 146 had been analyzed for sodium. Of these, 18% contained 0.05% Na or less, 41% had between 0.05 and 0.10%, 18% 0.11 to 0.20%, and 22% above 0.2%. (McDowell *et al.*, 1974).

In Western Panama, *Hyparrhenia rufa* (Jaragua grass) from 11 different locations contained 0.05 ± 0.02% Na in April compared with 0.036 ± 0.006% Na in November, 1970. (Chicco, 1972).

FAO has recently published an extensive summary of the composition of tropical feeds (Gohl, 1975). High sodium sources were salt bush 6.34% Na, creeping salt bush 4.66%, seaweed meal 2.93% and sunflower meal 2.09%. Animal by-products contained from 0.4 to 1.6% Na. The cereal grains, high protein by-products, all legume forages and many grasses were low in sodium (0.01 to 0.1%).

Salt Toxicity

Excess intakes of salt are toxic. When salt hungry animals are given free access to salt they may eat so much it will cause death, especially if fresh water is limited. Generally, animals will not eat harmful amounts if salt is always available, but they often eat more than their minimum requirements. When animals consume more salt the fresh water requirement increases. Higher temperatures also increase water requirements. Shirley *et al.* (1974) reviewed the data on nutrients and toxic substances in water. They reported that European breeds of beef cattle weighing 450 Kg and eating 10 Kg of dry feed per day may drink 28, 41 and 66 liters of water daily at 4, 21 and 32°C, respectively. They listed the water needs of average sized mature animals in a temperate climate as follows: dairy cattle 38 to 110 liters, sheep and goats 4 to 15 liters.

In many hot drier areas the water available for livestock may contain harmful amounts of salts. In addition to NaCl, potassium, magnesium and calcium are major constituents occurring as chlorides, carbonates, bicarbonates and sulfates. Minor mineral elements, both essential and toxic also occur in water. Saline water containing NaCl is less toxic than Na_2SO_4, $CaCl_2$ or $MgSO_4$. Shirley *et al.* (1974) concluded from the published research that water containing salt concentrations up to 5.0 g/L are safe for lactating cattle. Levels up to 7.0 g/L are safe for non-lactating cattle and sheep, but higher amounts are harmful. Several studies show that cattle can adapt to water containing 10.0 g/L of NaCl and

sheep somewhat higher levels. It can be calculated that for the beef cattle cited above that drink about 40 liters of water daily the Na requirement would be met by a concentration of about 0.5 g/L of NaCl. Surface water in ponds and streams in the U.S.A. contains 0.001 g to 7.5 g/L of NaCl with an average of 0.055 g/L. Values below 1.0 g/L are considered fresh water, from 1.0 to 3.0 g/L slightly salty and 3.0 to 10.0 g moderately salty. Salt brine contains 35.0 to 100.0 g/L. Water in Great Salt Lake, Utah contains 89.4 g/L of sodium and 278.0 g/L total salts.

Summary

Selected research reports on the salt (NaCl) requirements of ruminants, the natural occurrence of salt deficiency in grazing animals, the specific signs and physiological changes resulting from critical deficiencies produced experimentally, the sodium content of some feeds and forages and the occurrence of salt toxicity have been briefly reviewed.

Low intakes of sodium on natural feeds cause an intense craving for salt, reduced feed intakes, depressed growth rates, lowered milk yields and in some cases death of lactating animals. Urinary excretion of NaCl declines markedly, and the sodium in parotid saliva decreases while potassium increases. NaCl levels in the blood and milk of deficient animals change very little. Chlorine deficiency is not known to occur in grazing ruminants. Lactating animals have the highest requirement for sodium, 0.1-0.15% of the dry diet. Growing cattle need 0.02 to 0.08% Na in the diet dry matter based on reports from different areas. Many forages are low enough in Na to cause deficiency unless salt is provided, but there are exceptions. Salt requirements may be higher for animals in hot, dry regions because of higher losses in saliva and perspiration, but comparative data are not available on the differences.

Salt toxicity is not likely to occur when animals have ample fresh water available. They will not drink salty water if there is a choice. Lactating cattle can tolerate salty water containing up to 5.0 g/Liter of NaCl, and other cattle and sheep up to 7.0 to 10.0 g/L, but higher concentrations are harmful. About 0.5 g/L of salt would meet the sodium requirements.

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MAGNESIUM IN RUMINANT NUTRITION

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Introduction

The subject is approached with emphasis on cattle, and to a lesser degree, on sheep and their respective deficiencies and metabolic disturbances. There are no references pertaining to goats.

Magnesium is an essential macroelement in the nutrition of ruminants, which is present in the body of the animal in the proportion of approximately 0.05%. About 60% of magnesium is found in the skeleton with the remainder in the soft tissue. In spite of existing in the body in quantities much smaller than calcium and phosphorus, magnesium is closely associated with them. In general, the distribution of magnesium in the animal follows that of phosphorus rather than calcium. Like calcium and phosphorus, it is excreted in the urine and the feces, but primarily by way of the latter route.

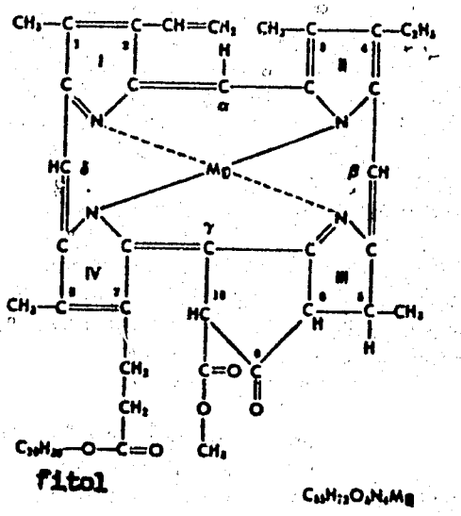
Besides being an essential constituent of the bones and teeth, it participates directly or indirectly in about 80 known enzymatic reactions (Schutte, 1966), being particularly essential in the metabolism of sugars (Krebs cycle), catalyzing the formation of Acetyl-CoA and Succinyl-CoA, key compounds of that cycle (Conn and Stumpf, 1972). It participates in the transmission of neuromuscular stimuli. Specifically, it activates all the enzymes of transference of phosphorus from ATP to ADP and for this reason, influences all vital processes (Maynard and Loosli, 1969).

In the plant kingdom, magnesium is a component of chlorophyll, essential in photosynthesis. This, considered the most important reaction in nature, gives the dimension of the physiological importance of magnesium.

The magnesium content of food tends to follow that of nitrogen and phosphorus. The oil-rich seeds and their by-products contain relatively high levels of magnesium, but the cereal grains contain substantially less. By-products of animal origin are poor sources of magnesium. Forages are highly variable in magnesium with legumes generally higher than grasses (Nelson, 1973).

In general, the quantities of magnesium decline as the plant matures (Underwood, 1966). In contrast, Prospero and Peixoto (1972), in São Paulo, found that the magnesium content, in contrast with other minerals, tended to increase in the napier variety of elephant grass *(Pennisetum purpurem,* Schum), with increasing maturity (Table 1).

Figure 1. Chlorophyll.



These researchers considered this an unexpected finding because magnesium is quite mobile within the plant. Previous findings of Gomide *et al.* (1969) showed a tendency for magnesium to decrease in the dry matter of elephant and pangola grass from 28 to 140 days. Without a doubt these more recent studies will prompt new investigations.

Table 1

EFFECTS OF MATURITY ON MACRONUTRIENT CONTENT IN NAPIER GRASS (DRY BASIS)

Stage of maturity in days	Percent in dry matter					
	Nitrogen	Phosphorus	Calcium	Sulphur	Potassium	Magnesium
45	2.38	0.21	0.14	0.15	5.07	0.10
75	1.10	0.12	0.16	0.08	3.71	0.10
105	0.93	0.15	0.19	0.10	3.16	0.11
135	0.63	0.05	0.42	0.07	1.60	0.15
165	0.53	0.15	0.30	0.06	2.20	0.11
195	0.43	0.03	0.18	0.06	1.19	0.16
225	0.43	0.11	0.41	0.07	1.36	0.13
255	0.36	0.04	0.20	0.09	1.67	0.11
285	0.30	0.09	0.24	0.05	1.21	0.13
315	0.32	0.04	0.15	0.07	1.25	0.15

In the last few years, the interest in the study of metabolic disturbances related to magnesium in ruminants has been increased, especially due to the apparent geographic expansion of hypomagnesemic tetany. This metabolic disease was found almost a century ago in Holland, and later in England, Ireland, the majority of the European countries, New Zealand, the United States of America and Australia (Minyard and Dearborn, 1965).

Under practical conditions, usually spontaneous deficiencies of magnesium are considered improbable because the required quantities in the diet are about 0.05–0.1% of the element on a dry matter basis and there are few forages where the concentration is less than 0.1% (De Alba, 1973). It is therefore necessary to find values lower than 0.07% to suspect deficiency.

Hypomagnesemic Tetany

Hypomagnesemic tetany in reality is not a tetany, but convulsions attributed to the hypomagnesemia. It occurs principally in very productive pastures and in equally productive animals with elevated metabolic activity (De Alba, 1973).

According to Crookshank and Sims (1955), the clinical signs begin with marked excitation, incoordination and loss of appetite. As it progresses, dizziness, and falling is observed. The nervousness becomes more apparent, with muscular contractions. The animal shows an anxious expression, grinds its teeth and salivates profusely. The eyelid protrudes or quivers as in the case of tetany. General contractions continue until the animal becomes almost prostrate. Still, sudden noises or a touch may provoke reflexive responses. There is laborious respiration, tachycardia, and animal passing into a coma. If the animal is not treated, there are intermittent periods of convulsion and relaxation ending in death. Generally there are six to ten hours between the onset of the first clinical signs and the passing into a coma state. If treatment was not initiated before the coma, there is little chance of recuperation. The blood generally shows reduced quantities of magnesium, diffusible calcium, inorganic phosphate, low albumin-globulin rates and elevated levels of total protein, globulin and, possibly, potassium, in comparison with the serum of normal cows.

Grass tetany has been diagnosed in a limited number of non-lactating cows and in calves, but never in adult males or in steers. Even when steers, heifers, and cows had been submitted to identical rations, the death rate restricts itself to the oldest cows during pregnancy or lactation.

Hughes and Cornelius (1960) examined the blood of lactating beef cows grazing pasture, grown after a period of rain following a prolonged interval of drought. Only in the case of low amounts of Ca, Mg, and P were there typical tetany convulsions. The magnesium in the serum was frequently low in steers, bulls, calves, and in apparently healthy cows in similar pastures. Therefore, simple magnesium deficiency was not the cause of this disturbance.

Tetany can exist without hypomagnesemia (Todd and Thompson, 1960). Custer (1959) and Marshak (1959) also considered that tetany is not only the consequence of hypomagensemia, but also the consequence of hypocalcemia. The albuminuria generally present, is not present in the case of parturient paresis, whose symptoms at times become confused with those of grass tetany.

Hall and Reynolds (1972) studied the concentrations of magnesium and calcium in the plasma of Hereford cows, before and after the tetany; in the beginning of the symptoms, magnesium was 0.66 meq/1 and the calcium was 3.89 meq/1 and three to five days after the tetany, the values increased to 1.07 and 5.69, respectively.

Grace (1972) observed levels of magnesium in plasma of cows in pastures during gestation and lactation. In adults, gestation caused significant increase until 3-4 weeks before birth. Lactation resulted in an increase in the beginning and significant reduction 3-4 weeks after the birth. But in young cows, neither the gestation nor the lactation had any significant effect on the levels of magnesium in the plasma.

According to Maynard and Loosli (1969), in agreement with evidence from the Experimental Station of Nevada, tetany could be produced by the administration of excessive potassium and citric acid or transaconitic acid. These substances apparently depress the quantity of magnesium in the blood, enough to cause tetany. In this case supplements of magnesium help to prevent the disturbance.

According to Underwood (1968) grass tetany, in its acute form, results from the insufficiency of magnesium or from unavailable magnesium in the diet, associated with the incapacity of the animal to mobilize the magnesium from its skeleton in sufficient quantities to maintain the levels of magnesium in the serum which may be influenced by unknown dietetic factors.

Requirements

Much less is known about the requirements of magnesium in ruminants and the factors that affect these requirements, than is known about the requirements of calcium and phosphorus.

The majority of the evidence suggests that pastures or rations containing more than 0.07% Mg in the dry form ought to satisfy the minimum requirements for the growth of cattle and sheep and that the level of 0.1% is adequate as the minimum for cows and ewes in lactation (Underwood, 1966). According to Hawkins (1957), 0.07% to 0.08% of magnesium in the ration seems adequate to satisfy the minimum requirements for calves up to the age of 260 days. The levels of serum magnesium vary from 2.0 to 2.2 mg/100 ml.

The results of nutritional balance trials in Holland indicate daily requirements of available magnesium on the order of 2.5g for maintenance and of 0.12g per liter of milk produced in cattle (Kemp, 1963). The serum magnesium level began to decline when the excretion in the urine was less than 1g instead of the average 2.5g.

Rook *et al.* (1964) found that the serum magnesium level in lactating cows fell to 0.5 mg/100 ml within four days after the supplement of magnesium had been removed which had provided 9.3g of magnesium per cow per day. The excretion of magnesium in the urine ceased but the magnesium in the milk was not affected. The ingestion of 9.3 to 13.9g of magnesium was sufficient to support the production of 11 to 15 liters of milk during the midpoint of lactation.

Minyard and Dearborn (1965) presented in detail five experiments with cows during a period of two years in South Dakota on three different farms, which previously had produced tetany from their pastures. In each experiment the herd was divided at random into two groups. One group received a calculated supplement to furnish 6g of magnesium and 12 g of calcium per cow per day.

The other group remained as the control group with a similar supplement, however, without the addition of magnesium. The two groups in each experiment were placed in adjacent pastures that were considered similar with respect to the probable occurrence of grass tetany. There were 18 cases of tetany in 505 cows in the control group as compared to one case (this one being fatal) in 504 animals in the treated herd.

O'Kelley and Fontenot (1969) studied the requirements of magnesium for beef cows during gestation. In order to maintain 2 mg/100 ml of serum magnesium, the requirements calculated by regressions were 8.5, 7.0 and 9.0 mg of magnesium per day per cow for 145, 200, and 255 days of pregnancy, respectively, corresponding to 0.12, 0.10, and 0.13% of magnesium in the dry matter of the ration. The recommendations of O'Kelley and Fontenot (1969) are higher than those of other researchers, inasmuch as they are related to the maintenance of serum magnesium at a level of 2 mg/100 ml which is above the renal limit of 1.46 to 1.76 mg/100 ml as demonstrated by Storry and Rock (1963). According to Nelson (1973) a common recommendation is about 57g of magnesium oxide per cow per day in pastures that are predisposed to tetany. This level is in excess to that which is generally considered adequate.

Chicco *et al.* (1972) calculated the minimum requirements of magnesium and of magnesium oxide as being on the order of 4.03 mg/kg of live weight to substitute the endogenous losses and the renal limit of 1.63 mg/100 ml in the plasma of sheep on a purified diet.

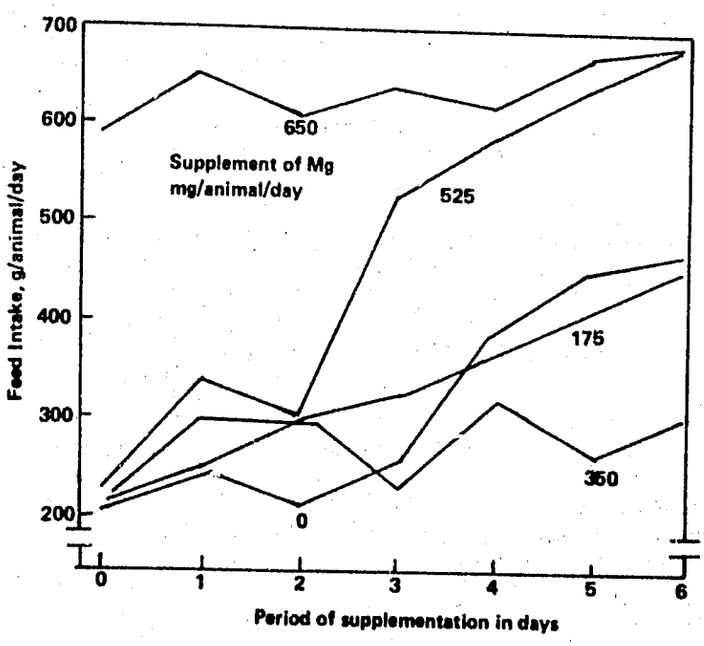


Figure 2. Response of voluntary ingestion of feed by sheep to the oral administration of Mg as MgO after they remained on a Mg deficient diet for 6 days. Ammerman et al, 1971.

Ammerman *et al.* (1971) suggested 8.0 to 10 mg/kg of live weight per day of magnesium as magnesium oxide as the necessary quantity to reestablish the normal feed intake in sheep. These researchers demonstrated that, in sheep fed a ration that was essentially free of magnesium, the voluntary feed intake was reduced by 32% in relation to the controls after they received the diet for four days. Figure 2 shows the effect of magnesium supplementation on the voluntary feed intake.

Availability

There is evidence that the availability of magnesium in some type of feeds, particularly grass and roughages, is frequently under 30% and sometimes as low as 5% (Underwood, 1966). On the other hand, there is considerable individual variability among cows in the absorption of magnesium from determined sources. In the case of magnesium being scarcely 20% available instead of 33%, the real requirements would be multipled by 5 instead of by 3.1. Thus, a cow producing 9 kg of milk per day needs 3.0 g of net magnesium. In the case of 33% availability of magnesium in the diet, about 9.1g of the total magnesium would be necessary and in the case of 20%, approximately 15.0g.

Underwood (1966) suggests that magnesium availability in an animal is particularly low during certain periods. Kemp *et al.* (1961) presented evidence that the availability of magnesium increases with the degree of maturity of the forage as seen in Table 2.

Table 2

AVAILABILITY OF MAGNESIUM IN GRASS AT AN INCREASING DEGREE OF MATURITY

% of protein in the dry matter of the grass	Availability of Mg for cows
26	10
18	16
14	20

These authors suggest that the low availability of magnesium in grass can be accentuated by the heavy fertilization with potassium and nitrogen. Therefore, the fertilization would have the effect not only to reduce the concentration but also lower the availability of magnesium. The availability of magnesium also varies among mineral supplements. Chicco *et al.* (1972) found magnesium from magnesium oxide was 75% available to sheep. Gerken and Fontenot (1967) reported that with steers the magnesium from the oxide was better absorbed than the magnesium from the calcareous dolomite and resulted in a significantly elevated magnesium serum level. Moore *et al.* (1971) also reported that, in steers, the magnesium from the oxide was significantly better absorbed than from the calcareous dolomite. According to Storry and Rook (1963), in cows, the level of magnesium in salt, determined from the percentage of magnesium of the supplement excreted in urine, was much higher in the citrate, followed by oxide, nitrate, acetate, and lactate forms of the mineral. The sulfate, chloride and silicate were comparatively less available. The authors demonstrated a linear relation between magnesium in the urine and in the serum above the limit of 1.46 and 1.76 mg/100 ml of serum.

Ammerman *et al.* (1972) verified that Mg of the carbonate, oxide, and sulfate were well utilized by sheep, in agreement with data on absorption and retention. Voluntary feed intake was higher when magnesium carbonate was fed.

Interrelations Among Nutrients

According to Newton *et al.* (1972) high potassium ingestion results in a decrease in apparent magnesium absorption in sheep. Young lambs received diets containing 0.1% and 0.6 or 4.9% of potassium bicarbonate. The diets were equal in calcium and phosphorus. The average absorption of magnesium was 49.1% and 26.4% for the animals fed the low and high levels of potassium, respectively.

House and Van Campen (1971) conducted a nutritional balance study with sheep using ^{28}Mg in a control diet of 0.17% magnesium and 0.76% potassium. Data showed that the daily administration of 60g of potassium chloride significantly reduced the absorption of magnesium, and resulted in a decrease of magnesium in the urine and an increase in the feces.

Moore *et al.* (1972), in metabolism trials with sheep, studied levels and sources of nitrogen with the level of potassium being constant, with two levels of crude protein and two of non-protein nitrogen (NPN). In the animals consuming diets high in nitrogen the excretion of magnesium in the urine was much higher and the retention much lower. However, there was a difference in the apparent absorption of nitrogen, indicating the high levels of ammonia in the rumen did not interfere with the absorption. There was no difference in relation to the form of nitrogen given. There was a tendency for the retention of calcium to be lower and the absorption of potassium to be higher in lambs with rations high in nitrogen.

With respect to the interrelations among magnesium, calcium, and phosphorus in laboratory animals, especially guinea pigs and rats, it has been shown that in diets adequate in magnesium and other nutrients, adding calcium or phosphorus or both resulted in symptoms of magnesium deficiency. There is evidence for the decrease of absorption or the increase of excretion of magnesium or both. Certainly, the high ingestions of calcium and phosphorus have the practical effect of increasing the minimum requirements in the studied species. It is unknown if these effects are valid for ruminants and have practical importance (Maynard and Loosli, 1969).

The interrelations among calcium, phosphorus, and magnesium were also investigated in sheep (Chicco *et al.*, 1973). In diets high in calcium there is a decrease of magnesium in plasma and bones, an increase in plasma calcium and a tendency for reduced plasma phorphorus. A diet already high in magnesium (from mangesium carbonate) reduced plasma calcium and slightly reduced plasma phosphorus. Dietary phosphorus had little effect on the utilization of magnesium.

Dulton and Fontenot (1967) studied the effect of phytic acid on magnesium absorption in sheep. Previous studies have shown that phytic acid decreases the absorption of magnesium in non-ruminants. The form of phosphorus used (organic or inorganic) did not show a significant effect on the absorption or retention of magnesium or calcium and on the absorption of the phosphorus. However, the decrease of magnesium in the serum for the diets low in magnesium and the increase with high dietary magnesium were more accentuated when the inorganic phosphorus was used. The interaction between level of magnesium and form of phosphorus was significant.

Pasture Fertilization and Composition of Forage

The mineral composition of plants reflects, in varying degrees, the nature of the soil in which they grow.

Stillings *et al.* (1964) studied the utlization by ruminants of the mineral elements in forage produced with extra or liberal quantities of nitrogen. The forage resulting from high levels of nitrogen contained more magnesium, potassium and nitrate. The apparent availability of magnesium was higher in the forage that was low in nitrogen, varying from 18 to 24% while the forage high in nitrogen varied from 11 to 16%. However, the balance of nitrogen was similar due to the greater intake of magnesium in the last instance. Generally, European researchers tend to believe that fertilization with nitrogen and potassium results in pasture that is predisposed to hypomagnesemia tetany (De Alba, 1973).

Induced Hypomagnesemia

Rook (1961) reports normal levels of magnesium as 2 to 3.5 mg per 100 ml of serum.

By the use of artificial diets, purified and low in magnesium, researchers have attempted to induce hypomagnesemia. Among others Rook (1961) used purified diets and succeeded in reducing serum magnesium of cattle from 2.2 mg to 0.8 mg/100 ml in only 2 days, but Storry and Rook (1963) reported that 12 days were required to obtain the values of 1.0 to 1.5 mg/100 ml.

Bohman *et al.* (1969) produced clinical signs in cows resembling field cases of hypomagnesemia tetany by means of oral administration of potassium chloride (KCl) plus either citric acid or transaconitic acid. These two acids or the KCl administered separately did not produce tetany. The researchers were unable to clarify the mechanism by which the condition occurred. The administration of KC1 alone lowers the magnesium in the plasma for long periods, but the combination of KC1 and citric acid lowers the magnesium of the plasma from between 24 hours and one week. The quantity of these compounds that would be necessary to induce tetany is related to the live weight of the animal. Animals receiving 157 g/100 kg of live weight from each compound exhibit the disease while others ingesting smaller quantities do not.

Techniques of Administering Magnesium

Different techniques of magnesium administration directly or indirectly (fertilization) have been used in the areas subjected to the hypomagnesemia tetany.

Todd and Morrison (1964) fertilized pasture with about 31.4 kg of magnesium carbonate per hectare two days before the animal grazed the area. The level of magnesium in the serum remained above 1.8 mg/100 ml in cows transferred from predominately concentrated feed or from non-fertilized pastures, in which the level of magnesium in the serum was much lower. Tetany occurred in cows grazing non-fertilized pastures. The magnesium fertilization elevated the level of magnesium in the dry matter of the pasture from 0.16 to 0.31% and did not affect its acceptability.

Todd *et al.* (1966) reported that dairy cows in pastures with free access to a mixture of magnesium carbonate and molasses in equal parts by weight had improved magnesium status. There were only a few cases of hypomagnesemia but when the mixture was removed severe tetany occurred. The average consumption of magnesium carbonate was 54g per head per day.

The use of mineral mixtures or licking blocks containing magnesium oxide in proportions varying from 10 to 50% for cows consuming tetany prone pastures is not completely successful. Daily doses of 56g of magnesium oxide given in liquid form for such cows as highly efficient and it seems that 50 to 60g of magnesium oxide is the minimum effective prophylactic dose for dairy cows (Underwood, 1966).

Research in Latin America

According to De Alba (1973), grass tetany was first reported in Latin America in a pasture near Buenos Aires. Without a doubt, it can become more frequent as the productivity of pastures increases.

In Coahila, Mexico, De Alba (1973) observed symptoms very suggestive of possible hypomagnesemia in recently weaned calves but the problem was not adequately studied.

Nores (1944) found critical mean levels of magnesium in the forages of one (Florida) of 23 localities studied in Uruguay. According to De Alba (1973), the results need confirmation in order to verify if there is a relationship of low forage magnesium to the nutritional problems observed. This same researcher states that the only confirmation to field experiments that he has found was in Riet *et al.* (1944) where symptoms referring to the disturbance are

mentioned, whose clinical signs suggest grass tetany. The cases came from Florida in Uruguay: "Apparently healthy animals, upon being taken to corrals or pens, demonstrated tremors or muscular contractions restricting their mobility, causing some to fall, and some to die a few hours later or two or three days later".

In Argentina, Abiusso (1964) determined the Mg concentration in the grasses of Anguil and Castelar found levels less than 0.12%. However a greater incidence of grass tetany was confirmed on several occasions in Buenos Aires with values of magnesium much higher in these pastures. The conditions were described briefly by Culot and Fernández Tunon 1967) indicating that the loss of steers in fields of winter cereals in the relatively well drained pampa areas was on the order of 15%. The aforementioned authors studied the mineral composition of oat pastures and concluded that the tetany was produced by conditions that reduced the absorption of magnesium, which was found in concentrations of 0.15% with the exception of one case (0.08%). The level of protein in the dry matter (27-28%) without a doubt functioned as a predisposing condition. The percentage of potassium was also high.

In Peru, Barua *et al.* (1967) found an acceptable average magnesium level (0.28%) in grasses of Huancayo although some individuel values were critical. It would be interesting to relate them with possible zonal problems.

In Colombia, Blasco *et al.* (1967), in the Cauca Valley, did not find any low values in different forage species. In the same valley, Montilla and Leon (1971) found an inverse relationship between calcium and magnesium in soils.

In Venezuela, French and Chaparro (1960) found high values of up to 1.92% magnesium in pastures, with the minimum level of not less than 0.17%.

In Surinam, Dirven (1963) found an average of 0.35% magnesium in the dry matter of four grasses, the higher average value was 0.39% and the lower was 0.19%.

In Costa Rica, samples analyzed in Florida (USA) gave deficient values of magnesium (0.04%) in some regions (De Alba, 1973). He believed that this anomaly could cause some disturbances similar to grass tatany, but the frequency might not be very high since he did not observe any clinical signs during the long period during which he worked in that country.

In Brazil, Andreasi *et al.* (1966-67) and Gomide *et al.* (1969) found levels of magnesium that were considered normal in the dry matter of grasses. Próspero and Peixoto (1972) studied the mineral composition of elephant grass *(Pennisetum purpureum,* Schum), the napier variety, from 45 to 315 days of age. The level of magnesium showed a tendency to increase as the plant matured, going from 0.10% to 0.15%. Lopes *et al.* (1972) determined the levels of serum magnesium monthly from November to March in grazing lactating cows, heifers (from 1.5 to 2.5 years) and calves (from 1 to 1.5 years). Magnesium concentration from 2.32 to 2.50 mg/100 ml, were found and these values were considered normal. During the same period they collected samples of grass and soil. In six samples of grass from the field and "cerrado" areas, they found the levels of magnesium ranging from 0.077% to 2.27% in the dry matter of leaves. They also determined the levels of magnesium in the soil from which they had gathered the grasses. The levels varied from 0 to 5.05 ME%. Dayrall *et al.* (1972) found that the levels of magnesium in the serum of cattle grown in "cerrado" pastures varied from 2.55 to 2.46 mg/100 ml. Recently, Simão Neto (1975) reviewed magnesium in the nutrition of ruminants.

Summary and Observations

The importance of magnesium in the nutrition of ruminants and living tissues in general is a subject that has been known for some time. Nevertheless, most recently, it has resulted in more attention by virtue of results of recent research.

Magnesium takes part, directly or indirectly, in about 80 known enzymatic reactions, it is particularly essential in the metabolism of sugars (Krebs cycle) and participates in the transmission of neuromuscular stimuli.

As a component of chlorophyll, it is essential in photosynthesis which is considered the most important reaction in nature and is responsible in the final analysis for the provision of the feeds and forages utilized in the nutrition of ruminants.

While found in diverse geographical areas, there apparently is not a great possibility of magnesium deficiency in ruminant nutrition. Yet the substantiations of possible deficiency tend to increase as a consequence of research and application of advanced technological processes such as heavier fertilization of pastures and increased productivity.

According to Nelson (1973) the levels of magnesium in feed tend to follow those of protein and phosphorus. As in tropical regions, the levels of nitrogen and phosphorus in the forage is low (predominately grass), it would be expected that the magnesium would likewise be low. However, this may not happen (Próspero and Peixoto, 1972). Another possibility would be the prevalence of slight deficiencies of magnesium as opposed to serious ones.

In Latin America, the research concerning magnesium in ruminant nutrition is still rather limited; although, interest in the subject is growing. There is, evidently, the necessity of research, especially of a survey type like the one being carried on in South Africa (Boyazoglu, 1972). A survey is being conducted to learn mineral levels in livers of cattle in the State of Minas Gerais, but it does not include magnesium (Brant *et al.*, 1973).

Apparently the lack of great pressure for research on the subject in Latin America originates from, among others, the following possible facts: the generally low productivity of the pastures and of the herds and; lack of fertilization of pastures with nitrogen and potassium; the evidence, if consistently substantiated, by Kemp *et al.* (1961) that the availability of magnesium increases as the stage of maturity of grasses increases.

Concerning the geographic distribution, apparently, grass tetany, in agreement with available research, occurs more in temperate regions than in tropic and subtropic regions. In Latin America it was only confirmed with certainty in the regions of Buenos Aires (De Alba, 1973).

From all of these results the necessity for more regional and local research is in order so that the aspects observed here can emerge from the condition of being solely speculation to answers based on research results.

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SULFUR IN RUMINANT NUTRITION

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Sulfur is one of the more abundant elements in the world. Yet a shortage of sulfur-containing amino acids is one of the world problems in animal nutrition. Sulfur is well known as a part of the amino acids methionine and cystine. It occurs in animal tissues in many sulfate forms. One of these compounds is chrondroitin sulfate, an important component of cartilage, bone, tendons and walls of blood vessels. Decreased collagen formation was found in rats fed low sulfur diets (Brown *et al.*, 1965). The blood anti-coagulant heparin is a sulfuric acid ester of a polysaccharide.

Symptoms of sulfur deficiency have been described by Thomas *et al.* (1951) in sheep fed purified diets as loss of weight, weakness, lacrimation, dullness and death.

Sulfur enters into metabolic pathways at oxidation levels of sulfate or sulfide. Forms of sulfur such as thiosulfate, polysulfides and elemental sulfur must be either oxidized to sulfate or reduced to sulfide before they are actually utilizable by ruminants. Sulfate reductions and sulfide oxidation constitutes an overall process termed the "sulfur cycle". It is largely a microbial process, but both plants and animals make some application of it. However, mammals do not reduce sulfate to sulfide needed in the synthesis of sulfur-containing methionine and cystine, and the vitamins, biotin and thiamin (Houvinen and Gustafsson, 1967).

Plants and sulfur. Plants and most bacteria can reduce sulfate to sulfide as indicated by their growth with sulfate as their only source of sulfur. Plants generally reduce only enough sulfate to sulfide to meet nutritional requirements, and this is generally true of most bacteria. A limited group of anaerobic sulfate reducing microbes produce large amounts of sulfide during growth in the presence of sulfate. This has been identified as respiratory sulfate reduction in that the sulfate serves as a terminal electron acceptor in much the same way as oxygen does in aerobic respiration (Peck, 1970).

Plants have a nutrient sulfur requirement for maximum yields. The critical sulfur content of sugarcane is 0.04% or less (Stanford and Jordan, 1966), compared to about 0.22% for alfalfa (Pumphrey and Moore, 1965). The wide variability in sulfur content of plants depends largely on the amount of sulfur in the plant protein (Allaway and Thompson, 1966). The protein content varies widely with species, maturity, environment and nutrients available. It appears that the ratio of sulfur to nitrogen in the plant is a more reliable measure of the sulfur requirement than is the total sulfur concentration. Genetic factors determine the amino acid composition of the various plant proteins. Stewart and Porter (1969) found that nitrogen utilization of wheat was largely dependent on the sulfur available for the plant. They observed that when nitrogen is limited, sulfate accumulates and the total nitrogen to sulfur ratio is below that found in plant protein. Apparently sulfate sulfur does not build up in the plant to a significant extent until the sulfur requirement of the plant for protein formation has been met. Sulfate sulfur may be an indicator of the sulfur status of the plant.

Soils deficient in sulfur are not uncommon in humid areas of granitic and basaltic origins where forages are commonly grown. Superphosphate (11 to 13% S) and ammonium sulfate (24% S) can correct the sulfur deficiency in these soils.

McClung *et al.*, (1959) reported that when sulfur was not applied to soils of the central Plateau of Brazil plant growth was only 4 to 30 percent of that obtained when a complete fertilizer was applied. These workers suggested that the very low sulfur content of soils in this area of Brazil was due to repeated burning of dry grass which resulted in losses of 75 percent of the sulfur by volatilization. In El Salvador Muller (1965) observed that soils previously cultivated were deficient in sulfur. When sulfur was applied to soils in Costa Rica medium responses were obtained (Martini, 1969).

Dietary requirements of animals for sulfur. Evaluating sulfur requirements of livestock has been through supplementing diets with methionine or cystine, sulfates, or elemental sulfur in balance trials and by radioisotope studies. Attempts were made many years ago to supplement ruminant diets with sulfur-containing amino acids (Anon., 1913). These early attempts were generally inconclusive because only trace amounts of amino acids were used or the diets frequently already contained adequate levels of sulfur. Loosli and Harris (1945) improved the growth of lambs being fed a diet containing 6.55% crude protein by increasing the level to 10.28% with urea plus sulfate, or urea plus methionine. Lofgreen *et al.* (1947) increased nitrogen retention when 0.2% methionine was added to 10% crude protein basal ration in which 40% of the N came from urea. McLaren *et al.* (1965) increased N retention and wool production in sheep that were supplemented with methionine or with methionine and cystine. Decreased digestion of cellulose by steers occurred with purified rations deficient in sulfur (Martin *et al.*, 1964).

Elam (1975) reviewed a number of important effects of sulfur in animal nutrition. One of these is the influence of sulfur on cellulose digestion *in vitro* as reported by Barton *et al.* (1971) in Table 1. Bull and Vandersall (1973) found that sodium sulfate, calcium sulfate, DL-methionine, and methionine hydroxy analog (MHA) were equal in promoting cellulose digestion *in vitro* at equivalent sulfur levels. They concluded that the optimum sulfur level was from 0.16 to 0.24%. Elam (1975) listed the observation in Table 2 giving the sulfur requirements of ruminants based on *in vitro* results. Whiting *et al.* (1954) used mature ewes fed supplemental sulfur from various sources in low sulfur basal diets.

Table 1
INFLUENCE OF SULFUR ON CELLULOSE DIGESTION IN VITRO

Trial 1		Trial 2	
Total S in D.M.	Cellulose digestion	Total S in D.M.	Cellulose digestion
%	%	%	%
0.08	36.6	0.02	20.8
0.13	56.1	0.04	33.1
0.16	73.2	0.08	52.0
0.23	82.3	0.12	61.4
0.33	83.0	0.14	74.7
0.43	83.2	0.16	69.5

Table 2
SULFUR REQUIREMENTS OF RUMINANTS BASED ON IN VITRO RESULTS

Type	Criterion	% sulfur	Reference
Sheep	Performance of ewes	0.100	Whiting *et al.*, 1954
	Growth of lambs	0.138	Albert *et al.*, 1956
	Growth of lambs	0.155	Rendig and Weir, 1957
	Nitrogen retention	0.140	Bray, 1965
	Cellulose digestion	0.290	Evans and Davis, 1966
	Various	0.176	Moir *et al.*, 1967-68
	Growth	0.100	NRC, 1968
Beef	Various	0.110	Chalupa *et al.*, 1971
	Growth rate	0.100	NRC, 1971
Dair	Sulfur balance	0.120	Bouchard and Conrad, 1973a
	Milk yield	0.110	Grieve *et al.*, 1973
	Various	0.200	NRC, 1971

They concluded that the sulfur requirement was less than 0.1% of the diet (Table 2). Working with lambs Albert *et al.* (1956) supplemented a purified diet with different levels of elemental sulfur, sodium sulfate or methionine and concluded the requirement was 0.138% sulfur based on growth rate. Rendig and Weir (1957) reported that yearling wethers fed 0.155% total dietary sulfur gave good rates of growth. Evans and Davis (1966) upon studying cellulose digestion in the rumen of fistulated steers found the optimum sulfur level to be 0.29%. A ration that contained 11% protein was

calculated to require 0.176% sulfur by Moir *et al.* (1967-1968) based on a need for a N:S ratio of 10:1. Chalupa *et al.* (1973) found better gains in weight of Angus steers when sodium sulfate or elemental sulfur were added to increase dietary sulfur from 0.05 to 0.13%. Feeding these forms of sulfur in steer diets up to approximately 0.6% had no deleterious effects. However, Bouchard and Conrad (1973b) reduced feed intake of dairy cows when dietary sulfur as calcium sulfate exceeded 0.3% of the ration; and Johnson *et al.* (1968) found that the addition of 0.5% sulfur as calcium sulfate decreased the daily gains of lambs.

Availability of sulfur from different sources. In Table 3 is presented a summary (Elam, 1975) of the percentage availability values of various sources of sulfur reported by various investigators. The biological availability of sulfur in both L-methionine (Johnson *et al.*, 1971) and DL-methionine (Albert *et al.*, 1956) was higher than other sources of sulfur. Methionine administered orally is almost completely degraded in the rumen (Moir, 1974). For this reason methionine does not serve primarily as an amino acid source for the animal, but as a source of sulfur. As shown in Table 3 MHA compares favorably with methionine as a source of sulfur. In general, inorganic sources of sulfur are less available than that in methionine. These inorganic sources of sulfur include sodium sulfate, calcium sulfate, potassium and magnesium sulfate and ammonium sulfate.

Kahlon *et al.* (1975) fed semipurified diets supplemented with DL-methionine, hydroxy analog of methionine (MHA), calcium sulfate, sodium sulfate or elemental sulfur gained faster, consumed more dry matter, and digested and retained greater weights of nitrogen and sulfur (see Table 4) than lambs fed the sulfur deficient diet. Those fed the sulfur deficient diet were removed from the trial after 40 days due to severe weight losses.

Elemental sulfur is usually found to be less available than most other sources. Approximately three times more supplemental sulfur was needed in the elemental form for lambs than as methionine (Albert *et al.*, 1956; Johnson *et al.*, 1971). However, Chalupa *et al.* (1973) found elemental sulfur was as effective as sulfate sulfur for cattle.

Bull and Vandersall (1973) reported that the sulfur in their basal diet of corn and corn silage was less available than that in sodium sulfate, methionine and MHA. Bouchard and Conrad (1973b) observed that sulfur in molasses was 65 to

Table 3

AVAILABILITY OF SULFUR FROM VARIOUS SOURCES AS FOUND IN IN VIVO STUDIES

Source	Criterion	%	Reference
L-methionine	True digestibility	77.8	Johnson *et al.*, 1971
DL-methionine	Apparent digestibility	59.9	Kahlon *et al.*, 1973
Methionine analog	True digestibility	77.0	Bull and Vandersall, 1973
Methionine analog	True digestibility	81.5	Bouchard and Conrad, 1973b
Methionine analog	Apparent digestibility	67.1	Kahlon *et al.*, 1973
Sodium sulfate	Growth rate	47.7	Albert *et al.*, 1956
Sodium sulfate	True digestibility	78.0	Johnson *et al.*, 1971
Sodium sulfate	True digestibility	87.0	Bouchard and Conrad, 1973b
Sodium sulfate	Apparent digestibility	64.0	Kahlon *et al.*, 1973
Elemental sulfur	Growth rate	29.4	Albert *et al.*, 1956
Elemental sulfur	True digestibility	36.0	Johnson *et al.*, 1971
Elemental sulfur	True digestibility	43.0	Kahlon *et al.*, 1973

Table 4

PERFORMANCE AND UTILIZATION DATA OBTAINED WITH SHEEP FED SULFUR FROM VARIOUS SOURCES (Kahlon *et al.*, 1975) FROM 0 TO 60 DAYS (INITIAL WEIGHT 32.8 kg)

	Sulfur source					
	Control	DL-Methionine	Hydroxy analog of methionine	Calcium sulfate	Sodium sulfate	Elemental sulfur
No. lambs	6	4	5	6	6	5
Daily gain, 0-60 days, g	—	206	172	190	171	174
Dry matter digestibility, %	—	78.5	79.7	80.1	79.4	77.9
N retention, % of intake	—	40.1	38.3	39.7	37.3	37.6
S intake, g/day	—	1.69	1.64	1.65	1.64	1.68
S retention, % of intake	—	41.1	47.0	43.2	39.0	37.9

75% digestible with dairy cows. This was 15 to 20% less than the availability of sulfur in calcium and sodium sulfates. The availability of sulfur in sheep rumen microbes was determined by using radioactive ^{35}S which had been incorporated into the cell walls (Bird, 1972). By infusing the labelled microbes into the a[illegible]nasum of sheep they observed a sulfur digestibility of 71%, which was close to the digestibility of sulfur as methio[illegible] (Johnson *et al.*, 1971). Kulwich *et al.* (1957) identified ^{35}S in the amino acids of milk, wool, blood plasma and [illegible]ner tissues after feeding them labelled ^{35}S-sulfate.

Kennedy (1974) reported that the addition of sulfate to the diet of cattle fed tropical spear grass (*Heteropogon contortus*) and Townsville stylo (*Stylosanthes humilis*) gave a small increase in digestibility of dry matter, but had no effect on feed intake. The cattle fed spear grass with sulfur supplement had more volatile fatty acids in the rumen contents. High quality dietary proteins may be reduced in nutritive value in the rumen, while low quality proteins and inorganic nitrogen and sulfur are increased in value by rumen microbial activity (Williams and Moir, 1951; Hungate, 1966; Purser and Buechler, 1966).

Sulfur status of ruminants has also been measured by circulating serum levels (Bray, 1964) and relative serum amino acid levels (Schelling and Hatfield, 1968). Kennedy *et al.* (1975) studied the movement of sulfate in plasma and rumen fluid in sheep and cattle fed alfalfa or spear grass hay. With the alfalfa diet 98 mg sulfur was recycled daily to the rumen of the sheep compared to 3.9 mg sulfur with the spear grass diet. The cattle fed alfalfa recycled 522 mg sulfur compared to 234 mg sulfur recycled to the rumen when fed spear grass. When radioactive sulfur as sulfate was administered intravenously to cattle and sheep fed alfalfa 5 to 10% of the dose was excreted in the feces and about 10% retained. Corresponding values for animals fed spear grass were 23-31% in feces and 40-51% retained. Overall they concluded that sulfate recycling to the rumen appears to be a limiting factor in microbial synthesis for ruminants fed low quality roughage.

Interrelationship of sulfur with other minerals. The dietary intake of an excess of S, Se or Mo may alter the requirements for each of the others (Vanderveen and Keener, 1964; Goodrich and Tillman, 1966). Feeding wethers 50 ppm molybdenum and .40% sulfate resulted in greater accumulation of copper in the kidney and increased copper excretion in the urine (Marcilese *et al.*, 1970). Their wethers also had reduced copper level in the liver and ceruloplasmin (Marcilese *et al.*, 1969). Perdomo *et al.* (1966) demonstrated that 50 and 100 ppm S as $KHSO_4$ in fertilizer decreased selenium uptake by alsike clover, corn and millet. Copper deficiency or copper liver retention relative to varying amounts of molybdenum and sulfur in pasture, forage and in hay diets have been studied by Hogan *et al.* (1968) and Dick (1953).

Sulfur alleviated somewhat the depression of cellulose digestion caused by excess copper in both *in vivo* and *in vitro* trials with steers (Evans and Davis, 1966). The relationship of sulfate to selenium in the treatment of muscular dystrophy in lambs was studied by Hintz and Hogue (1964). They reported that sulfur (0.33%) as sodium sulfate increased the clinical incidence of dystrophy and when given in combination with selenium prevented any beneficial effect of selenium. Pope *et al.* (1968) found orally administered radioactive selenium -75 was greater in wethers fed diets that contained 0.05% total sulfur than in those fed levels of 0.10, 0.16 and 0.20% sulfur. There were no differences in blood ^{75}Se in the latter three dietary groups. Less isotope was excreted in the urine of the wethers fed 0.05% dietary sulfur.

Sulfur and urea. The absence of sulfur in urea makes necessary special attention to the sulfur content of the diet for protein synthesis by rumen microbes (Loosli *et al.*, 1949; Thomas *et al.*, 1951; McLaren *et al.*, 1965). Jacobson *et al.* (1967) reported that a commercial-type diet of corn silage and urea concentrate reduced milk production in dairy cattle after 9 weeks compared to production of cows fed a concentrate that contained 0.9% $Na_2SO_4 \cdot 10H_2O$. Gil *et al.* (1973a) working with *in vitro* rumen bacteria fermentation of glucose with urea as the only source of nitrogen observed that out of 18 amino acids tested only the sulfur-containing amino acids and methionine hydroxy analog stimulated bacterial dry matter synthesis and glucose utilization. Inorganic sulfate was as effective as MHA and DL-methionine in stimulating protein synthesis only when fermentation was prolonged beyond 18 hours with starch and 24 hours with cellulose using urea as the only source of nitrogen (Gil *et al.*, 1973b). During shorter fermentation periods MHA and DL-methionine had significantly greater stimulatory action than inorganic sulfate.

Sulfide in nutrition. Sulfide sulfur may be the principal source of sulfur in microbial protein synthesis, and sulfur amino acid synthesis utilizes the sulfide substrate. The reduction of sulfate to sulfide as well as the desulfuration of cystine and cysteine in the rumen were demonstrated by Lewis (1954). Cystine and cysteine are rapidly broken down in the rumen, but methionine is decomposed to H_2S very slowly. Sulfide concentration usually reaches a peak in the rumen within two hours of feeding. The addition of sufficient sulfide to make 330 mg sulfide sulfur per ml of rumen fluid by Spais *et al.* (1968) did not produce any toxic symptoms in sheep. They observed a half-life of sulfide loss in the rumen of approximately 35 minutes.

Ruminants requirement for limited dietary N:S ratios. Ruminants through their rumen and its microbes may satisfy their metabolic requirements with dietary nitrogen and sulfur compounds and cellulosic materials that are inadequate nutritionally for non-ruminants.

Ruminant products such as beef, lamb and milk have nitrogen to sulfur (N:S) ratios of about 15:1, while wool is approximately 5:1 (see Table 5, for N:S ratios of various animal products).

In Table 6 are presented relative values (N:S ratios) of nitrogen and sulfur found by investigators in various feedstuffs (Garrigus, 1970).

Table 5

NITROGEN TO SULFUR (N:S) RATIOS OF VARIOUS RUMINANT PRODUCTS

Item	N:S ratios	Reference
Beef, raw, frozen	15.1:1	McCance and Widdowson, 1940
Milk, fresh, whole	18.3:1	McCance and Widdowson, 1940
Milk, goat	17.9:1	Macy *et al.*, 1953
Milk, goat	15.7:1	Mitchell and McClure, 1937
Mutton, leg roast	14.8:1	McCance and Widdowson, 1940
Wool, clean	4.9:1	Burns *et al.*, 1964

Table 6

NITROGEN TO SULFUR (N:S) RATIOS IN VARIOUS FEEDS FOR LIVESTOCK

Item	N:S ratios	Reference
Alfalfa hay	7.4:1	Loosli, 1952
Bacteria	15:1	Johanson *et al.*, 1949
Barley	9.8:1	Mitchell and McClure, 1937
Clover, alsike, 2nd cut	5.1:1	Crampton and Harris, 1969
Clover, Ladino, 2nd cut	16.7:1	Crampton and Harris, 1969
Clover, Red, hay	13.5:1	Loosli, 1952
Grains, distil., dehyd.	10.3:1	Crampton and Harris, 1969
Maize, silage	16:1	Loosli, 1952
Maize, grain	11.6:1	Crampton and Harris, 1969
Oats	8.5:1	Mitchell and McClure, 1937
Pasture plants	10.23:1	Begg and Freney, 1960
Sudan grass	28.2:1	Loosli, 1952
Timothy hay	8.5:1	Loosli, 1952
Vetch hay, 2nd cut	21.2:1	Crampton and Harris, 1969

An average N:S ratio of 13 to 1 was observed for a range of plant species with sulfur contents ranging from 0.05 to 0.58% (Barrow and Lambourne, 1962). The data of Begg and Freney (1960) show the N:S ratio narrowed from 23:1 to 10:1 as the sulfur content increased from 0.03 to 0.29% in plants. Nitrogen fertilizers without sulfur may cause greater N:S ratios (Stewart and Porter, 1969) in forages.

In Table 7 are presented N:S ratios of various Australian feedstuffs (Moir, 1970). The N:S ratios range about 10:1, except the peanut meal which is 18:1. Other well known pure vegetable proteins such as zein, edestin and gliadin have N:S ratios of 26.9:1, 21.2:1, and 17.2:1, respectively. Casein, myosin and serum globin have N:S ratios of 19.7:1, 13.1:1 and 14.3:1, respectively; while egg protein is close to 10:1.

Table 7

NITROGEN AND SULFUR CONTENT AND NITROGEN TO SULFUR (N:S) RATIO OF FEEDSTUFFS (MOIR, 1970)

Item	N %	S %	N:S ratio
Alfalfa	2.65	0.191	13.9
Wheat straw	0.91	0.111	8.2
Wheat	2.18	0.178	12.2
Oats	1.18	0.124	9.5
Coconut meal	3.44	0.283	12.2
Cottonseed meal	6.46	0.441	14.6
Linseed meal	5.87	0.452	12.9
Peanut meal	7.28	0.396	18.2
Safflower meal	2.86	0.212	13.5

However, the N:S ratio of the feedstuff protein is not important in itself if it is totally degraded in the rumen. If it is totally degraded then the ratio of the nitrogen to the total sulfur is the critical value (Moir *et al.*, 1967-68). They found a relationship between nitrogen intake (X_n), sulfur intake (X_s) and nitrogen balance (Y) to be $Y = 3.945 + 0.436X_n + 2.899X_s$. A maximum nitrogen balance was observed when animals were fed a N:S ratio of 10:1.

The amino acid composition of rumen bacterial has not been observed to vary with the diet composition (Purser and Buechler, 1966). However, with inadequate sulfur total yield of protein will be reduced (Gil *et al.*, 1973a,b).

Pope *et al.* (1968) found wide N:S ratios promoted selenium uptake and retention in sheep; but that narrow ratios depress retention. Narrow ratios may cause acidosis and depress fed intake (L'Estrange *et al.*, 1969).

Summary

While sulfur is one of the more abundant elements in the world a shortage of sulfur-containing amino acids is one of the world problems in animal nutrition. Sulfur occurs in animal tissues such as cartilage, bone, tendons and walls of blood vessels. Symptoms of sulfur deficiency have been described as loss of weight, weakness, lacrimation, dullness and death.

Most forms of sulfur must be either oxidized to sulfate or reduced to sulfide before they can be utilized by ruminants. This is largely a microbial process. Mammals do not reduce sulfate to sulfide needed for synthesis of sulfur-containing methionine and cystine, and the vitamins biotin and thiamin.

Plants and most bacteria can reduce sulfate to sulfide as indicated by their growth with sulfate as the only source of sulfur. The sulfur content of plants depends largely on the amount of sulfur in the plant protein. Apparently sulfate sulfur does not build up in the plant to any significant amount until the sulfur requirement of the plant for protein formation has been met.

Sulfur requirements of livestock have been determined through supplementing diets with methionine or cystine, sulfates, or elemental sulfur in balance trials and by radioisotope studies. Generally sulfur in the form of sodium sulfate, calcium sulfate, DL-methionine, methionine hydroxy analog and elemental sulfur has been demonstrated to be highly available for livestock. Animals supplemented with these five sources of sulfur have gained faster, consumed more dry matter, and retained more nitrogen and sulfur than those fed sulfur deficient diets. Sheep, beef and dairy cattle generally get along best with 0.1 to 0.2 percent sulfur in their diets. Additional sulfur may be needed when high levels of urea are fed. Inadequate sulfur levels will reduce the yield of microbial protein in the rumen. Maximum nitrogen balance was observed when animals were fed a N:S ratio of 10:1.

The dietary intake of an excess of sulfur, selenium, molybdenum and sulfur may alter the requirements or utilization of each of the others. High intakes of molybdenum and sulfate give greater accumulation of copper in the kidney and increased copper excretion in the urine. High levels of sulfur in fertilizer decreases selenium uptake by clover, corn and millet; and high dietary intake of sulfur resulted in decreased benefit of selenium in muscular dystrophy of ruminants.

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POTASSIUM AND IODINE IN RUMINANT NUTRITION

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Potassium

Potassium has been known to be of nutritional importance to animals and man since the science of nutrition was in its infancy. McCollum (1957) sights many experiments and observations of the early and middle nineteenth century that showed the essential nature of potassium in the diets of animals. Since these early experiments, much information on the physiological functions and the distribution in body fluids of this element has accumulated. There has been much less emphasis on the nutritional investigations of potassium.

Distribution of Potassium. Potassium is the third most abundant mineral element in the animal body, surpassed only by calcium and phosphorus.

MINERAL CONTENT OF ADULT CATTLE
(Average Values)

Major Elements	%	Minor Elements	ppm
Calcium	1.1–2.2	Iron	80
Phosphorus	0.7–1.2	Zinc	30
Potassium	0.3	Copper	3
Sulfur	0.25	Iodine	0.4
Sodium	0.15	Manganese	0.3
Chlorine	0.15	Cobalt	0.2
Magnesium	0.045		
		Molybdenum	+
		Selenium	+
		Fluorine	+

In contrast to sodium, which is the main electrolyte in the plasma and extra-cellular fluids, potassium is present primarily inside the cells (Wilde, 1962; Ganong, 1965; Kerman, 1965). The blood cells, or erythrocytes, contain approximately 25 times as much potassium as is present in the plasma. Muscle and nerve cells also are very high in potassium, containing over 20 times as much as that present in the interstitial fluids.

The remarkable segregation of sodium and potassium in the body fluids is one of the real "mysteries" of life.

Since potassium is found in every cell, the organs or tissues of the body with the largest number of cells, will contain the largest amount of potassium. The distribution of potassium within the body is shown in the following table (Ginsburg *et al.*, 1954):

CONCENTRATION AND DISTRIBUTION OF POTASSIUM

Tissue or Organ	K meq/kg	Potassium Content % of Total K
Muscle	110.0	56.0
Skin	58.6	11.1
Digestive Tract	96.6	5.6
Liver	95.0	5.3
Red Blood Cells	106.0	4.2
Blood Plasma	4.2	2.2
Brain	98.6	1.4
Kidney	77.6	0.9
Lung	79.3	0.5
Spleen	130.0	0.4
Heart	77.8	0.4
Bones and other Organs	–	12.0

Over two-thirds of the body potassium is found in the muscle and skin. A dressed carcass will contain about 75% of the body potassium.

Functions of Potassium. Potassium is absolutely essential for life. Young animals fail to grow and will die within a few days when the diet is deficient in this element. The principal functions of potassium are as follows:

1. It is the main factor in cellular osmotic balance.
2. In acid-base equilibrium, it acts as available base to neutralize acids.
3. An ionic balance exists between K^+, Na^+, Ca^{++}, and Mg^{++}. These ions affect capillary and cell function and the excitability of nerve and muscle. (For instance, potassium acts as a brake in regulating heart beat and suppresses heart flutter. It also helps prevent tetany, convulsions and an unsteady gait.)
4. Potassium is functional in maintaining proper water balance in the body.
5. Potassium activates or functions as a co-factor in several enzyme systems. These include energy transfer and utilization, protein synthesis, and carbohydrate metabolism.
6. It is an important component of several animal products—milk, meat, eggs.

Active transport of potassium and sodium across the cell membrane plays an important part in certain potassium dependent phenomena. These include the electrical activity of nerve and muscle cells and synaptic transmission (Harrison, 1954), electrolyte and water distribution between various body fluid compartments, intra- and extra-cellular pH (Harper, 1965), cellular respiration (Bilodean and Elliott, 1963), gastro-intestinal function (Seekles, 1960), and urine formation.

Many enzymes have a specific requirement for potassium (Kerman, 1965; Ussing 1960; Boyer, 1953). In certain instances, potassium may act along with certain other ions such as Na^+, Mg^{++}, and Ca^{++} in influencing enzyme activity. In other cases, potassium will accelerate an enzymatic reaction while sodium or calcium may inhibit the reaction (Cannon *et al.*, 1953; Ussing, 1960). Some of the enzyme systems influenced or activated by potassium are as follows:

SOME ENZYME SYSTEMS ACTIVATED BY POTASSIUM

Enzyme	Function
Adenosine triphosphatase	Splits phosphate from energy-rich ATP and releases energy. ATP is one of the major energy storage compounds in tissue.
Hexokinase	Aids in the formation of phosphorylated sugar derivatives in carbohydrate metabolism.
Carbonic anhydrase	A decarboxylating enzyme which acts on bicarbonate with CO_2 and water as end products.
Cholinesterase	Inactivates muscle stimulation by hydrolyzing acetylcholine to choline and acetic acid.
Galactosidase	Important for the hydrolization of certain polysaccharides to simple sugars in carbohydrate metabolism.

OTHER ENZYMES ACTIVATED BY K:

Salivary amylase	Pyruvic kinase
Acetate activating enzyme	Phosphotransacetylase
Homoserine dehydrase	Fructokinase

Inside the cell K^+ is concerned with many metabolic reactions involving phosphate (Boyer *et al.*, 1943; Eckel, 1966). Here part of its function may be local buffering or neutralizing of phosphate esters. Since phosphate metabolism is so fundamental, a great diversity of metabolic reactions of the cell seem to be influenced by K^+.

Potassium Homeostasis. There is no single organ that plays a more important role in the maintenance and control (homeostasis) of potassium than the kidney (Ganong, 1965). The mechanism by which the kidney controls electrolyte balance is mediated almost entirely through the hormones of the adrenal cortex (Harper, 1965). The hormones of this gland, particularly aldosterone, have an important effect on the handling of sodium and potassium by the renal tubules. These hormones favor the reabsorption of sodium and the excretion of potassium. In certain diseases, there is an insufficient production of these hormones resulting in an excess loss of sodium and retention of potassium. Conversely, the hyper-activity of the adrenal cortex, or the administration of adrenal hormones, results in excessive reabsorption of sodium and urinary loss of potassium. Normally, hormonal output is controlled by various receptors throughout the body which are affected by such things as osmotic pressure and concentration levels of the various electrolytes. Stress conditions tend to increase the activity of the adrenal gland—this is a normal reaction of any animal. With the increased circulating levels of adrenal hormones, kidneys tend to conserve sodium but increase the excretion of potassium. The result is an excessive loss of potassium from the body due to the reponse of the animal to its control mechanisms. Animal management systems often subject the animal to increased stress levels and, consequently, possibly increase the potassium requirement. The most severe cases of stress are found during periods of shipment to market—crowding into trucks, rail cars, etc. During this period of time, the animal actually excretes or loses a large percentage of its potassium

stores, in addition to intra-cellular water. While the normal kidney functions well in removing excessive amounts of potassium in the plasma, it seems to have little capacity for the conservation of potassium in the face of deficiency. In fact, renal excretion of potassium continues even when body levels are dangerously low.

Potassium Deficiency. Potassium deficiency can be the result of several causes:

1. Inadequate amount in the diet and consequently an inadequate intake.
2. Loss in digestive secretions caused by vomiting or diarrhea. Large amounts of electrolytes are lost from the body during dysentery or scours.
3. High salt consumption increases the requirement for potassium and can precipitate a potassium deficiency when intakes are marginal. Increased urination due to a high water intake caused by either hot weather or increased salt intake, increases the loss of potassium from the body.
4. Stress conditions (cold weather, diseases with fevers, hard work, injury).

Potassium depletion may commonly be manifested by:

1. Depressed growth
2. Muscular weakness
3. Stiffness and paralysis
4. Decreased feed intake
5. Intra-Cellular acidosis
6. Degeneration of vital organs
7. Nervous disorders

Potassium is a dietary essential that needs to be supplied in the daily ration because it is a very mobile element. There are no appreciable reserves other than that in the muscle and nerve cells, where it is vital to normal cellular functions.

Potassium has been shown to affect appetite in ruminants. Various experiments have shown that daily feed consumption of lambs and steers was decreased by inadequate potassium (Driedger, 1966). The effect of potassium on appetite does not appear to be mediated solely via the oral cavity. St. Omer (1965) observed that steers receiving a potassium deficient ration in conjunction with intra-ruminal injections of potassium, displayed superior appetite and gained significantly more body weight than steers receiving the same ration but intra-ruminally injected with only deionized water.

Sheep. Telle *et al.* (1964) demonstrated the effects of graded levels of potassium on finishing lambs over a 108-day period.

DATA FOR LAMBS FED VARIOUS LEVELS OF POTASSIUM (K_2CO_3 and $KHCO_3$)

Item	Feed Potassium Level (%)			
	0.30	0.38	0.42	0.62
No. of lambs	8	8	8	8
Body weight, lb.				
Initial	59.2	60.5	60.0	63.6
Final	100.5	101.8	104.6	110.3
Average daily gain	0.38[a]	0.38[a]	0.42[b]	0.44[b]
Feed Intake, lb.				
Daily	2.53	2.73	2.53	2.74
Per lb. gain	6.62	7.15	6.18	6.21
Carcass data				
Dressing %, hot	54	55	53	56
Carcass gain, lb.	25.6	27.6	27.5	31.4
Carcass grade	Low Choice[c]	Low Choice[c]	Choice[d]	High Choice[e]

a-e Values with different letters are significantly different ($P < .05$)

These data show that the best overall results were obtained at the highest level of potassium that these researchers tried, i.e., 0.62%. This is reflected in rate of gain, feed intake, dressing percent, carcass gain, and carcass grade.

Campbell and Roberts (1965) fed various levels of potassium in the carbonate form to finishing lambs for 56 days. Their results are as follows:

FEEDLOT PERFORMANCE OF LAMBS ON GRADED LEVELS OF POTASSIUM (K_2CO_3)

Item	Feed Potassium Level (%)			
	0.1	0.3	0.5	0.7
No. of lambs	16	16	16	16
Average daily gain, lb.	0.31[a]	0.05[b]	0.38[c]	0.37[c]
Feed intake daily, lb.	0.92	1.91	2.64	2.71

a-c Values with different letters are significantly different ($P < .01$)

Beef Cattle. In feeding trials with steers, Devlin, Roberts and St. Omer (1965) obtained the following results in a 110-day trial using potassium carbonate.

FEEDLOT PERFORMANCE AND RUMEN MICROBIAL ACTIVITY OF STEERS FED GRADED LEVELS OF POTASSIUM (K_2CO_3) FOR 110 DAYS

Item	Feed Potassium Level (%)			
	0.27	0.51	0.72	0.85
No. of steers	6	6	6	6
Body weight, lb.				
Initial	621	619	642	611
Final	643	837	962	914
Average daily gain	0.20[A,a]	1.98[B,b]	2.91[B,c]	2.15[B,c]
Feed intake, lb.				
Daily	8.4	13.9	17.8	17.2
Per lb. gain	42.4	7.0	6.2	6.3
Rumen microbial activity[1]	30.6	50.3	66.5	73.3

1 Changes in mm. H_2/gm dry matter/90 minutes.
A,B Values with different letters are significantly different ($P < .01$).
a-c Values with different letters are significantly different ($P < .05$).

In a following trial, these researchers (Roberts *et al.*, 1965) used potassium chloride and its effect on potassium requirement and performance can be observed.

FEEDLOT PERFORMANCE AND CARCASS DATA OF STEERS FED SUPPLEMENTAL POTASSIUM (KCl) FOR 104 DAYS

Item	Feed Potassium Level (%)			
	0.50	0.69	0.93	1.05
No. of steers	6	6	6	6
Body Weight, lb.				
Initial	734	746	729	735
Final	990	998	1023	999
Average daily gain	2.46	2.42	2.88	2.54
Feed intake, lb.				
Daily	18.0	19.4	19.6	19.8
Per. lb gain	7.3	8.0	6.8	7.8
Dressing percent	59.5	59.7	58.5	59.6
Carcass grade	Low Choice	Choice	Choice	Choice

From the two preceding trials, maximum gains and feed efficiency occurred at 0.72% K with potassium carbonate and at 0.93% K when potassium chloride was used. However, feed intake continued to increase even at the highest level of potassium chloride supplementation. The addition of potassium carbonate had an effect on ration palatability which was not noted with potassium chloride.

Cattle on low potassium rations chewed wood in the pens and barns in which they were kept to such an extent that it became a real facilities maintenance problem. Commercial nutritionists have noted that supplemental potassium will halt wood chewing where phosphorus nutrition is adequate.

Woods and Foster (1970) noted improvements in feedlot cattle performance when supplements for use with shelled corn contained KCl.

Based upon these research findings, the fourth edition of the National Research Council's Nutrient Requirement of Beef Cattle (1970), makes the following statement regarding the K requirements of beef cattle: "potassium requirements of beef cattle have not been critically measured, but the optimum level for growing and finishing steers has been reported to be 0.6-0.8% of ration dry matter. Requirements at this level would be amply met with high-forage rations, which usually contain several times the amount present in high-grain rations. Grains often contain less than 0.5% of potassium, and the level may become critical in high-or all-concentrate rations." The NRC bulletin goes on to list the potassium requirement for growing and finishing steers and heifers as 0.6-0.8% of ration dry matter.

Dairy Cattle. Du Toit *et al.* (1934) were the first to investigate the potassium requirements for dairy cattle. They found that a ration providing K as 0.32% of the dry matter was adequate to maintain milk production of two gallons per day over a period of two lactations.

There is only a limited amount of research on the dietary K requirements of dairy cattle. Ward (1966) in his review of K metabolism of domestic ruminants indicated that the dietary requirement was probably no more than about 0.5% of the ration. Pradham and Hemken (1968) indicate that the level required may be 0.8%.

Pradham and Hemken studied K deficiency symptoms in lactating cows using a change-over experiment involving eight cows. K deficient (0.06 and 0.15% K) and K adequate (0.80% K) rations were tested. Deficiency symptoms were manifest in about 3-4 weeks on the cows receiving the low potassium ration. These include partial to almost complete inanition and pica, characterized by hair licking of stall-mates, floor licking, and chewing of wooden partitions. The coat showed a gradual loss of glossiness and finally turned very rough.

Cows fed deficient rations consumed 34% less ($P<0.01$) feed than those fed a ration adequate in potassium.

When we examine the composition of cow's milk, we find that the mineral element present in highest concentration is potassium.

COMPOSITION OF COW'S MILK

	%
Water	87.2
Protein	3.5
Fat	3.7
Lactose	4.9
Ash	0.71
	%
Potassium	0.147
Calcium	0.102
Chlorine	0.101
Phosphorus	0.055
Sodium	0.053
Sulfur	0.028
Magnesium	0.010
Iron	0.001

It is not appreciated by many that the need for potassium in milk production is considerably greater than that of either calcium or phosphorus. A dairy cow in high milk production excretes large quantities of potassium each day in her milk. Studies by Rook and Wood (1959) as well as Sasser *et al.* (1966) indicate that healthy cows have the ability to produce milk with a constant concentration of potassium.

The National Research Council bulletin on the Nutrient Requirements of Dairy Cattle, (1971) comments that based on the limited research data available, the dietary potassium requirement for dairy cattle is between 0.5 and 0.8%. To date, there is no research data available to indicate what the exact needs of the high producing cow are; however, it is possible that at peak lactation, the potassium requirement could be as high as 1.0% of the ration dry matter.

Potassium supplementation of finishing rations for beef is now becoming a common practice. Diets based largely upon milo, corn, or corn and cob meal together with low potassium hays and silages, may fall short in providing sufficient potassium for fast growing or high producing animals.

Forages, traditionally recognized as good sources of potassium, can vary significantly in potassium content with the season of the year. Potassium additions to range supplements or minerals has been shown to have a beneficial effect on animal performance.

In some areas dairy farmers have taken hay out of their programs and use corn silage as the only roughage. In addition, greater use is being made of NPN protein sources. All of these factors reduce the total daily intake of potassium. Many nutritionists have noted marked improvement in appetite and subsequent increases in milk production when dairy herds assumed to be receiving sufficient potassium were supplemented with an inorganic source.

The following table summarizes the known potassium requirements and indicates recommended dietary levels. Nutritionists are recognizing that potassium is not only a useful element but is a critical element for maximum production with today's management systems.

RECOMMENDED POTASSIUM LEVELS
(% in Total Ration Dry Matter)

Animal	NRC	IMC
Beef Cattle	0.6-0.8	0.7-0.8
Sheep	–	0.7-0.8
Dairy Cattle		
Heifers & dry cows	0.7	0.7-0.8
Lactating cows	0.7	0.8-1.0

Iodine

Iodine is unique among the required trace elements in that it is a constituent of a hormone-thyroxine. Thyroxine regulates the metabolic rate in animals, thus, iodine through this mechanism, has a strong influence on growth and production in livestock. As far as is known, iodine has no other function. Numerous reviews are available on the subject of iodine metabolism and its relationship to thyroid function and body metabolism. Underwood (1971) has presented a complete and descriptive coverage on this element. Other excellent reviews are that of Gross (1962) and Miller *et al.* (1975).

Iodine tends to be highly concentrated in the thyroid gland, evidence indicating that 70-80% of the total body supply is found in this gland. Gross (1962) points out that thyroid iodine is found as thyroglobulin and its constituent iodinated amino acids (principally tri-, di-, and mono-iodotyrosine or di- and tri-iodothyronine). Thyroxine, however, is the major organic iodine compound in plasma, being bound to plasma proteins (globulins and albumins) that can be precipitated for analysis. Inorganic iodides, which can be removed with anion exchange resins, are also found in plasma, but they account for only about 10% of total plasma iodine in cattle (Aschbacher *et al.*, 1963).

Underwood (1971) points out that a deficiency of thyroid hormones may be the result of an absolute dietary deficiency of iodine, a deficiency of iodine conditioned by the presence of goitrogens, or the result of a metabolic defect in the synthesis of thyroid hormones. In ruminants, it is assumed that the first two of these are the cause of most problems related to iodine.

With respect to deficiency symptoms observed, a lowered basal metabolic rate is seen in all animals, the value declining to 50% or less when cows have been thyroidectomized. In the pregnant animal, a deficiency is apt to result in the birth of hairless (or woolless), weak, or dead young. Goiter (enlarged thyroid) is a result of changes in thyroid tissue cells which enlarge as a result of the deficiency of iodine. It would appear that goiter may be a symptom of a less severe deficiency than the lack of hair or wool. In animals of breeding age, a thyroid or iodine deficiency severely reduces productivity, resulting in suppressed estrus periods in the female and a lack of libido in the male.

Several studies have been made comparing the relative value of iodine sources. Stability of iodine compounds is important since iodine is easily destroyed in the diet unless it is protected against oxidation. A variety of iodine compounds have been used in mineral mixes. Salts such as KI or NaI are easily lost. Generally the iodates or some organic forms of iodine are considered to be the most stable. Availability studies on various iodine compounds indicate that several sources are relatively equal in availability (Ammerman and Miller, 1972). Research reports from the University of Tennessee (Miller *et al.*, 1964; Aschbacher *et al.*, 1963) have indicated that diiodosalicylic acid (DIS) is not a good source of iodine for ruminant animals. These studies show that the iodine from DIS was absorbed as rapidly as the iodine from the iodides but the iodine from DIS is metabolized quite differently. It was shown that the iodine from DIS is not split from the ring structure by the animal and is subsequently excreted and not made available to the thyroid.

Underwood (1971) points out that iodine requirements of ruminant species have not been well established. The effect of goitrogens on the inhibition of thyroid activity has been well documented. A wide variety of plants have been implicated (Underwood, 1971). The net effect, in most instances, is to increase the iodine requirement. The feeding of other feedstuffs, such as a high intake of corn silage, has been shown to result in calves with goiter (Hemkon *et al.*, 1971). The following table summarizes the current recommended dietary levels of iodine for ruminants.

RECOMMENDED IODINE LEVELS
(ppm in total ration dry matter)

Animal	NRC	IMC
Dairy		
Calves	0.1	0.5
Heifers-growing	0.1	0.5
Cows-dry	0.6	0.8
Cows-lactating	0.6	0.8
Beef		
Steers & Heifers	–	0.5
Cows-pregnant	0.05-0.1	0.5
Cows-lactating	0.05-0.1	0.5
Sheep		
Lambs	0.1	0.5
Breeding animals	0.8	1.0

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COBALT IN RUMINANT NUTRITION

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Although cobalt was shown to occur in plant and animal tissue many years ago, Waltner and Waltner (1929) presented the first clear evidence that cobalt possesses biological activity. In large doses, cobalt stimulates erythropoiesis in rats and induces polycythemia. Underwood (1971) credits this discovery with great historical significance because it stimulated interest in the possible physiological role of cobalt and was responsible for this element being given an early trial in "coast disease," the first of the naturally-occurring diseases of sheep to respond to cobalt therapy. There is no evidence, however, that the polycythemic action of cobalt is related to its normal functioning in any species.

Descriptions of symptoms which have later been attributed to cobalt deficiencies in ruminants began to appear in the literature around 1800 (Fraser, 1794; Hogg, 1807 and 1831). During the following years, reports of the same or similar conditions in cattle and sheep appeared in the literature in various parts of the world. A condition known in Florida as "salt sick" was first reported by Maxwell in 1888. It is interesting to note that the bulletin in which this work was reported was the first published research report by the Florida Agricultural Experiment Station. In this sense, cobalt deficiency was among the first problems to be recognized by what was later to become known as the Animal Science Department of the University of Florida. Becker *et al.* (1965) have reviewed the history of "Salt Sick" in Florida from its earliest beginnings.

The effects of cobalt deficiency have been known by a multitude of names throughout the world:

U.S.A.	"Salt Sick," Florida. "Neck Ail," Massachusetts. "Burton Ail," New Hampshire. "Grand Traverse Disease," Michigan. No special name, Wisconsin.
Australia	Coast disease, bush sickness, enzootic marasmus.
New Zealand	Bush sickness, Morton Mains disease.
East Africa	Nakuritis.
Scotland	Pining disease.
Brazil	"Mal de colete," "peste de secar," "sablose," "mal de fastio."

The disease was essentially the same in each case and could only be controlled by periodic removal of animals to healthy areas. Because of this, the condition was correctly assumed to be caused by a nutritional deficiency.

Deficiency Symptoms

The deficiency symptoms of acute cobalt deficiency reported by workers in Florida are essentially the same as those reported by researchers in other parts of the world (Davis, 1958). These include lack of appetite, rough hair coat, thickening of the skin, anemia, wasting away, and eventually death, if the animals are not moved or if cobalt supplements are not made available. These symptoms are identical to those of simple starvation and may indicate that the effect of a lack of cobalt may be simply the effect on appetite, rather than a direct effect of the mineral on the body itself.

Although acute symptoms are more dramatic, Latteur (1962) has suggested that areas where sub-deficiencies of cobalt exist may represent an even greater economic loss. The author discusses some of the effects of sub-deficiencies of cobalt on predisposition to paratuberculosis, primary digestive disorders and anomolies of fertility. No estimate can be made of the effect of cobalt sub-deficiencies on animal performance in general, but in many areas of the world, it is one of the major causes of poor production.

The Iron Deficiency Theory

While anemia is not usually the first symptom observed under severe deficiency conditions, it is one that is easily verified in the laboratory. Because an anemic condition is one of the symptoms of acute cobalt deficiency, it is natural that some of the first research work involved supplementation with iron compounds such as limonite ($Fe_2O_3 \cdot H_2O$, a naturally-occurring hydrated oxide of iron). Early investigators often effected cures by supplementing cattle with iron compounds (Aston, 1924). For a time, iron deficiency was accepted to be the cause of this condition (Becker *et al.*, 1931). Filmer (1933) recognized that the iron deficiency theory did not adequately explain the condition as it existed in Australia and suggested that some other nutrient must be involved. A report by Rigg and Askew (1934), revealing insignificant differences in the iron content of forages from "healthy" and "sick" pastures and the low correlation of the iron content of compounds and their curative effects (Grimmett and Shorland, 1934), lent support to Filmer's Theory that something else must be involved.

Cobalt Deficiency

Australian workers (Filmer, 1933; Filmer and Underwood, 1934), working with a wasting disease in sheep (enzootic marasmus) in the south coastal areas, became suspicious of the large doses of iron compounds that were necessary to cure the disease. They could find little relationship between the size of an effective dose and the amount of iron that it supplied. They also noted that the liver and spleen of affected animals often contained large stores of iron. This was further compounded by the fact that when whole liver which contained very little iron was given to sick animals, they recovered. The most convincing evidence was their discovery that an iron-free extract of limonite was just as effective

as the ore itself in curing the disease. These authors advanced the theory that enzootic marasmus was caused by the deficiency of some trace element which was present as a contaminant in the iron ore which had been used successfully to cure the disease.

Underwood and Filmer (1935) chemically fractionated limonite and after some misleading tests with nickel (suggested by the large amounts of that element present), found that the potency of limonite resided in the cobalt that it contained. Subsequently, small doses of cobalt were shown to cure the disease in all areas where limonite had been effective.

At this same time, Marston (1935) was studying a coast disease in sheep which occurred on the calcarious sandy dunes of South Australia. A mineral mixture containing small amounts of various micro-elements was highly effective in curing the disease. The fact that coast disease was accompanied by anemia, coupled by the earlier findings that cobalt stimulates hemopoiesis in rats, led to the suggestion that cobalt might be the element responsible for the beneficial effects of the mixture. Marston (1935) showed that sick sheep given 1 mg/day of cobalt improved dramatically.

Filmer exchanged samples of limonite with Becker and Gaddum (1937) for samples that had not been effective in curing "salt sickness" in Florida. Spectrographic analyses showed that the effective limonite contained .005 percent cobalt oxide, while the ore from Florida contained none. Supplementation of cattle in Florida with small amounts of cobalt along with copper was shown to cure "salt sickness" (Becker *et al.*, 1965). Experiments in Australia have also indicated that copper is sometimes necessary to cure marasmus (Underwood, 1971).

Vitamin B-12

Although cobalt was recognized as an essential microelement for ruminants, the action of cobalt in the body and the reason for its necessity were not discovered until the simultaneous discovery of vitamin B-12 by Smith (1948) in England and Rickes *et al.* (1948) in the U.S.A. Both of these groups had reported the presence of cobalt in their compounds, which were effective against pernicious anemia in humans.

Cobalt is required by microorganisms of the rumen for the synthesis of vitamin B-12. If the element is deficient in the diet, the vitamin cannot be produced in the rumen in amounts sufficient to satisfy the requirements of the protozoa that live symbiotically in the rumen, nor of the animal itself. Ruminants have a higher requirement for cobalt than monogastrics because some of the element is wasted in microbial synthesis of organic compounds with no physiological activity in the host's tissues. Vitamin B-12 is poorly absorbed from the digestive tract of ruminants, the availability in some cases being as low as 3 percent. In addition, it has been shown that the ruminant animal has a higher requirement than the non-ruminant, presumably because of its involvement in the metabolism of propionic acid, a major energy source that is produced by the rumen microorganisms.

Enzootic marasmus is therefore regarded as being due to a deficiency of vitamin B-12. Injections of the vitamin alleviated the condition whereas cobalt injections did not.

There is evidence that the intestinal microorganisms in non-ruminants can also synthesize vitamin B-12. In pigs and poultry, this synthesis may be insufficient to meet requirements. It is common practice to include in monogastric diets some animal protein food rich in vitamin B-12 or the vitamin itself, rather than the cobalt salt.

In addition to the importance of cobalt as a component in vitamin B-12, it is believed to have other functions in the body as an activating ion in certain enzymes. Evidence to support this belief has not been forthcoming.

Cobalt In The Soil

Kubota (1968) has reported a high correlation between type of soil and cobalt deficiency in the U.S.A. Workers in other countries have also reported high correlations between soil types and cobalt deficiencies.

Soil containing less than 2 ppm cobalt is generally considered deficient for ruminants. (Corner and Smith, 1938; Correa, 1957). Because of the many factors that can affect the availability of cobalt to the plant and animal, Latteur (1962) has cautioned against the use of level of cobalt in the soil alone as an indicator of the adequacy or deficiency of this mineral. When cobalt levels in the soil are high, the amount available to the plant is usually sufficient. At borderline levels of cobalt in the soil however, it is difficult to correlate soil level and deficiency symptoms in ruminants.

Factors That Affect The Availability Of Cobalt To The Plant

Overliming and the subsequent rise in soil pH renders cobalt almost completely unavailable to the plant. Plants grown on a 15 ppm soil that is neutral or slightly acid may contain more cobalt than those grown on a 40 ppm alkaline soil.

High rainfall tends to leach cobalt from the topsoil. This problem is often aggravated further by the rapid growth of forage during the rainy season which dilutes the cobalt content.

Plants have varying degrees of affinity for cobalt, some being able to concentrate the element much more than others. Legumes, for example, generally have more ability to concentrate cobalt than do grasses. Most of the cobalt present in plants tends to concentrate in the leaves. Robertson (1971), reviewing the literature concerning the cobalt content of soil and herbage, concluded that there is a wide variation in what is considered low cobalt levels in soils, and to a lesser extent, in plants. He concludes that because of this variation and because of the factors which can affect the uptake of cobalt by the plant, the level of cobalt in the soil at any one point in a field at a particular time is only of academic interest.

Cobalt Level In Plants

As previously stated, the level of cobalt found in forages is determined by many factors and not merely by soil content. This becomes increasingly true when the level of cobalt in the soil is low. The level of cobalt in the forage is a much more useful tool in measuring its adequacy, since there seems to be a direct relationship between cobalt in the forage and the health of ruminants grazing that forage. Latteur (1962) has presented the following figures to indicate the commonly found levels of cobalt in forages as related to deficiency status in ruminants:

.01 ppm	extreme deficiency
.01-.04 ppm	deficient
.04-.07 ppm	insufficient
.07 ppm	lowest limit for health
.10-.30 ppm	increase in productivity

It appears that less than .1 ppm in the forage should be considered cobalt deficient.

Cobalt Level In Animal Tissues

Although cobalt is widely distributed throughout the body, there is no excessive accumulation tissue. The highest concentrations usually occur in the liver, kidneys and bones. Askew and Watson (1943) have studied the concentrations in the various organs of healthy and cobalt deficient sheep. The results are presented in Table 1.

Table 1
CONCENTRATION OF COBALT IN TISSUES OF HEALTHY AND DEFICIENT SHEEP (ppm)

Organ	Healthy	Deficient
Liver	.15	.02
Spleen	.09	.03
Kidney	.25	.05
Heart	.06	.01
Pancreas	.11	.02

It is obvious that cobalt concentrations are reduced in the organs of cobalt deficient sheep. They can also be increased above normal levels by cobalt injections or dietary supplements (Underwood, 1971). There has been much interest shown in the use of the level of cobalt in the liver as a tool to diagnose cobalt deficiences under practical conditions. Table 2 presents the levels of cobalt found in the livers of healthy and deficient ruminants by several researchers.

Table 2
LEVEL OF COBALT IN THE LIVER OF HEALTHY AND DEFICIENT RUMINANTS (ppm)

Species	Healthy	Deficient	Author
Sheep	.28	.06	Marston *et al.*, 1948
Sheep	.34	.09	Underwood and Harvey, 1938
Cattle	.21	.06	Correa, 1957; Gessert *et al.*, 1952
Sheep	.20	.02	Lee, 1963

Underwood (1971) has stated that because cobalt injections can raise liver cobalt 10 times without being available to the microbes for B-12 synthesis and because ruminants on cobalt-deficient diets can be maintained in good health by vitamin B-12 injections without raising liver cobalt, high or low levels of cobalt in the liver do not in themselves indicate the cobalt status of the animal. Under practical conditions, however, the concentration of cobalt in the liver of ruminants is sufficiently responsive to changes in cobalt intakes to have value in the diagnosis of cobalt deficiency. It should be remembered that the only positive proof of a mineral deficiency is a positive production response when that mineral is given as a supplement.

Underwood (1971) believes that blood cobalt values are so variable as to be of little use in diagnosing cobalt deficiency.

Cobalt Requirements

Although B-12 injections will prevent marasmus in ruminants, it is more convenient and cheaper in cobalt-deficient areas to supplement the diet with this element, allowing the microorganisms to synthesize the vitamin for subsequent absorption by the host. The evidence of the quantitative needs for cobalt rests on studies of its content in herbage where trouble does and does not occur. It has been reported that the dry matter of grass of healthy areas, contains around .1 ppm of cobalt on the average as compared with .004 to .07 ppm for deficient areas. As little as .1 ppm has restored sick animals to health.

Reliable data concerning the adequacy or inadequacy of cobalt in the food supply of our ruminants is very scarce. Pasture grasses are often known to be low in cobalt. Where a deficiency of cobalt is suspected, the simplest way to insure its prevention is to provide a cobalt supplement to sheep and cattle. Most complete mineral supplements (including salt) containing .01% cobalt are usually adequate for protecting against cobalt deficiencies. Slightly more may be added if cobalt deficiency in the area has been confirmed. For milking cows, cobalt sulfate can be added to the grain mixture at the rate of 0.2 g per metric ton. On this basis 1 kg of grain would provide the requirement of approximately 1 mg of cobalt per day. A continuous supply from a single dose can be obtained by giving a cobalt "bullet" containing 90% cobaltic oxide. The "bullet" remains in the rumen and slowly releases the element over a long period of time. In early work, trouble was incurred with regurgitation of the "bullet" or by the coating of it in the rumen. Recent reports from Australia indicate that these problems have been overcome to a large extent.

Cobalt Toxicity

Excess cobalt can be toxic to animals. Although most authors consider the margin between safe and toxic doses to be wide enough to render a toxicity under natural conditions to be unlikely, several reports have appeared in the literature concerning cobalt toxicity (Dickson and Pond, 1974). These reports almost invariably involve management mistakes in formulating mineral mixtures.

Cobalt Deficiency In Brazil

Tokarnia and Döbereiner (1973) have recently reviewed the literature concerning diseases caused by mineral deficiencies in Brazil. Cobalt deficiencies have been noted in São Paulo (Correa, 1957), Ceará (Tokarnia *et al.*, 1961), Amapa (Tokarnia *et al.*, 1971), Espirito do Santo (Tokarnia *et al.*, 1971), Maranhão (Damaso and Tokarnia, 1961), and Rio Grande do Sul (Gavillon and Quadros, 1970). Without doubt, many other areas in Brazil and Latin America are deficient or sub-deficient in cobalt.

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COPPER AND MOLYBDENUM IN RUMINANT NUTRITION

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Copper

Introduction

The presence of copper in the tissue of plants and animals was identified more than 150 years ago. Its presence was considered unimportant until 1926 when McHargue demonstrated its essentiality in the diet of rats. In 1928, Hart and collaborators showed that in addition to copper, iron was also indispensable in the formation of hemoglobin.

Shortly after the discovery of the essentiality of copper for rats, certain illnesses in cattle and sheep in pasture were identified as being caused by a deficiency of copper and were cured by the administration of this element. In 1931 in Florida, Neal and collaborators (Underwood, 1971), performed experiments, indicating for the first time that copper deficiency can occur naturally in animals. After this data, diseases in cattle and sheep identified as copper deficiency were also reported in Holland, Australia, and in other parts of the world. Problems with pigment formation, keratinization of wool, bone formation, reproduction, cardiac function, formation of connective tissues, plus problems of growth and hematopoiesis, were recognized as being clinical signs of the copper deficiency.

Research was also developed pertaining to the mode of action of copper at the cellular level. Many copper containing proteins were isolated from living tissues; most of which were enzymes involved in oxidative reactions.

Copper in the tissues

The level of copper in the animal's tissues varies with the age of the animal, with young animals normally having higher concentrations of copper than adults. Underwood (1971) presents a summary of the literature, showing the copper concentrations in various tissues of different animal species at varying ages. Obviously, the distribution of copper in the tissues varies with species, age, and nutritional state of the animal. Individual variations within the species are quite great with sex of the animal apparently having no influence on tissue concentrations.

Under normal conditions, the liver in the majority of adult species contains between 10 to 50 ppm of copper (dry basis) with levels from 15 to 30 ppm being more frequent. Ruminants have normal concentrations much higher than these values, on the order of 200 to 600 ppm. Table 1 summarizes copper concentrations found in livers of sheep and cattle in diverse conditions of age and nutrition, according to Cunningham, cited by Underwood (1971).

Generally, copper liver concentrations in the majority of the animal species decreases as the animal matures. Yet, sheep and cattle constitute an exception. In sheep, liver copper levels increase continuously with maturity of the animal and in cattle there is little variation between young and mature animals. However, the young ruminant in some cases may have higher levels than the adult (Church, 1971).

Table 1

LEVELS OF COPPER IN THE LIVER OF CATTLE AND SHEEP AS A FUNCTION OF THE AGE AND NUTRITION

Specie	Age and Treatment	No. of Animals	Concentration of copper (ppm)*	Reference
Sheep	New born			
	Normal diet	27	168(74-430)	Cunningham, 1946
	Deficient diet	29	13(4-34)	" "
Sheep	Adult:			
	Normal diet	44	599(186-1374)	" "
	Deficient diet	35	27(7-106)	" "
Cattle	New born:			
	Normal diet	41	381(143-655)	" "
	Deficient diet	20	55(8-109)	" "
Cattle	Adult:			
	Normal diet	23	200(23-409)	" "
	Deficient diet	41	11.5(3-32)	" "

*Liver dry matter basis.

Abnormal ingestions of copper during gestation can cause abnormal levels of copper in the liver of the newborn. Bennets and Beck, cited by Underwood (1971), found levels of copper from 4 to 8 ppm in the dry matter of the liver of lambs born of mothers whose diets were deficient, in comparison to levels from 120 to 350 ppm in the liver dry matter of lambs whose mothers received normal diets. Copper supplementation during gestation is extremely effective in increasing the level of copper in the newborn. Yet, extreme doses of copper, with obvious respect to toxic limits, will not signify that the newborn will have hepatic levels above normal, possibly due to small placental transfer.

Dick (1954) studied the accumulation of copper in the liver of sheep when receiving diets that contained daily intakes of copper varying between 3.6, and 33.6 mg per day during a period of 177 days. The level of copper in the liver increased from 562 ppm in the poorest diet to 2,340 in the richest diet. Up to the level of 18.6 mg per day, the quantity of accumulated copper in the liver was proportional to the intakes. The behavior of monogastrics in this aspect is different from ruminants; in these animals, apparently, the hepatic concentrations increase in relation to the daily intake, only after having overloaded the mechanism of excretion.

The intracellular distribution of copper in the liver does not appear to have been studied in ruminants; however, in rats, Gregoriadis and Sourkes, cited by Underwood (1971), found that mitochondria and nucleus have a higher copper concentration than microsomes and cytoplasm. According to Milne and Weawing, cited by Underwood (1971), when ingestion of copper by rats is increased, the relative quantities present in the mitochondria and in the soluble fraction remain constant, whereas the quantity present in the microsomes increases and in the other parts decreases. (Table 2).

Table 2

DISTRIBUTION OF COPPER IN THE LIVER OF RATS

Copper, ppm (dry basis)		Other parts	Mitochondria	Microsomes	Soluble
Diet	Liver	% of Total Present in the Liver			
1	8.7	20.3	12.4	13.9	53.4
10	19.9	14.3	12.7	17.1	55.9
50	18.2	15.2	11.9	20.5	52.4
100	19.7	14.1	15.1	18.1	52.7
200	68.5	14.2	11.0	23.8	50.8

Liver copper concentration in liver is also influenced by various other dietetic factors, for example, in sheep and cattle the concentration can be reduced when there are increases in the dietetic levels of molybdenum and sulfates. The retention of copper in the liver is also influenced by the dietetic levels of zinc, iron, and calcium carbonate. High intakes of zinc reduce the absorption of copper and iron as well as their retention. The antagonism between zinc and copper is evident, as much when the copper is deficient as when it is in toxic levels.

There exists a negative correlation between the concentrations of iron and copper in the liver of rats, as confirmed by the work of Sourkes and collaborators, cited by Underwood (1971), where rats consuming a diet deficient in copper showed excessively high levels of iron in the liver after 7 to 8 weeks and rats receiving diets deficient in copper showed excessively high levels of iron in the liver after a much shorter period of time.

The copper is found in the red blood cells in a copper-protein compound called hemocuprein with a molecular weight of 35[illegible]00, containing 0.34% copper. The blood of ruminants possesses an average of 1 [illegible]g of this protein/ml (Church, 19[illegible]). In the human erythrocytes is found a protein-copper complex called erythrocuprein (Underwood, 1971).

In the plasma, copper occurs in two principal forms, one consists of a copper-protein compound with blue coloration called ceruloplasmin which is an α-globulin with a molecular weight of 151,000, containing 8 atoms of copper/molecule. Under normal conditions about 80% copper in the plasma of sheep is, in the form of ceruloplasmin, according to Holmberg and Laurel, cited by Underwood (1971).

The copper of the plasma that is not present in the form of ceruloplasmin is known as a "direct reacting" because it reacts directly with dithizone, a reagent utilized in order to determine copper colorimetrically. This copper is slightly associated to a protein, probably serum albumin (Harper, 1973). It is believed that this is the form of copper transport in the plasma. Besides this, the plasma also contains enzymes containing copper, such as cytochrome oxidase and monoamine oxidase, in concentrations that vary with the copper nutritional status of the animal. Table 3 shows the copper distribution in the blood of sheep at different ages, according to McCosker, cited by Church (1971).

Table 3

DISTRIBUTION OF COPPER IN THE BLOOD OF SHEEP AT DIFFERENT AGES

	Blood				
	Total µg/ml	Plasma µg/ml	Direct Reacting* µg/ml	Indirect Reacting** µg/ml	Red Cells µg/ml
Adult	0.98	1.02	0.20	0.81	0.95
Fetus	0.45	0.26	0.17	0.11	0.78
Newborn	0.83	0.63	0.47	0.16	1.04

*Equivalent to the copper linked to the albumin.
**Equivalent to the copper in the form of ceruloplasmin.

The normal level of copper in the blood, for the majority of species, inclusive of ruminants, varies from 0.5 to 1.5 µg/ml, considering that in sheep, levels that are consistently lower than 0.6 µg/ml are considered deficient. Individual variations exist and in the case of sheep there have been reported differences among breeds (Wiener and Field, cited by Underwood, 1971). The levels of copper in the blood can be altered for gestating animals, in the same way estrogens can also alter blood copper concentrations.

The concentrations of copper in the blood is influenced by dietetic copper and the relation between copper and other dietary components principally molybdenum, inorganic sulfates, zinc and iron. Supplementation of copper to the normal diets has little effect on blood copper levels in the majority of species.

Milk copper levels vary with species, stage of lactation, and dietary copper concentrations. Container contact during and after milking could result in contamination and increase milk copper. The colostrum is especially rich in copper and in the majority of cases there is a progressive decline in the level of milk copper concentrations as the stage of lactation advances. Beck, cited by Underwood (171) observed in ewes a decline on the order of 0.2–0.4 g of copper/ml of milk at the beginning of lactation, to 0.04–0.16 µg of copper/ml several months later.

Feeds deficient in copper can result in subnormal levels of copper in the milk; levels on the order of 0.01 to 0.02 µg of copper/ml were found in the milk of ewes and cows maintained on copper-deficient pastures (Beck, cited by Underwood, 1971). Copper supplementation to diets that already have adequate levels of this element have little influence on copper concentrations in milk of cows, goats, and ewes (Elvehjem and Thomas, cited by Underwood, 1971). Dunkley and collaborators, cited by Underwood (1971) obtained a substantial elevation of milk copper for at least four weeks following subcutaneous injection of the cows with 300 mg of copper as copper glycinate.

Metabolism of the copper

Copper is absorbed principally from the upper jejunum in dogs, the small intestine and the colon in swine, the duodenum of humans and birds and in rats, it is absorbed equally in the stomach and small intestine (Underwood, 1971). Available literature has no information concerning ruminants.

Copper has a relatively low availability for the majority of animal species, owing to the fact that its absorption and retention depends on the chemical form in which the element is ingested, the dietetic level of various other minerals and organic substances, and on the acidity of the intestinal contents in the region of the absorption.

Relatively little is known about the mechanism of copper absorption. According to Starcher (1969) there exists a complex between protein and copper in the mucous membrane of the duodenum of birds which plays an important role in copper absorption in these animals.

A reduction in the copper absorption in sheep can occur if the dietary levels of calcium carbonate and ferrous sulfide are elevated. The former reduces absorption by increasing intestinal pH and the latter by the formation of insoluble copper sulfide.

Lassiter and Bell (1960) studied the availability of copper to sheep by adminstering orally and intravenous cupric sulfate, nitrate, chloride, carbonate, and oxide and cuprous oxide and copper wire, all labeled with ^{64}Cu. The copper in the copper wire form had the lowest availability and the copper in the form of the oxides was less available than that in the water-soluble forms or the carbonate.

Little is known about the chemical form in which copper exists in foods. Changes in these forms ought to affect the availability of copper because fresh grass is significantly less efficient in increasing the deposit of copper in the body than hay or dehydrated grass with the equivalent content of copper (Hartmans and Bosman, cited by Underwood, 1971).

In forage plants, a great part of the copper exists in bound form as water-soluble organic complexes. An aqueous extract from fresh forage contains a small proportion of copper as free ions or as positively charged complexes. The greater part exists in the form of neutral or negatively charged complexes. When fed to copper deficient rats, these complexes induce a more rapid response and greater liver storage than does the feeding of equivalent amounts of copper as copper sulfate. In view of the results of these studies, Mills, cited by Underwood (1971), suggested that copper can be transported across the intestinal mucosa both as ionic copper and in the form of complexes such as those encountered in herbage. This suggestion receives support from an earlier observation that the sodium salt of a copper-alylthiourea benzonic acid complex is more efficient as a stimulus to the growth and hematopoiesis in rabbits than in inorganic copper. Besides this, other research has shown that the affinity of the copper ions for the organic

and inorganic ligands in food can reduce the rate of its absorption, depending upon the size and the stability of the resulting complexes. The absorption of small and stable complexes may be superior to that of copper sulfate. In complexes of individual amino acids with copper, the absorption depends on the type of amino acid, its configuration and its degree of polymerization (Underwood, 1971).

Phytates can also reduce the absorption of copper as well as high dietary concentration of ascorbic acid can increase the severity of the deficiency, by reducing the absorption. Various other inorganic compounds affect the absorption, retention, and distribution of copper in the body. Among them, zinc and molybdenum have already been mentioned. High levels of cadmium in the diet reduce the absorption and later the distribution of the element in the body. The presence of mercury in the diet can also reduce the absorption of copper, while silver has little effect, but each of these exerts some influence on the distribution of copper in the body of the animal. The various physiological response and interactions with copper produced by zinc, cadmium, mercury, and silver, which are chemically very similar is surprising and at present, inexplicable (Underwood, 1971). Starcher, cited by Underwood (1971) obtained evidence that the depressive effect of zinc and cadmium on copper absorption in the chick arises from the fact that these elements bind to and displace copper from a duodenal mucosal protein. The molybdenum interferes with the absorption of copper, possibly due to the formation of a copper-molybdenum compound of low availability probably the $CuMoO_4$ (Matrone, cited by Underwood, 1971).

According to Dick (1954), molybdenum and inorganic sulfate reduce the absorption of ingested copper by increasing the urinary excretion of absorbed and stored copper, due in each case to interference with membrane transport of copper. Mills (cited by Underwood, 1971) found that high intakes of sulfate and molybdate do not increase the rate of radioactive copper in sheep excretion, but reduce the solubility of copper in the digestive tract. Table 4, taken from the research of Dick (1954) shows the effect of the intake of molybdenum and sulfate on the storage of copper in the liver of sheep.

Table 4

EFFECT OF THE INTAKE OF MOLYBDENUM AND SULFATE ON THE STORAGE OF COPPER IN THE LIVER OF SHEEP

Intake			Copper stored in the liver
Cu mg	Mo mg	Sulfate g	mg
9.5	5.3	1.1	+18.3
9.5	5.3	1.8	+ 5.0
9.5	5.3	3.1	− 7.3
9.5	5.3	5.7	−21.7
9.5	14.7	1.1	+ 1.7
9.5	14.7	1.8	− 5.0
9.5	14.7	3.1	−12.7
9.5	14.7	5.7	−23.7

The copper that is absorbed in the intestine enters the plasma and becomes loosely bound to serum albumin to form the small direct-reacting pool of copper in which form it is distributed widely to the tissues and can pass readily into the erythrocytes. This "reservoir" also receives copper from the tissues. The copper in ceruloplasmin does not appear to be so readily available for exchange or transfer.

The copper, upon reaching the liver, which is the principal organ involved in the metabolism of this element, is incorporated in the mitochondria, microsomes, nuclei and soluble fraction of the parenchymal cells in proportions that vary with age, strain, and copper status of the animal. Copper is stored in these sites or is released for incorporation into erythrocuprein, ceruloplasmin and the various copper containing enzymes of the cells. Ceruloplasmin is synthesized in the liver and secreted in the serum and erythrocuprein is probably synthesized in the normoblasts of the bone marrow. Hepatic copper is also secreted in the bile and consequently excreted in the intestinal contents. Extremely small quantities of copper can also pass directly from the plasma into the urine or through the intestinal wall.

A high proportion of ingested copper appears in the feces. Most of this consists of unabsorbed copper, but active excretion via the bile occurs in all species. Biliary excretion is the principal mode of excretion in humans, pigs, dogs, mice, ducks and fowls (Underwood, 1971). Intravenous copper injection results in the elevated blood and tissue copper levels and is accompanied by the increase of this element in the excretion via the bile and consequently in the feces, but normally not an increase in the urinary excretion.

Comar *et al.* (1948) administered radioactive copper orally or intravenously (Cu^{64}) to steers and found that in an oral dose, 75% of the copper was excreted in the feces and 3% in the urine over a period of 5 days. When the steers received the intravenous dose, about 3% of the dose was excreted in both the urine and the feces. Larsen and Bell (1960), also using intravenous injections of copper in sheep, found similar results where about 3% was excreted in the feces and 3% in the urine.

Deficiencies and functions of copper

A wide variety of disorders has been associated with copper deficiency or with responses to copper therapy. Among them include anemia, depressed growth, bone disorders, depigmentation of hair and wool, abnormal wool growth, neonatal ataxia, impaired reproductive performance, heart failure, cardiovascular defects, and gastrointestinal disturbances. The major or minor degree of manifestation of these disturbances depends on species, sex, environment and the severity and duration of the copper deficiency.

Anemia. Anemia is a common but not inevitable expression of copper deficiency. Levels of copper in the blood on the order of 0.10 to 0.12 μg/ml are considered minimum limits for the formation of blood in sheep (Beck and others, cited by Underwood, 1971). If such levels are maintained for some time anemia develops, possibly followed by death.

The morphological characteristics of the anemia occurring from copper deficiency varies with the species. In lambs it is hypochromic and microcytic; in cattle and ewes, it is hypochromic and macrocytic. Copper is an essential component of adult red cells and a certain minimum of copper must be available both for their production and for the maintenance of their integrity in the circulation.

The effect of the copper deficiency in the synthesis of hemoglobin can originate from abnormalities in the biosynthesis of protoporphyrin and heme, or of globin or the abnormalities in iron metabolism. This last hypothesis seems most viable, yet the exact explanation is still obscure.

Formation of the bones. Bone abnormalities have been reported for various animal species, yet it is not a common characteristic of copper deficiency in ruminants. However a low incidence of spontaneous bone fractures has been observed in sheep and cattle grazing copper deficient pastures.

Neonatal ataxia. Neonatal ataxia is a nervous disorder of lambs, characterized by incoordination of movement which is normally associated with subnormal levels of copper in the affected pastures and in the blood and tissues of ewes as well as lambs. This can be avoided by copper supplementation to the ewe during gestation. Among the various explanations for this disturbance, one of them is "the low content of copper in the brain leads to a deficiency of cytochrome oxidase in the motor neurones".

Pigmentation of hair and wool. Depigmentation and loss of hair occurs in ruminants deficient in copper and constitutes a better indication of the deficiency than anemia. Apparently, the interruption in the production of pigments, notably in black sheep, occurs at copper intakes sufficient to prevent anemia or other signs of copper deficiency. The exact mechanism involving the function of copper in the process of pigmentation is unknown although a breakdown in the conversion of tyrosine to melanin may be the most probable explanation, considering that this conversion is catalyzed by copper-containing polyphenyl oxidase (Raper, cited by Underwood, 1971).

Keratinization. Changes in the growth and physical appearance of hair or wool have been noted in cattle and sheep that were deficient in copper. The wool loses its characteristic crimp until the fibers more closely resemble hair than wool.

Fertility. Low fertility in cattle has been associated with copper deficiency. The nature of the reproductive problem is not totally clarified, but retardation in estrus has been common in cows raised in copper deficient areas.

Cardiovascular problems. Cardiac lesions have been noticed in cattle, with atrophy of the myocardium with replacement fibrosis. The morbid process is a progressive one, extending even over a period of years and proceeding to the replacement of large areas of atrophied myocardium with dense collagenous tissue.

Diarrhea. Cattle sustained in areas extremely deficient in copper can suffer from diarrhea in response to the deficiency.

Toxcity of copper

Among domestic species, sheep are the most susceptible to toxicity, cattle appear less susceptible, yet relative results concerning the latter are conflicting and at times it depends on other components of the diet. In some cases even 5 g/day per cow of copper for several months does not produce a harmful effect and in other cases 5 g/day for steers for several days caused hemoglobinuria and death. The susceptibility of ruminants to the copper poisoning is in part due to the fact that the liver continues to store copper, with no control mechanism to limit the absorption and storage of copper, consequently the hepatic level can reach 2,000 to 4,000 ppm in the dry matter (Church, 1971).

Requirement of copper

It is difficult to clearly establish the copper requirement for ruminants, because there are several factors present in the diet that interfere with copper metabolism. The minimum requirement is still not well-defined, yet Matrone and collaborators, cited by Church (1971), working with calves, suggest that the requirement of copper may be between 3 and 6 mg/day; whereas, Engel and collaborators, administered to calves a ration containing 4 to 5 ppm of copper and observed that this level was not sufficient to maintain the reserves in the liver. Dent and collaborators (cited by Underwood, 1971) observed that, on the average, 17 mg of supplemented copper per day was sufficient to maintain reserves in the liver. However, the levels of copper in the blood were low in relation to those considered normal.

Working with sheep, Dick and others (1954) observed that a daily intake of 3.6 mg was enough to promote liver storage. They suggested that an intake of 1 mg/day could be adequate if the ingestion of molybdenum and sulfate were at a minimum level. Suttle and Field cited by Church (1971), working with diets containing 1 or 11 ppm of copper and/or 50 mg of molybdenum and 10 g of sulfate, for ewes in gestation and at the beginning of lactation, concluded that 1 ppm was not sufficient. The diet with 11 ppm apparently was adequate to maintain the normal levels in the blood, but not when sulfate and molybdenum were present.

According to the Agriculture Research Council (1965) copper requirement on a dry matter basis is approximately 5 ppm for sheep and 10 ppm for cattle, while the National Research Council (1970) recommended for growing and fattening cattle a requirement of 4 ppm.

According to Maynard and Loosli (1966), 5 to 8 ppm in the dry matter of the pasture is sufficient for adequate maintenance of animals; based on the lower level one can calculate a daily quantity of 50 mg of copper for cattle and 5 mg for ewes. Adams (1975) recommends as the minimum for dairy cows, 11 ppm in the dry matter of the ration.

Molybdenum

Molybdenum in tissues

Evidence of the biological function of molybdenum was obtained in 1930 when Bortels, cited by Underwood (1971), showed that this element is an essential nutrient for the growth of *Azotobacter*. The first indication of the function of this element in animal production appeared in 1953 when groups of researchers discovered that the flavoprotein enzyme, xanthine oxidase is a molybdenum-containing metalloenzyme, whose activity depends on the presence of this element. More direct evidence using highly purified diets directly substantiated the essentiality of this element for lambs, chicks and turkey poults. Under natural occurring conditions, uncomplicated molybdenum deficiency has never been reported either in man or in farm animals.

Under normal dietary conditions the liver contains 2 to 4 ppm of molybdenum in the dry matter for the majority of species. This level can be elevated to 25-30 ppm when adult sheep and cattle ingest large or moderately large quantities of molybdenum. The levels rapidly return to normal when the administration of the extra molybdenum ceases. The degree of retention in the liver and in other tissues and the rapidity with which the level returns to normal, depends on the quantity and the proportion of inorganic sulfate ingested in relation to the molybdenum. Thus, the level of molybdenum in the liver of the animal is of little value in the indication of the nutritional state of the animal in this element, unless the sulfate and protein status of the diet of the animal are also known.

An average of 1 μg of molybdenum/100 ml of blood was found by Beck, cited by Underwood (1971), in sheep sustained on pastures with a normal level of copper and a low level of molybdenum. The same animals consuming part of their diet as a cereal base and hay, low in sulfate, show a blood level of about 6 μg/100 ml. Cunningham, cited by Underwood (1971), considers a level of 6 μg/100 ml of blood to be normal for sheep and cattle maintained on pasture with a normal level of copper and a low level of molybdenum. When animals received molybdenum in doses equivalent to the dietetic ingestion of 30 ppm of molybdenum, the levels of blood molybdenum increased to 60 to 80 μg/100 ml in young cattle and to 240 to 340 μg/100 ml in ewes in reproduction. Similar data was obtained in England when the dietetic ingestion of molybdenum exceeded the normal by 40 ppm.

Molybdenum blood concentration in sheep is not only proportional to the ingestion of molybdenum but, within certain limits, it depends, inversely on the ingestion of the inorganic sulfates (Dick, cited by Underwood, 1971). The magnitude of these effects on blood molybdenum and the changes in the distribution of this molybdenum among red cells and plasma that occurs in several levels of ingestion of the molybdenum and sulfate can be seen in Table 5.

The data of Table 5 shows that, in the low levels of ingestion of molybdenum and sulfate, more than 70% of blood molybdenum is present in the red cells; whereas, when the levels of ingestion of both Mo + sulfate are elevated, a small portion (4 to 5%) of the enormous quantity of molybdenum that is present in the blood is found in the red blood cells.

Table 5

BLOOD MOLYBDENUM CONCENTRATION OF SHEEP AND THE DISTRIBUTION OF MOLYBDENUM AMONG RED CELLS AND PLASMA WHEN THE INGESTION OF MOLYBDENUM AND SULFATE ARE INCREASED

Intake per day		Molybdenum (μg/100 ml)			
Molybdenum mg	Sulfate (g)	Whole blood	Plasma	Red Cells	Percentage in Red Cells
0.5	1.7	9.5	4.3	17.8	71.8
50.0	1.7	968.0	1208.0	56.1	21.5
50.0	7.2	68.4	91.8	16.6	4.5
0.5	1.7	6.8	2.5	13.8	70.4
50.5	7.2	72.8	10.0	12.3	5.2

Little is known of the chemical form or combination in which molybdenum exists in blood, while there exists some evidence that in sheep, the molybdenum from the red cells as well as that from the plasma is a readily dialyzable anionic form, probably as molybdate.

The molybdenum content of milk is extremely susceptible to the changes in dietary molybdenum intakes in cows, goats, and ewes. Archibald, cited by Underwood (1971), found an average value for cows under normal conditions, on the order of 73 μg of molybdenum per liter of milk (with variations of 18 to 120 μg). This concentration was elevated to a mean of 371 g of molybdenum per liter when the cows received 500 mg of molybdenum in the form of ammonium molybdate daily. Several other reports of this nature have shown similar results.

Kale and Liftshits (cited by Underwood, 1971) reported the administration of 23 g of sulfate as sodium sulfate per day to ewes sustained on high molybdenum pastures (25 ppm). At the end of 3 days the level of molybdenum in the milk was reduced to 137 μg/liter, compared to 1043 μg/liter in the ewes that did not receive the sulfate supplementation.

Molybdenum metabolism

Studies with both stable and radioactive molybdenum (Mo^{99}) indicate that the molybdenum is quickly absorbed in the majority of diets. The hexavalent water-soluble forms such as sodium and ammonium molybdate and the molybdenum of high molybdenum forages, the majority of which is in water soluble form, are easily absorbed by cattle. Also the insoluble forms like MoO_3 and $CaMoO_4$, but not MoS_2, are easily absorbed when furnished in large doses for rabbits and hogs. A comparison between cattle and swine during growth indicates that the former have a much slower rate of absorption than the latter. For example, when oral administration of Mo^{99} is given, a maximum concentration is obtained in the blood of swine after a period of 2-4 hours while in cattle this value is obtained only after 96 hours.

There is a great variation among species in relation to excretory routes of molybdenum; in cattle principal means of excretion is in the feces while scarcely 15% is excreted in the urine, 168 hours after the intravenous dose of Mo^{99}. In swine, rats, and man the urine seems to be principal means of excretion. The presence or absence of sulfate can alter absorption, retention, and excretion of absorbed molybdenum.

The xanthine oxidase or xanthine dehydrogenase, which is widely distributed in animal tissues and the nitrate reductase of plants are the only known metalloproteins containing molybdenum. Then, the only biochemical function of the molybdenum in the animal besides the interactions with copper, is related to the formation and activity of xanthine oxidase.

A significant growth response from molybdenum was observed in sheep fed a semipurified diet in which the molybdenum was added to elevate the dietary level from 0.36 to 2.36 ppm. This response is possibly due to the improvement in the digestion of cellulose in the rumen (Ellis *et al.*, 1958). Other subsequent reports (Ellis and Pfander, 1960 and Sheriba *et al.*, 1962) did not show any favorable effects from the addition of molybdenum to the diet of sheep.

The deficiency of molybdenum in sheep also has caused the appearance of renal xanthine calculi. In these affected areas the pasture contained only 0.03 ppm of molybdenum, while in healthy areas with 0.4 ppm no disturbances were found.

The tolerance to the high levels of dietary molybdenum varies with the species and age of the animal, quantity and chemical form of the ingested molybdenum, the copper status and intake by the animal, the inorganic sulfate content of the diet and also the content of substances such as methionine, cystine, and protein capable of being oxidized to sulfate in the body, and with the level of ingestion of other metals inclusive of zinc and lead (Gray and Ellis, cited by Underwood, 1971). There is a great difference among species concerning the tolerance of high levels of molybdenum, cattle having the least tolerance, followed by sheep, while horses and pigs are the most tolerant of the animals commonly found on the farm.

Retarded growth and weight loss are inevitable manifestations of molybdenum intakes in all species. Diarrhea and anemia are conspicuous features of molybdenosis in cattle. Severe molybdenosis occurs in cattle in certain regions of the world including England, California, Nevada, Oregon, Ireland, and in New Zealand, where it is known as "peat scours". Cows in lactation and the young animals are the most susceptible among cattle, while sheep are more resistant. Normally in these diseased areas the level of molybdenum in the dry matter of the pasture varies from 20 to 100 ppm, compared with 3 to 5 ppm, which is the level that is considered normal.

Molybdenum requirement

According to ARC (1965) it is still not possible to establish the requirements given the scant information relative to the various interrelationships of molybdenum with copper and sulfate. On the other hand, Sheriba *et al.* (1962), working with purified or semi-purified diets which contained 0.01 to 0.45 ppm of molybdenum, concluded that the molybdenum requirement was lower than 0.01 μm in the dry matter of the ration. However, Miller (1975) considering the various existing interactions, considers that the requirement has not been adequately determined.

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SELENIUM IN RUMINANT NUTRITION

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Introduction

This paper is to discuss recent development in research with selenium as they relate to ruminant nutrition. Several reviews of research conducted with selenium have been published (Muth *et al.*, 1967; Allaway, 1968; Hogue, 1970; NRC, 1971a; Underwood, 1971; Jenkins and Hidiroglou, 1972; Frost, 1973; Ammerman and Miller, 1975).

Toxicity

Perhaps more than any other mineral element currently considered to be essential for animals, selenium has had a profound and lengthy history of toxicity. This history as a toxic element has undoubtedly influenced present thinking with regard to the use of selenium as a dietary essential. Rosenfeld and Beath (1964) provide quotes from the writings of Marco Polo suggesting that he encountered problems of selenium toxicity in "beasts of burden" during his travels through western China about 1295. The same authors refer to a report written in 1857 by T. C. Madison, an army surgeon, in which Madison describes conditions in cavalry horses at Fort Randall, South Dakota that eventually resulted in the sloughing of hooves, mane and tail. This condition or disease, termed "alkali disease" or "blind staggers", resulted in extreme losses of livestock in a number of western states and it was not until 1934 that selenium was identified as the causative toxic agent (Franke, 1934).

The Latin American countries where selenosis is encountered include Argentina, Chile, Colombia, Ecuador, Honduras, Mexico, Peru and Venezuela (Lemley, 1943; Russell and Duncan, 1956; Benavides and Mojica, 1965; Kerdel-Vegas, 1966; Dickson, 1969; Jaffe *et al.*, 1969). From the Botanical section of the National Museum of Brazil, it is noted that there are about 27 species of *Lecythis*, a high selenium accumulating species, in a region extending from the northern part of the country to the parallel which crosses Rio de Janeiro (Kerdel-Vegas, 1966). There are also unconfirmed reports of selenium toxicity in Northern Brazil thats leads to hair loss in humans (Kerdel-Vegas, 1966). Lemley reports rather heavy livestock losses in Argentina due to acute selenium poisoning caused by ingestion of *Astragalus pergi*. Throughout Argentina, descriptions of both acute and chronic selenium poisoning are common. In the Irapuato area of Mexico, "saliman disease," which is similar to alkali disease, occurs on vegetation containing 1 to 120 ppm selenium. From Irapuato, it is reported that a drover lost an entire herd of 126 cattle which rested for one night in an alfalfa field (Russell and Duncan, 1956). The occurrence of chronic selenosis since the 16th century has been recorded in Colombia. In some regions, plants were so poisonous that, when eaten by either man or animal, the hair was lost (Rosenfeld and Beath, 1964). The sites of selenium toxic regions and the economic importance in Colombia have been described by Benavides and Mojica (1965). The loss of the livestock industry lies not so much in livestock with acute selenium poisoning as in the subclinical chronic low-grade poisonings which probably are of greater economic importance.

At present, practical measures for controlling selenium toxicity for grazing cattle rely on pasture rotation and the use of supplemental feeds from nonseleniferous areas. Locating seleniferous soils and mapping them in sufficient detail is essential. The selenium content of grasses is highest in young plants and declines rapidly at later stages of maturity (Olson *et al.*, 1972). Therefore, use of pastures of low selenium content during the growing season and high selenium forages toward the end of the growing season is a very effective control measure (Olson, 1969).

Essentiality

Selenium has been considered an essential element since Schwarz and Foltz (1957) demonstrated that it was the effective component of "factor-3" (Schwarz, 1951) in prevent exudative diathesis in chicks (Patterson *et al.*, 1957; Schwarz *et al.*, 1957) and nutritional muscular dystrophy in calves (Muth *et al.*, 1967) and lambs (Hogue, 1958).

Requirement

The dietary requirements and toxic levels of selenium for domestic animals as summarized by the National Research Council are presented in Table 1. Whether the animal be a ruminant or nonruminant, it is generally considered that its selenium requirement will be satisfied by 0.1 ppm of the element in the diet. A higher level of 0.2 ppm, however, has been established as the requirement for turkeys. Since selenium can be toxic and thus dietary levels of the element must be controlled, it is important to consider levels which have been designated as toxic. Interpretation of available data has resulted in rather wide ranges for toxic levels established for certain species. Even so, the widest range of 3 to 20 ppm set for sheep yields a minimum toxic-to-required ratio of 30, indicating a greater margin of safety with selenium than occurs with copper, for example.

Selenium Deficiency

The most selenium deficient regions in the United States include the northwest, southeast and northeast including many of the states adjoining the Great Lakes (Kubota and Allaway, 1972). In regions bordering these areas, approximately 50% of the forage or grain samples contained 0.1 ppm or more of selenium, and in an area bounded by the Rocky Mountains to the west and the Mississippi River to the east, grains and forages were generally adequate (>0.1 ppm) in selenium.

Selenium deficiency is confirmed or suspected in seven Latin American countries (Brazil, Ecuador, Honduras, Mexico, Paraguay, Peru, and the Bahamas). It has been reported in Ecuador with calves exhibiting white muscle disease (Sotomayor, E., 1975, personal communication). From Peru, Terry (1964) reports a disease condition in ruminants that resembles Se-Vitamin E deficiency. When treated with Se-Vitamin E, 70% of the animals recovered from the condition. In Paraguay, Se administration increased weight gains and increased pregnancy rate in heifers over the controls (Boggino *et al.*, 1973). Low selenium levels in feeds from Mexico (Gutierrez *et al.*, 1974), the Bahamas (Dorsett, A., 1975, personal communication), Brazil (Moxon, 1971), and Honduras (Moxon, A. L., 1975, personal communication) have been reported. Moxon (1971) analyzed milo samples for selenium from 19 locations in Brazil and found

Table 1

DIETARY REQUIREMENTS AND TOXIC LEVELS OF SELENIUM FOR DOMESTIC ANIMALS

Species	Reference	Selenium, ppm Requirement	Toxic
Dairy Cattle	N.R.C., 1971b	0.1	5
Beef Cattle	N.R.C., 1970	0.05-0.1	—
Sheep	N.R.C., 1974	0.1	3-20
Swine	N.R.C., 1973	0.1	5-10
Chickens (0-8 weeks)	N.R.C., 1971c	0.1	10
Turkeys (0-8 weeks)	N.R.C., 1971c	0.2	—

average values of .060 and .036 ppm for 1969 and 1971, respectively. Milo from locations within Minas Gerais, Rio Grande do Sul, and São Paulo had particularly low selenium concentrations. A report from Campinas, Brazil indicated Se-Vitamin E deficiency problems in poultry when corn containing .035 ppm Se was fed and fish meal (a good source of Se) was omitted from the diet. This problem was corrected when .2 ppm of Se was added to the ration (Moxon, A. L., 1975, personal communication).

According to Underwood (1971), the total areas of the world affected by selenium deficiency are far greater than those afflicted with excesses. It seems inconceivable to suppose that the huge land mass included in the category of Latin America would have so few reports concerning selenium deficient and toxic areas. A possible explanation for lack of reported selenium deficiencies in ruminants of Latin America is that in the majority of these countries, the veterinary staffs have greater concerns with the prevention of major endemic diseases, so that disorders arising from selenium inadequacy may be easily overlooked. Also, techniques for determining low concentrations of selenium are relatively new and few tissue and feed samples have been analyzed for this element in Latin America. Illustrative of this fact is that of 3390 feeds included in the 1974 Latin American Tables of Feed Composition, there were selenium values for only .06% of the samples (McDowell *et al.*, 1974). With recent improvements in analytical methods for selenium and an increased awareness by researchers and veterinarians of the likelihood of a deficiency, it is expected that reports in the future will confirm selenium deficiency in grazing ruminants in more areas of the world.

Plant Selenium Levels

Selenium concentration of forages is dependent on soil factors, plant species, stage of maturity, yield, pasture management, climate, and soil pH. Total selenium content of soils has shown very little relationship to the concentration of selenium in the plants grown on it. This is probably due to the fact that selenium in the soil is present in chemical forms that vary widely in availability to plants (NRC, 1971a). Nevertheless, Cary *et al.*, (1967) indicated that soil concentrations of less than .5 ppm were prevalent in areas where deficiencies of selenium in livestock occurred.

For most minerals, poor drainage conditions increase forage mineral concentration (Mitchell *et al.*, 1957), whereas waterlogging and high rainfall are factors contributing to Se deficiency (Reuter, 1975). Low soil pH decreases plant uptake of Se (Miller *et al.*, 1972). Pasture management involving liming and selenium-containing fertilizers can be extremely beneficial to increasing forage selenium concentrations. Overliming, however, can accentuate selenium toxicity for livestock in a seleniferous region by increasing plant concentrations of this element. Cox (1973) notes that most of the soils of Latin America are acid and not alkaline. Acid soils do not normally produce plants containing toxic concentrations of selenium. It therefore might be expected that in Latin America selenium deficient regions would be more abundant than seleniferous regions.

Large variations in selenium content of different plant species growing on the same soil have been reported by a number of researchers. In certain regions, accumulator species containing over 1,000 ppm selenium are found growing alongside grasses containing less than 10 ppm (Beeson, 1961). Acute selenium poisoning is most often associated with consumption of selenium accumulator plants (i.e., *Astragalus racemous*) which may contain from 100 to over 9,000 ppm selenium and emit a strong odor. Accumulator plants rarely occur outside seleniferous areas and may, therefore, indicate selenium toxic regions (Underwood, 1966).

Detection of Deficiency

Signs of a pronounced dietary selenium deficiency in ruminants include reduced growth and white muscle disease (nutritional muscular dystrophy) in young animals and poor reproductive performance in older animals (Godwin *et al.*, 1970; NRC, 1971a; Underwood, 1971). When such signs of deficiency become evident, however, losses of economic importance have already occurred. It is of value to have a means of assessing the selenium status of animals without depending on the expression of overt signs of selenium deficiency. Levels of selenium in various tissues including liver, kidney, heart and muscle fluctuate with dietary intake of the element. Andrews *et al.*, (1968) indicated that levels of 1.0 ppm in the kidney cortex and 0.1 ppm in the liver (fresh basis) or above are indicative of adequate selenium in sheep. These authors suggest that 0.05 ppm selenium in the liver (fresh basis) is borderline and that 0.02 ppm represents a severe selenium deficiency.

Oh *et al.*, (1974) have reported that the measurement of tissue glutathione peroxidase, an enzyme containing selenium, may be useful in establishing selenium status of the animal. In studies with lambs, the serum level of the enzyme increased with additions of selenium to a basal diet containing 0.01 ppm selenium and plateaued with 0.1 ppm added selenium. Maximum growth and feed efficiency were obtained with the 0.05 ppm Se addition.

In studies conducted with sheep, Godwin and Fraser (1966) and Godwin (1968, 1970) have shown that subclinical cases of nutritional muscular dystrophy can be detected by electrocardiography. Confirmation of the condition was made by slaughter of young sheep and lambs.

Supplementation and Bioavailability

Positive responses have been obtained in grazing ruminants with oral or injected supplemental selenium as either sodium selenate or sodium selenite (Gardiner, 1969; Jenkins and Hidiroglou, 1972; Underwood, 1971). Preventive oral doses of inorganic selenium salts in amounts of 5 mg for adult sheep or 1 to 2 mg selenium for lambs during the first few weeks of life were effective in Australia and New Zealand. Four doses proved sufficient in practice (Gardiner, 1969). Paulson *et al.*, (1968) used sodium selenate in trace mineralized salt which was offered *ad libitum* to pregnant and postpartum ewes at levels of 26, 132 and 264 ppm selenium in the mixture or equivalent to 0.15, 0.90 and 1.80 ppm selenium in the diet. The lower level was quite effective in preventing nutritional muscular dystrophy (NMD) in lambs. The basal diet contained about 0.1 ppm selenium.

Physical characteristics of the two selenium salts are similar to sodium chloride and mix uniformly (Jenkins and Hidiroglou, 1972). Selenate was considered as preferable, however, because selenite is more readily reduced to less available elemental selenium which could form insoluble compounds with other metals.

Injections of selenium and/or vitamin E have been used in many countries when needed and have given good results under field conditions for a number of years (Muth, 1970). Injections are time consuming and expensive limiting their use primarily to therapy rather than as preventive measures. A continuous low dosage supply to the animal of selenium and/or vitamin E is desirable.

Australian workers have investigated the use of intraruminal selenium pellets in grazing sheep. Heavy pellets made of 1 g elemental selenium and 9 g iron were found to be well retained and free of calcium phosphate coating (Kuchel and Buckley, 1969). Selenium was being released to the sheep and concentrations of the element in edible tissues were similar to those in normal animals after 6 or 12 months. The availability to sheep of selenium in pellets labeled with ^{75}Se were calculated, on the basis of tissue and excretory analyses, to release about 1 mg selenium daily and

methionine. Variable results which have been derived from studies of selenium metabolism appear to depend on the intake of selenium relative to the animal requirement.

An enzyme has been identified with a dependency on selenium for activity and was termed glutathione peroxidase (GSH-Px) (Rotruck *et al.*, 1973). The GSH-Px obtained from bovine and ovine erythrocytes was very similar (Flohe *et al.* 1973; Hoekstra *et al.*, 1973). Recent reports have shown that GSH-Px activities in tissues of rats (Chow and Tappel, 1974) and chicks (Omaye and Tappel, 1974) were responsive and dose related to dietary selenium. In chicks no differences were found between GSH-Px activities when supplementary selenium was equivalent as sodium selenite or selenomethionine (Chow and Tappel, 1974). Cantor *et al.* (1973), however, found selenite more effective than selenomethionine in producing the response in chicks. Dietary selenium, fed to newborn lambs for 8 weeks with a low-selenium Torula yeast diet at increasing levels of 0 to 0.5 ppm selenium, gave relatively increased tissue selenium levels in ten tissues studied with each addition of selenium (Oh *et al.*, 1974). Tissue GSH-Px activities, however, reached a plateau with 0.1 ppm supplementary selenium except in pancreas and erythrocytes. The response correlated well with the estimated selenium requirement.

A strong case has been put forth in the literature for the antioxidative function of selenium. Others, however, question such a single role for selenium and continue to investigate other possible functions. Clarification of the "antioxidant" role of selenium in relationship with other cellular oxidation-reduction systems is awaited with interest. Oregon investigators (Broderius *et al.*, 1973; Whanger *et al.* 1974) have studied ruminant serum seleno-proteins, the effects of selenium on protection of proteins sulfhydryls and the possible relationships of selenium to cytochromes and oxygen metabolism. Several investigators have suggested an electron transfer role for selenium (Diplock, 1974; Levander *et al.*, 1973) in cytochrome systems. The improved status of animals with selenium-responsive disorders to supplemental selenium remains essentially unexplained.

Interrelationships

The complex nutritional interrelationships among selenium, vitamin E, lipids, sulfur and the sulfur amino acids have challenged many investigators. Among species, the effects of varying these nutrients in the diets of animals with selenium/vitamin E-responsive disorders have not been uniform. Dietary alterations of any one nutrient may alter the dietary requirement for any of the others. Such possible interactions have been discussed by others (Horwitt, 1965; Jenkins and Hidiroglou, 1972; Schwarz, 1965; Tappel, 1973; Ullrey, 1973).

In swine, with an increase in confinement feeding and a reduction in access to pasture, dietary vitamin E activity becomes reduced significantly and the available dietary selenium becomes more critical (Ullrey, 1974). The usual swine corn-soy diet, in addition, is generally low in sulfur amino acids. With ruminants under farm conditions, supplemental selenium has been effective in preventing NMD in lambs and calves, but it was ineffective against dystrophy produced experimentally with vitamin E deficient diets supplemented with unsaturated fats (Jenkins and Hidiroglou, 1972). In the latter condition, supplemental vitamin E was required in addition to selenium for protection.

Growing lambs were fed purified Torula yeast diets containing stripped lard as either artificial milk or pellets (Ewan *et al.*, 1968). Supplementation with increased dietary vitamin E and 1 ppm dietary selenium significantly increased muscle and liver selenium concentrations. As vitamin E levels increased without supplemental selenium, however, muscle and liver selenium levels declined progressively. In lambs, produced by ewes consuming dystrophic diets for 1 year and treated or untreated with α-tocopherol without selenium, plasma tocopherol levels were not different (Hidiroglou *et al.*, 1970). Direct administration of α-tocopherol to lambs provided protection from NMD mortality which occurred in untreated lambs leading the authors to suggest that the milk vitamin E was unavailable to the lambs. Reduced circulating tocopherol levels were observed in pregnant but not in non-pregnant ewes when diets were supplemented with selenium without added vitamin E (Boyazoglu *et al.*, 1967). Whether these results indicate that selenium is involved in the mobilization or utilization of vitamin E from ewe to milk or lamb tissues and could provide a sparing effect on available vitamin E for the animal is not yet substantiated.

The relationship of rumen development in lambs to NMD and supplemental dietary vitamin E or ethoxyquin has been studied with Torula yeast diets containing 0.5 ppm selenium (DeMille *et al.*, 1972). Occurrence of NMD was not reduced following rumen development when animals consumed dystrophic diets. These authors recommended vitamin E supplementation of milk replacer diets which are high in polyunsaturated fatty acids. Fatty acids in forages are largely polyunsaturated. Only a small proportion of the total fatty acids in ruminant milk is unsaturated. Viviani (1970) suggested that a rapid increase of polyunsaturated fatty acids (PUFA) in tissues of young calves with a dietary vitamin E-selenium deficiency was significant to induction of NMD.

There have been few reports on the trace mineral status of any of the animals in which Torula yeast or soy diets have been used to study selenium/vitamin E responsive diseases. In a study of pastured cattle, Miltmore *et al.*, 1973 found no synergistic effect of selenium and/or vitamin E injections administered with injections of Ca-DuEDTA. The animals were considered to be consuming equal to or greater than adequate dietary selenium and no toxicity was observed. The unthrifty animals were considered copper deficient or consuming inappropriate dietary ratios of copper to molybdenum. Boyazoglu *et al.* (1967) supplemented ovine diets with copper and molybdenum when studying effects of dietary sulfate on selenium utilization. Depressed hematocrit levels were observed in pregnant ewes with supplemental selenium, vitamin E and high sulfate intake. Lambs were not completely protected from NMD by selenium supplementation but incidence of the disorder was not as great as reported by others with increased consumption of dietary sulfate.

blood and tissue selenium levels were within normal limits (Handreck and Godwin, 1970). Lambs, fed a selenium-deficient ration until signs of NMD appeared, recovered after introduction of ruminal selenium pellets (Godwin *et al.*, 1972). With grazing beef cows on selenium-deficient pastures, 30 g pellets (10% Se, 90% Fe) increased selenium blood levels within five weeks to levels comparable to those of animals which had received a selenite drench. In some experiments, when as many as three heavy pellets (Se, Co and steel grinder) were present in the rumen simultaneously, the selenium pellets were well retained with the loss of only one selenium pellet per 40 or 50 animals in a period of approximately one year (Lee, 1972). The presence of a steel grinder pellet increased the release of selenium (Lee and Kuchel, 1969).

Canadian workers (Jenkins and Hidiroglou, 1972) investigated the use of slow-release vitamin E and selenium pellets in ewes and lambs for control of NMD. Sodium selenite pellets were implanted in the loose connective tissue behind the shoulder in pregnant ewes or in lambs which were fed dystrophy producing hay. Pellets containing 20 mg selenium as sodium selenite were implanted in ewes 49 to 78 days (mid-gestation) prior to lambing, or pellets containing 10 mg selenium as sodium selenite were placed in ewes 1 to 15 days (late gestation) before lambing (Hidiroglou *et al.*, 1971). Both treatments increased blood selenium levels in lambs and ewes two to four times the levels of untreated animals. A reduction in lamb muscle pathology was observed with selenium treatment of ewes. Implantation of selenium pellets into neonatal beef calves born to cows fed selenium-deficient rations was also effective in preventing NMD (Hidiroglou *et al.*, 1972).

The use of selenium-fortified salt blocks or mineral mixtures appears to be the most promising procedure for prevention of ruminant NMD resulting from a deficiency of selenium and/or vitamin E. A selenium and vitamin E fortified mineral supplement was fed to selenium-deficient cows during the latter 2/3 of gestation and to calves through the first month of lactation (Jenkins *ef al.*, 1974). Selenium content of the mineral mixture was 14.8 ppm and vitamin E was 2700 IU/kg, calculated to provide 0.07 ppm selenium and 13.2 IU vitamin E/kg of diet.

Much of the evaluation of various selenium sources has been done with nonruminants. In poultry, comparative availabilities of various selenium compounds have been determined either by tissue retention or by prevention of selenium responsive disorders. Scott and Thompson (1971) compared tissue selenium uptake in chicks and poults from a low selenium diet supplemented with sodium selenite and with a high selenium diet consisting of all-organic selenium. The authors concluded that protein-derived selenium is retained longer than that from inorganic salts. When measured by incidence of exudative diathesis, the effectiveness of various Canadian grains in preventing the condition was related to selenium content (Seier and Bragg, 1973).

Cantor *et al.* (1975), using sodium selenite as a reference (100%) in chicks for prevention of exudative diathesis, rated average biological availabilities of selenium in alfalfa meal as 210%, other plant products about 80%, and of fish and poultry meals about 20%. Ku *et al.* (1973) concluded that organically bound dietary selenium produced higher selenium tissue levels in swine than supplemental selenium fed as sodium selenite when fed at equal levels of 0.44 ppm dietary selenium. The addition of 0.1 ppm selenium as sodium selenite to diets naturally high in selenium (0.46 and 0.78 ppm Se) did not contribute significantly to tissue selenium levels (Jenkins and Winter, 1973; Ku *et al*, 1973).

Metabolism

The metabolism of absorbed selenium appears to be similar for ruminants and nonruminants. A portion of dietary selenium becomes incorporated into microbial material. The major excretory pathway for oral selenium is fecal in ruminants and urinary in nonruminants under most conditions. (Martin and Gerlach, 1972).

In the young preruminant lamb or calf, selenium deficiency exerts damaging effects more frequently than in the older animal. With development of the rumen, afflicted animals may recover from NMD (Whanger, 1970). The utilization of dietary selenium in milk by lambs and in their dams was investigated with both inorganic and organic dietary ^{75}Se (Jenkins and Hidiroglou, 1971). The organic form produced milk selenium which was more available to lambs although milk and tissue selenium levels were higher in dams fed selenite. Franke *et al.* (1966) found no influence of increased milk selenium levels on milk tocopherol levels or on reduction of oxidized milk flavor. Supplementation of the ration with tocopherol or ethoxyquin, however, increased the oxidative stability of milk (Dunkley *et al.*, 1967). Selenium levels in milk vary widely within animal groups and geographical areas and are influenced by processing. The mean level of selnium reported for dairy products analyzed by Morris and Levander (1970) was 69 ppb, expressed on a fresh weight basis. Lamb tissue levels were positively related to selenium levels in the diet of the ewe, particularly with deficient diets where muscle and kidney cortex selenium were below 0.5 and 5 ppm, respectively, on a dry matter basis (Hoffman *et al.*, 1973). There appears to be a requirement for available vitamin E in milk for the effective utilization of selenium by the young ruminant. Fetal loss due to embryonic or neonatal death has been reduced by administration of selenium and/or vitamin E to pregnant ruminants in areas where congenital NMD is found.

Selenium is found rather firmly attached to all types of protein following absorption. In plant and animal metabolites selenium is usually intimately related with sulfur-containing components and it has been suggested that the two elements may utilize the same metabolic pathways (McConnell *et al.*, 1974; Whanger, 1970). Since no known biochemical pathway has been identified in non-ruminants for reduction of inorganic sulfate, the possible biosynthesis of inorganic selenium into selenoamino acids has been questioned (Walter *et al.*, 1972; Whanger, 1970). Generally, selenium has been thought to be metabolized by incorporation into isologues of the sulfur amino acids, and particularly into

It has been suggested that cobalt deficiency in sheep reduced tolerance to high intakes of selenium (Gardiner, 1969). In addition, gain responses to supplemental selenium were positive in New Zealand sheep when cobalt was given. In rabbits, GSH-Px activity of red cells dropped to 26% of initial activity with the induction of nutritional iron deficiency (Rodvien *et al.*, 1974). Increased dietary protein also has reduced the supplemental selenium requirement of sheep. It would appear that effects of dietary selenium and/or vitamin E may be related to the sulfur, copper, iron and cobalt status of the animal as well as to dietary lipid and amino acid components.

Levander (1972) reviewed certain metabolic interrelationships and adaptations of various species to selenium toxicity with such orally consumed substances as arsenic, linseed oil, methionine and D-penicillamine. As a corollary to the known protective effects of selenium with certain heavy metal induced toxicoses, (Ag, Hg or Cd), partial reversal of selenium toxicity was shown in chicks by high dietary levels (500 ppm) of cadmium, mercury and particularly of copper salts (Hill, 1974; Jensen, 1975). The metabolic implications of dietary mineral imbalances for animals have been reviewed (Buck and Ewan, 1973; Mills, 1974).

Summary

The early interest in selenium related primarily to its toxicity, but since 1957 the element has been recognized as a dietary essential. The dietary requirement for selenium by most species is considered to be about 0.1 ppm. Deficiencies of selenium in cattle and sheep have been confirmed under natural grazing conditions in many countries of the world. Overt signs of inadequacy such as white muscle disease (nutritional muscular dystrophy) occur primarily in young calves or lambs born to selenium deficient dams. Increased infertility has been observed in ewes grazing pastures low in selenium. In general, signs of deficiency have not occurred under natural conditions in older animals such as finishing beef cattle and lactating dairy cows. Subclinical deficiencies of selenium are not easily determined, however, and thus an inadequacy of the element may be limiting maximum animal performance under certain circumstances of drylot feeding. The current nutritional status of ruminant animals in many geographical areas and involving various feeding programs with regard to this element has not been established. The recent rather widespread deficiency problems observed with nonruminants suggests that such an assessment should be made.

Tissue selenium concentration, particularly that in the liver, has been used in establishing selenium status of the animal. Recent studies with lambs have suggested that glutathione peroxidase activity in certain tissues may be a more accurate indicator of selenium adequacy than is tissue selenium content. Supplemental sodium selenite and sodium selenate by either oral administration or parenteral injection have prevented clinical signs of selenium deficiency and animal losses in both ruminant and non-ruminant animals. Heavy pellets containing elemental selenium for placement in the rumen have proved effective. In general, organic forms of selenium are more readily retained by animals than are the inorganic compounds.

The dietary requirements for selenium and its metabolism are influenced by many nutrient interrelationships including its interactions with sulfur, lipids, vitamin E, proteins, amino acids and several microelements.

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Photographs

Illustrating Mineral Deficiencies

and Toxicities

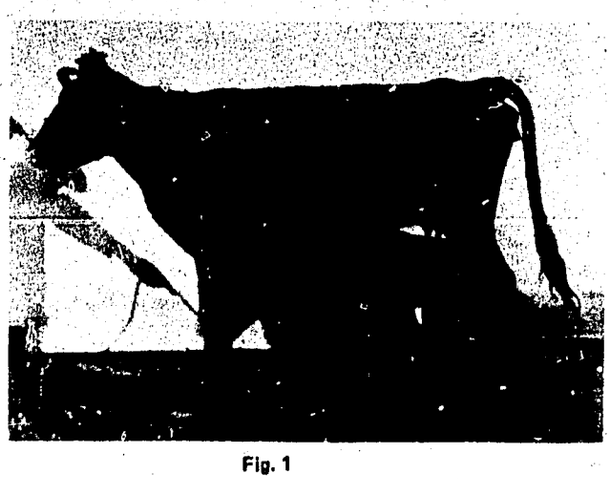

Fig. 1

Fig. 2

Fig. 1, after 281 days on a low phosphorus basal ration. Her average gain was 0.15 pounds on a feed intake of 31 percent above requirements. She showed abnormal appetite (for bones) after several months.

Fig. 2, after receiving sodium phosphate in her ration for 90 days. On a feed intake of 33 percent above requirements, her average gain was 2.18 pounds daily. The depraved appetite disappeared within six weeks. (Minnesota Station Bulletin 229. 1926. C. H. Eckles, R. B. Becker and L. S. Palmer, St. Paul, Minnesota, U.S.A.).

Fig. 3

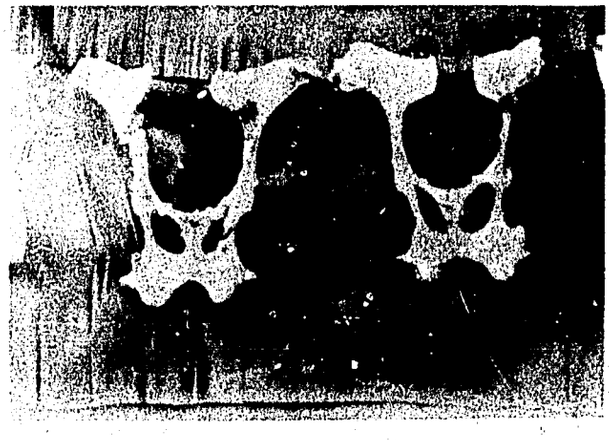

Fig. 4

Fig. 3 and Fig. 4. Both hips of cow shown above were broken (knocked down) as a result of a low-calcium ration. Her skeletal reserve of calcium was depleted to the point that her weakened bones were broken easily. Pelvic bones of a herdmate (Fig. 4) were broken in three places. (Florida Station Bulletin 262. R. B. Becker, W. M. Neal and A. L. Shealy, University of Florida, Gainesville, Florida, U.S.A.).

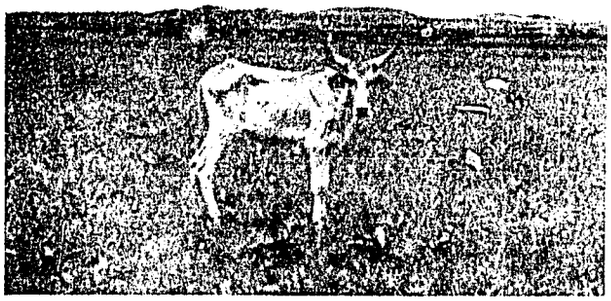

Fig. 5

An almost adult ox, raised on the phosphorus deficient "lavrado" fields of Roraima, northern Brazil, showing severely stunted growth. (Courtesy Jürgen Döbereiner and Carlos H. Tokarnia, EMBRAPA, Rio de Janeiro, Brazil).

Fig. 6

Fig. 6 and Fig. 7. Salt deficiency in a dairy cow. Illustrates before and after 1 year of salt deprivation (Cornell Bulletin 938, courtesy S. E. Smith, Cornell University, Ithaca, New York, U.S.A.).

Fig. 7

Fig. 8

Fig. 8 and Fig. 9. Cobalt deficiency. Fig. 8 shows a cobalt-deficient heifer that had access to an iron-copper-salt supplement. Note the severe emaciation. Her blood contained 6.6 g of hemoglobin per 100 ml on February 25, 1937. Fig. 9 is the same heifer fully recovered with an iron-copper-cobalt salt supplement while on the same pasture. (Florida Station Bulletin 699, 1965. R. B. Becker, J. R. Henderson and R. B. Leighty, University of Florida, Gainesville, Florida, U.S.A.).

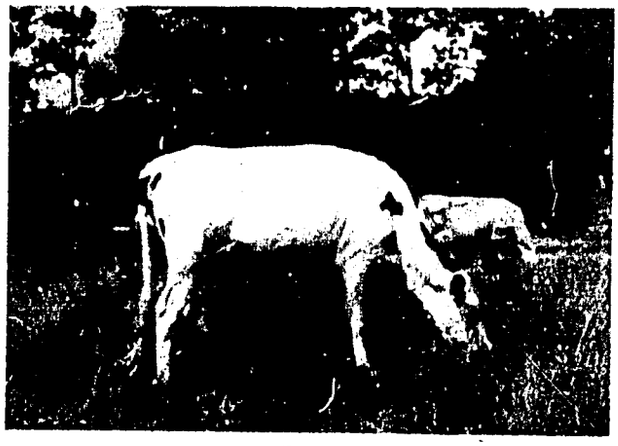

Fig. 9

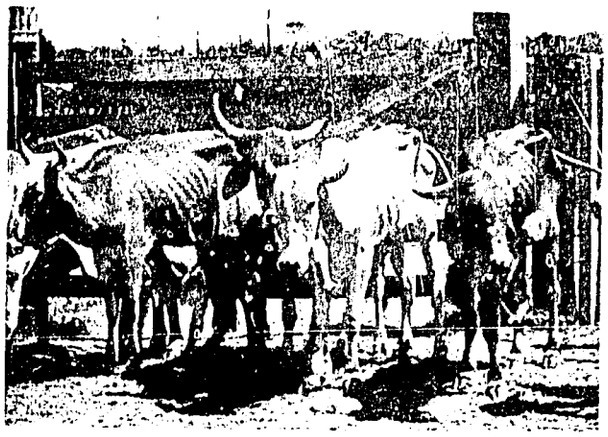

Fig. 10

Cobalt deficient cattle in northern Mato Grosso, Brazil. (Courtesy Jürgen Döbereiner and Carlos H. Tokarnia, EMBRAPA, Rio de Janeiro, Brazil).

Fig. 11

Extreme condition of cobalt deficiency of a Indu-Brazil steer in São Paulo, Brazil (Courtesy Nelson dos Santos Fernández, Instituto Biologico de São Paulo, São Paulo, Brazil).

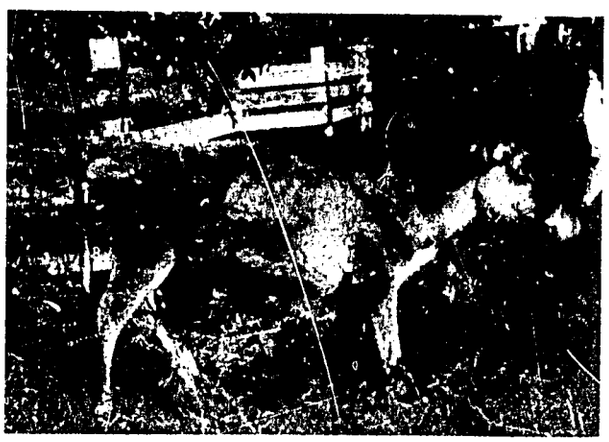

Fig. 12

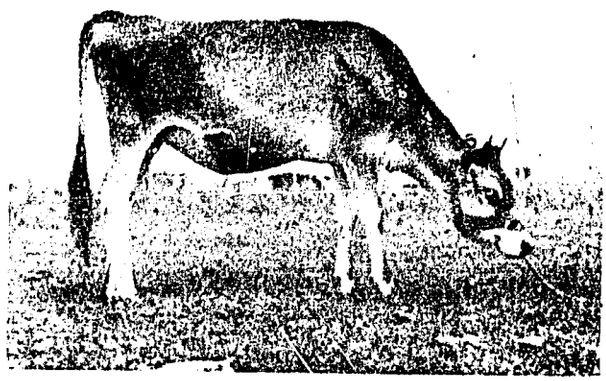

Fig. 13

Fig. 12 and Fig. 13. Jersey heifer E-15 had a hemoglobin reading of 5.9 gm. per 100 ml. of whole blood on October 21, 1930, (Fig. 12) Administration of ferric ammonium citrate and copper sulfate (50 Fe: 1 Cu) was started on December 15, 1930; it was 13.74 gm. per 100 ml. E-15 was fully recovered by March 27, 1931 and became a normal cow in the dairy herd (Fig. 13). This was the first bovine to confirm that copper was essential for ruminants. Two herdmates, receiving iron as the sole supplement to the basal ration died of anemia meanwhile. (Florida Station Bulletin 231. 1931, R. B. Becker, W. M. Neal and A. L. Shealy. University of Florida, Gainesville, Florida, U.S.A.).

Fig. 14

Copper deficient cattle in the sandy coastal region of Piaui, Brazil. (Courtesy Jürgen Döbereiner and Carlos H. Tokarnia, EMBRAPA, Rio de Janeiro, Brazil).

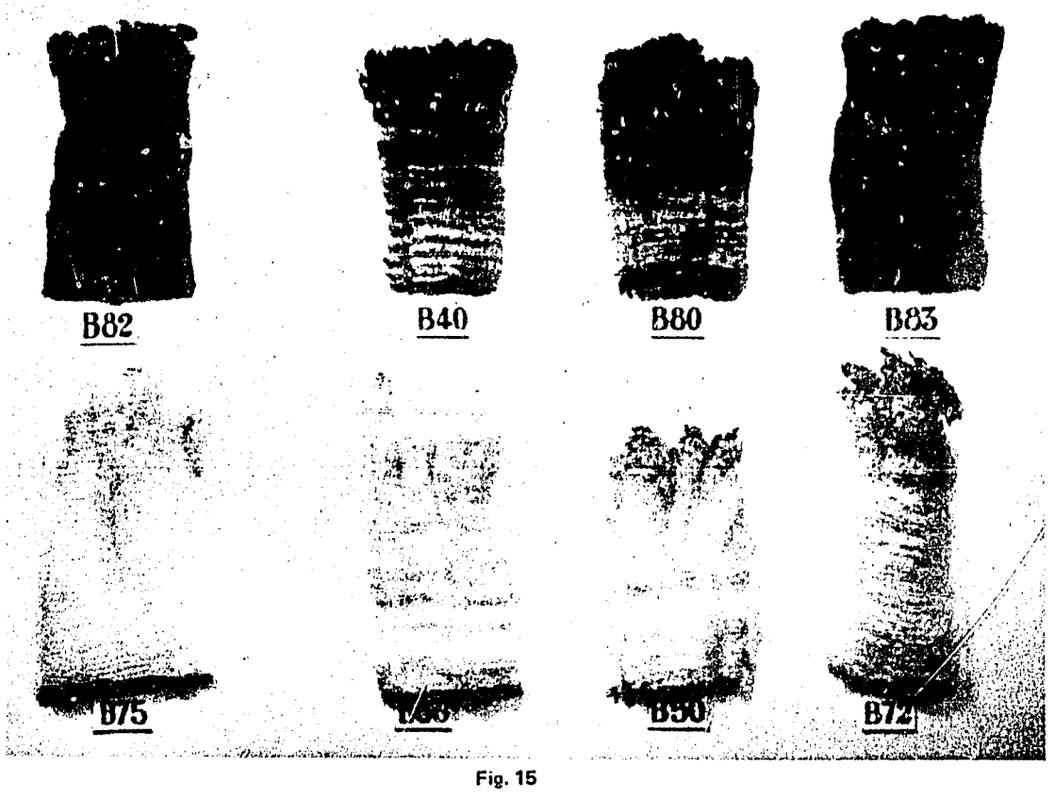

Fig. 15

Wool from normal and copper deficient sheep. On the left are typical normal black and white wools from sheep fed a basal diet. The other samples are from sheep on sulfur-molybdenum supplemented diets, showing banding of black wool, loss of definition of crimp and, in some, occurrence of secondary waves. (Australian Journal of Agricultural Research Vol. 7, 1956. K. Wynne and C. L. McClymont, Nutrition Research Laboratory, Glenfield, N.S.W., Australia).

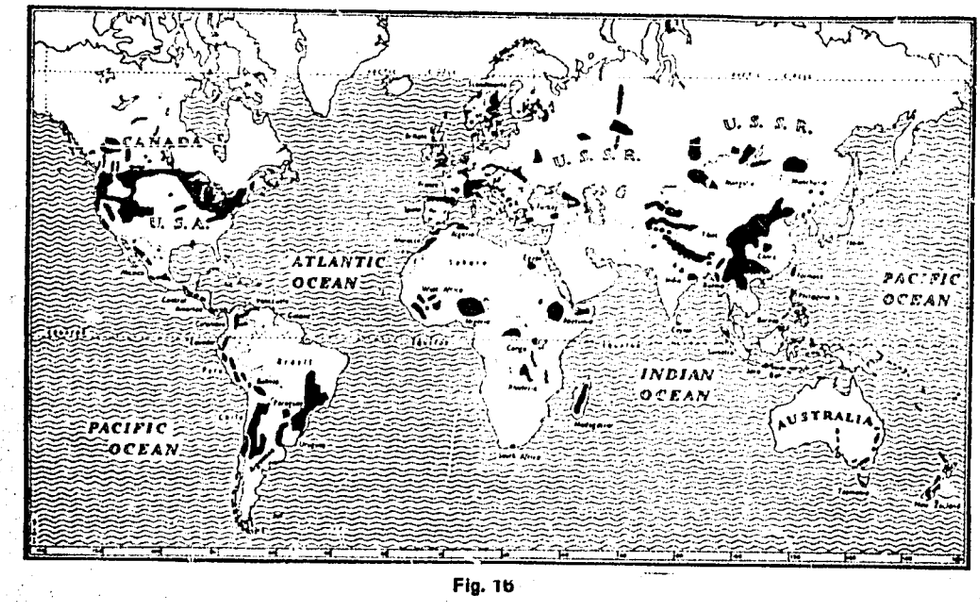

Fig. 16

World map showing occurrence of endemic goiter. Black areas indicate areas where endemic goiter has been found. (Courtesy Chilean Iodine Educational Bureau, Chile House, 20 Ropemaker Street, London E. C. 2.)

Fig. 17

Goiter caused by iodine deficiency in calves and goats, in Minas Gerais, Brazil. (Courtesy of Francisco Megale, Federal University of Minas Gerais, Belo Horizonte, Brazil).

Fig. 18

Fig. 19

Fig. 20

Fig. 18, 19 and 20. White muscle disease. The calf in the top photograph is about 3 months old. Lameness and generalized weakness of muscles can be seen. Photographs below show abnormal white areas in the heart muscles. (Courtesy, O. H. Muth, Oregon Agricultural Experiment Station, Carvallis, Oregon, U.S.A.).

Fig. 21. Cow with exostosis (bony growth) of the bones caused by ingesting large amounts of fluorine in Polk County, Florida. (Florida Station Bulletin 683. Courtesy R. L. Shirley, University of Florida, Gainesville, Florida, U.S.A.).

Fig. 22

Fig. 23

Fig. 24

Fig. 22 Incisors from four year old bovine with severe dental fluorosis. Lesions include enamel hypoplasia, hypocalcification, staining and abnormal wear and reflect a near constant elevated fluoride intake during the period of tooth formation.

Fig. 23 Incisors from five years old bovine with severe dental fluorosis and reflect intermittent periods of elevated fluoride ingestion during the period of tooth formation.

Fig. 24 Bovine metatarsals. Left: normal. Right: osteo-fluorosis with severe periosteal hyperostosis with roughened irregular surface consisting of disorganized and poorly mineralized bone. Note that the articulating surfaces are unaffected.

Fig. 22,23 and 24: Courtesy of J. L. Shupe and A. E. Olson, Utah State University, Logan, Utah. Reproduced with permission of the National Academy of Sciences.

Fig. 25

Selenium toxicity in the selenium toxic region of Puerto Boyaca, Colombia. Mishapen hoof due to selenium injury. (L. R. McDowell, University of Florida, Gainesville, Florida).

Fig. 26

Malformed lambs observed in Wyoming, U.S.A. The lambs show congenital deformity traceable to selenium injury during fetal development. (Courtesy P.O. Stratton, University of Wyoming, Laramie, Wyoming, U.S.A.).

Fig. 27

Zinc deficiency lesions in grazing cattle observed in Bethlehem, Orange Free State, South Africa. The major clinical sign is widespread alopecia. The most severe lesions were between the rear and front legs, which cannot be seen. Bleeding of the cracked skin in this area was sometimes observed. (Courtesy B.D.H. Van Niekerk, Voermol Products Limited, Natal, South Africa).

Fig. 28

Manganese deficiency in a new born calf; legs are weak and deformed. (Courtesy I. A. Dyer, Washington State University, Pullman, Washington, U.S.A.).

Fig. 29

Magnesium deficiency in a lamb. Note stiff legs. (Courtesy U.S. Garrigus, University of Illinois, Urbana-Champaign, Illinois, U.S.A.).

Fig. 30

Fig. 31

The lamb at left received a potassium-deficient ration (0.1 percent potassium), whereas the lamb at right received sufficient dietary potassium (0.6 percent potassium). (Courtesy the University of Missouri and R. L. Preston, current address, Washington State University, Pullman, Washington, U.S.A.).

Fig. 32

Lambs fed a low-sulfur diet. Lamb 6 received 3 g of sulfur per pound of ration, whereas lamb 5 received none. Note the excessive salivation, lacrimation, and shedding of wool by lamb 5. (Courtesy U.S. Garrigus, University of Illinois, Urbana-Champaign, Illinois, U.S.A.).

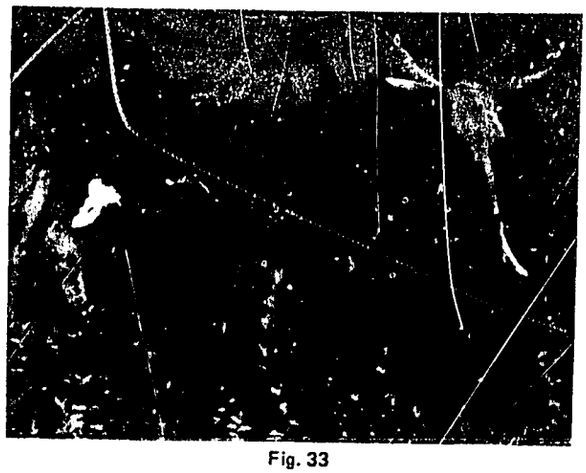

Fig. 33

A cow chewing bone in the "Llanos" region of Santa Maria de Ipire, State of Guarico, Venezuela. Bone chewing is often associated with a phosphorus deficiency. (Courtesy David Morillo, Centro de Investigaciones Agronomicas, Maracay, Venezuela).

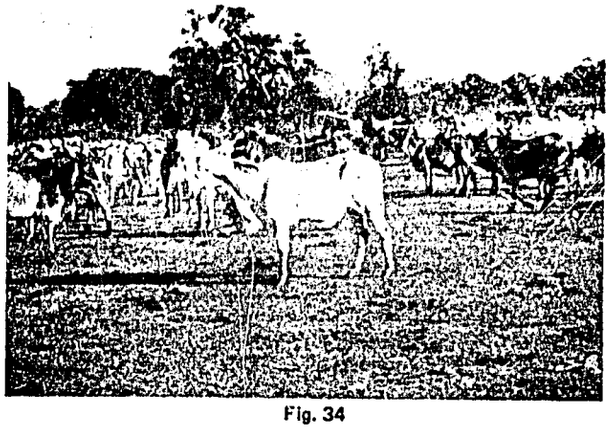

Fig. 34

A cow chewing bone in a phosphorus deficient area in southern Mato Grosso, Brazil. Osteophagia is a characteristic manifestation of phosphorus deficiency and is easily recognized, even at a distance, due to the typical position of the distended neck. (Courtesy Jürgen Döbereiner and Carlos H. Tokarnia, EMBRAPA, Rio de Janeiro, Brazil).

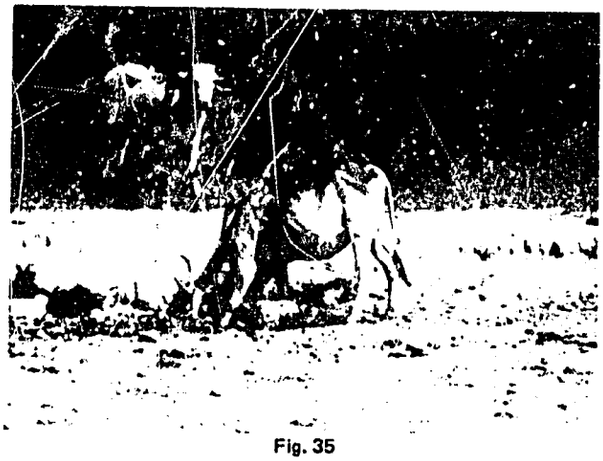

Fig. 35

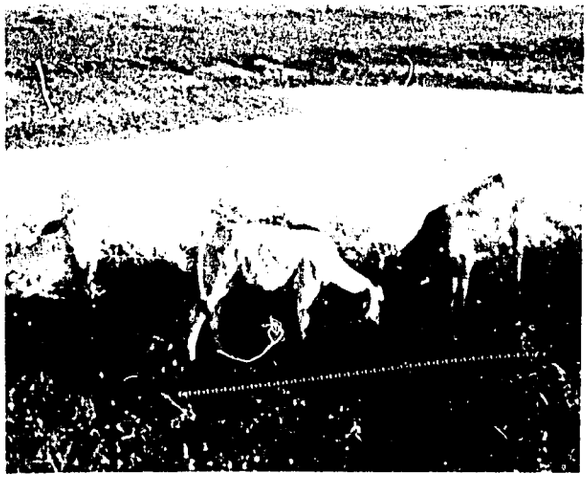

Fig. 36

Fig. 35 and Fig. 36. Cattle consuming soil at "Hato El Frio" in the "Llanos", State of Apure, Venezuela. Note holes in soil from previous consumption (Fig. 35). Excessive soil consumption is associated with pronounced mineral deficiencies. (Courtesy: Fig. 35 Elicer Alberto Velasco, Hato El Frio, Apure State, Venezuela; Fig. 36 Lee R. McDowell, University of Florida, Gainesville, Florida, U.S.A.).

IRON, MANGANESE, AND ZINC IN RUMINANT NUTRITION

by
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Introduction. Research-to-date from tropical regions suggests that trace mineral mixtures for grazing ruminants should contain Co, Cu, I, and sometimes Se. These minerals are known with certainty to be required in large areas, and under some conditions, in amounts greater than those available from forage. However, the advisability of supplementing grazing livestock with Fe, Mn, and Zn is much less sure. These three minerals are treated together in this review, not because they are similar in some aspects of metabolism, but rather because they may be the least likely to be deficient under grazing conditions. Thus it is most important to explore under what conditions these minerals need to be incorporated into mineral mixtures.

Iron

Introduction. Iron deficiency is one of the most commonly occurring deficiency diseases of swine and humans. Nevertheless, it is rarely of practical concern in grazing cattle and sheep, except in circumstances involving blood loss or disturbance in iron metabolism as a consequence of parasitic infestation or disease. Even during the suckling period, Fe deficiency is unlikely to occur in these species, but if they are maintained on milk alone for an abnormally long period, anemia may occur.

Functions of Iron. Iron exists in the animal body mainly in complex forms bound to protein as heme compounds (hemoglobin or myoglobin), as heme enzymes (mitochondrial and microsomal cytochromes, catalase, and peroxidase), or as non-heme compounds (flavin-Fe enzymes, trasferrin and ferritin). The role of Fe in the body is almost exclusively confined to the processes of cellular respiration, with the functions of myoglobin and hemoglobin to store and transport molecular oxygen by coordination with Fe atoms in these compounds (Underwood, 1971).

Iron requirements. Little is known of the Fe requirements of ruminants (Underwood, 1966). The suggested Fe requirement for beef cattle is 10 to 30 ppm (ARC, 1965; NRC, 1976) and dairy cattle 100 to 150 ppm (NRC, 1971; Adams, 1975). Results of Fe supplementation experiments with lambs showed that the minimum dietary Fe requirement for growing-finishing lambs is greater than 25 ppm but less than 40 ppm (Lawlor *et al.*, 1965).

Iron absorption, excretion, tissue levels, and homeostasis. Thomas (1970) summarizes Fe absorption concepts as follows: (1) absorption is more efficient when body stores are low, (2) the amount absorbed is usually a small portion of that ingested, (3) many dietary factors influence amount absorbed, (4) absorption occurs directly into blood with limited amounts into the lymphatic system, (5) the quantity absorbed from the duodenal area exceeds that from other portions of the tract, and (6) orally administered ferrous (Fe^{+2}) salts are more effective for hemoglobin regeneration than ferric (Fe^{+3}) salts.

Hemoglobin and myoglobin represent approximately 60 and 3%, respectively, of the total Fe. About 25% of body Fe is in the storage forms, ferritin and hemosiderin, found in liver, spleen, bone marrow, and other tissues (Thomas, 1970).

High levels of dietary phosphate (Underwood, 1966; Lassiter, 1967) or phytate (Underwood, 1966) interfere with the absorption of Fe, Zinc, Cd, Cu, and Mn, at high intakes, also interfere with Fe absorption, apparently through competition for protein-binding sites in the intestinal mucosa (Underwood, 1971).

Iron is excreted in the urine and feces, in addition to losses in the sweat, hair, and nails. However, absorbed Fe is retained with great tenacity and is not readily lost from the body except through hemorrhage. Iron is released from hemoglobin during red blood cell breakdown, is carried to the liver and secreted in the bile. Most of the Fe in the bile is reabsorbed and can be used again to form hemoglobin.

Iron deficiency. Iron deficiency is characterized clinically by poor growth, lethargy, blanching of the visible mucous membranes, increased heart and respiration rates, decreased resistance to infection, and in severe cases, a high mortality. In all species, Fe deficiency results in a hypochromic, microcytic anemia with low serum Fe, increased total serum, iron-binding capacity and a decreased saturation of transferrin (Underwood, 1966, 1971).

Hibbs *et al.* (1961) reported that calves may be deficient in Fe at birth since 30% of those born in a 12 year U.S. study had low hemoglobin values (<9 g/100 ml). Newborn calves receiving milk have increased hemoglobin formation as a result of supplemental Fe (Thomas *et al.*, 1954). It is well known that anemia develops in calves restricted to a milk diet for long periods and that the condition can be alleviated by administration of Fe (Blaxter *et al.*, 1957; Roy *et al.*, 1964).

Heavy infestation with intestinal parasites results in an Fe deficiency type of anemia in lambs and calves (Campbell and Gardiner, 1960). Anemia can result from the direct loss of blood via blood-sucking parasites or through a rise in the rate of degradation of blood cells and also through a depression of hematopoiesis from the action of toxic substances produced by the parasites.

Iron toxicity. Coup and Campbell (1964) reported weight loss, diarrhea, decreased milk production, and an abnormal skin condition in dairy cattle either dosed orally with 40 to 60 g Fe per day or grazing pastures which were irrigated with water containing high levels of Fe. Standish *et al.* (1969, 1971) indicated that high dietary levels of Fe as ferrous sulfate resulted in reduced performance and changes in mineral composition of steer tissues. Average daily feed intake and average daily gain were depressed by as little as 400 ppm. Standish *et al.* (1971) reported a decrease in plasma P by high levels of dietary Fe.

Detection and diagnosis of iron status for ruminants. Departure from normal levels of serum Fe, total Fe-binding capacity, percentage transferrin saturation value, hemoglobin and hematocrit values can be used to diagnose Fe deficiency in livestock. Low homoglobin and hematocrit values are not sensitive indicators of early Fe deficiency stages because they only occur when storage Fe is severely depleted. Their use is often limited to diagnosis and confirmation of Fe deficiency (Miller and Stake, 1974). Percent stauration of transferrin is the best criterion of Fe-deficient erythropoiesis (Underwood, 1971). Under practical conditions, an assessment of Fe deficiency can be made with reduced transferrin saturation (<13 to 15%) and hemoglobin levels (<10 g/100 ml) (McDowell, 1976).

Iron deficiency, prevention and control in Latin America. Iron deficiency is considered rare for grazing cattle due to generally adequate pasture concentrations together with contamination of plants by soil. Mitchell (1963) indicated that soil contains 20 to 100 times the Fe content found in pastures grown on a particular soil. Under New Zealand grazing conditions, annual ingestation of soil can reach 75 kg for sheep and 600 kg for dairy cows (Healy, 1974).

Acid soil conditions favor availability and plant uptake of Fe. Even plants grown on neutral or slightly alkaline soils often contain quite high levels of Fe. Since most of the soils are not alkaline in Latin America, Fe deficiency would not be expected to be widespread (Cox, 1973).

Of 256 forage averages in the 1974 **Latin American Table of Feed Composition**, (McDowell *et al.*, 1974) only 3.5% contained less than 30 ppm Fe. Forage analyses from Sao Paulo (Andreasi *et al.*, 1968), Minas Gerais (Gomide *et al.*, 1969), and Rio Grande do Sul (Gavillon and Quadros, 1973), Brazil, Guatemala (Scaillet, 1969), and Panama (Blue *et al.*, 1969) all indicate Fe concentrations in excess of ruminant requirements. However, other reports from Panama note that 7 out of 28 locations average less than 30 ppm Fe for samples of *Hyparrhenia rufa* (Chicco, 1972).

A substantial number of investigators who fed supplemental Fe have revealed no increase in weight gain or productivity and little or no change in hematological characteristics when older animals had been consuming typical rations. However, Fe deficiency exists, and in some cases, supplemental Fe has produced marked improvement (Thomas, 1970).

The utilization of different Fe compounds by ruminants has only been studied to a limited extent. Dietary Fe in the ferrous form is considered to be absorbed more efficiently than that in the ferric form (Thomas, 1970). Ammerman *et al.* (1967) reported that for calves and sheep, orally administered ferrous sulfate, ferrous carbonate, and ferric chloride ranked in decreasing order of availability. Ferric oxide was only about 12% as available as the iron from ferric chloride.

Iron deficiency may be a problem where cattle are fed on low-quality forages such as straw for extended periods (Sen and Ray, 1964). These investigators noted that Fe supplementation reduced weight losses in lactating cattle and produced more rapid gains in sucking calves. Iron deficiency has been reported in Florida when cattle grazed forages grown on white and gray, sandy loam and fine sand soils (Becker *et al.*, 1965).

When Florida cattle are being pastured on light, sandy soils, and often when they have been subjected to heavy insect or parasite infestations, the addition of Fe has served a useful purpose and the hemoglobin levels, as well as the condition of the animals, have improved under such treatment (Davis, 1951). For any given region in Latin America, 10 to 30 ppm of supplemental Fe is warranted when forage analyses suggest low Fe concentrations and/or if cattle are infected with insects or parasites that result in substantial blood loss.

Manganese

Introduction. Although Mn deficiency has been produced experimentally in calves and cattle with effects on skeletal development and reproductive performance, until recently, doubt had been expressed whether this deficiency arises under field conditions. Manganese deficiency for ruminants under grazing conditions has been suggested in the United States (Bentley and Phillips, 1951; Dyer *et al.*, 1964; Shupe *et al.*, 1967), Holland (Grashuis *et al.*, 1953), the United Kingdom (Munro, 1957; Wilson, 1965), Union of South Africa (Bisschop and Groenewald, 1963), and Germany (Anke *et al.*, 1972).

A report from Wisconsin (U.S.A.) notes that sterility exists in about 10% of the cattle of certain herds where low Mn rations (<20 ppm) are fed (Bentley and Phillips, 1951). Reports from western United States show a positive relationship between a low Mn intake of gestating cows and the incidence of neonatal deformities in their calves (Dyer *et al.*, 1964). Shupe *et al.* (1967) report a "croaked calf" disease in nine western states (U.S.A.) which is similar to the clinical signs of Mn deficiency. A survey conducted over a 4-year period with a total of 4,000 head of cattle indicated that 2.7% of the calves born over this period were deformed (Shupe *et al.*, 1967).

From Holland, reports noted leg deformities, poor growth in calves, reduced fertility and frequent abortions in cows grazing Mn-depleted pastures (Grashuis *et al.*, 1953). Later research from Holland does not support the idea of Mn deficiencies in this country (Underwood, 1971). Manganese supplements have been reported to improve fertility of dairy cows in parts of England (Munro, 1957; Wilson, 1965). From South Africa are reports of low forage Mn levels in

natural pastures in addition to the clincial signs of Mn deficiency in young cattle, including a stilted gait and straight hocks (Bisschop and Groenewald, 1963). In Germany, Mn deficiency in cattle developed only after heavy liming (Anke *et al.*, 1972).

Functions of manganese. Everson (1970) summarized the functions of Mn as follows: (1) This element is essential for optimum growth; (2) A deficiency of Mn during gestation results in poor viability of the offspring; (3) The young of severely deficient animals have skeletal abnormalities; (4) Many of the Mn-deficient offspring are ataxia at birth, showing incoordination and poor equilibrium; and (5) Mn deficiency causes sterility in the male.

Like the other trace elements, Mn is closely involved with several enzyme systems. Liver arginase contains Mn as an essential component with numerous enzyme systems being activated by Mn *in vitro*. The fact that Mn is concentrated in the mitochondria has led to the suggestion that *in vitro* Mn is involved in the partial regulation of oxidative phosphorylation. Manganese is needed in bone formation, being essential for the development of the organic matrix which is composed largely of mucopolysaccharides. Many of the defects associated with Mn deficiency may be accounted for by the need for Mn in glycosyltransferase activity (Leach, 1974).

Manganese requirements. The minimum dietary requirements of Mn depend upon the species, the criteria of adequacy employed, the chemical forms in which the element is ingested, and the nature of the rest of the diet (Underwood, 1971). Necessary levels for growth of cattle are less than for reproduction. Bentley and Phillips (1951) concluded that concentrations of 10 ppm are adequate for growth but might be marginal or borderline for optimum reproductive performance.

Dyer *et al.* (1964) and Rojas *et al.* (1965) concluded that the Mn requirements of cows for maximum fertility are in excess of 16 ppm. Recommendations from the NRC (1976, 1971) and ARC (1965) conclude that the requirements are between 20 to 40 ppm. Cuthbertson (1969) reviewed the literature on the effects of Mn on growth, reproduction, milk yield, and blood hemoglobin levels and suggested that Mn should be present in the diet at a level of 40 ppm.

The level of Ca and P in the diet effects the Mn requirements. Hignett (1959) suggested that Ca and P affect the utilizing of Mn required for enzyme systems essential for establishing and maintaining pregnancy. Excessively high intakes of Ca and P over a long period reduced weight gains of growing calves reared mainly on a milk diet, possibly due to interference with Mn absorption, but additional Mn (50 ppm) tended to counteract the excess (Hawkins *et al.*, 1955).

On the basis of field evidence with cattle, unidentified factors, other than Ca and P, exist which are capable of producing "conditioned" Mn deficiency and thereby increasing Mn requirements (Underwood, 1971). Shupe *et al.* (1967) reported that cows ingesting *Lupinus caudatus, Lupinus sericeus,* lupine extracts and sparteine sulfate give birth to deformed calves. The alkaloids in the *lupinus* plants were toxic to animals with the teratogenic effects on calves similar to anomalies due to Mn deficiency (Dyer *et al.*, 1964; Rojas *et al.*, 1965). Howes *et al.* (1973) showed that lupines (sparteine sulfate) had a significant effect on mineral metabolism. The reduction and/or increase in ^{54}Mn and ^{65}Zn activity caused by the addition of sparteine sulfate suggests that this alkaloid causes a change in the tissue turnover rate of Mn and Zn.

Manganese absorption, excretion, tissue levels and homeostasis. The absorption of ingested Mn is generally considered to be very low at about 3 to 4% (Underwood, 1971). However, Howes and Dyer (1971) and Carter *et al.* (1974) have shown that Mn absorption in young calves was considerably higher than generally reported in other species. Howes and Dyer (1971), working with calves, showed that Mn is preferentially absorbed under low dietary intakes. Their data also suggest that Mn in the tissues of nonsupplemental calves has a slower turnover rate vs. those with adequate Mn status.

Britton and Cotzias (1966) previously suggested that variable excretion rather than variable absorption regulates tissue Mn. Animals on a low Mn diet continue to excrete Mn. The Mn body pool is small and the body does not ordinarily accumulate Mn, so that total body excretion is continuously very nearly equal to intake. Twenty-five to 50 percent of the body pool is often ingested daily (Lassiter *et al.*, 1970).

Oral Mn is mainly excreted in the feces (95 to 98%) with only .1 to 3% usually excreted in the urine (Thomas, 1970). Even toxic levels of Mn administered orally to lambs were excreted almost exclusively by way of the feces (Watson *et al.*, 1973). Normally, liver is regarded as the main organ in the control of Mn excretion. Bile flow is thought to be the main route of Mn excretion and has a principle role in Mn homeostasis (Underwood, 1971; Papavasiliou *et al.*, 1966). Carter *et al.* (1974) reported that increasing dietary Mn in calves from .5 to 15 ppm (a 30-fold increase) for 5 days caused a 30-fold increase in bile Mn. It is concluded from cattle research data that both variable excretion and absorption are major homeostasis mechanisms by which animals maintain normal health and performance over the wide range of Mn intake found under field conditions.

Manganese is distributed throughout the body and is found in higher concentrations in bone, liver, kidney, and pancreas than in skeletal muscle. Several researchers note only a small change in tissue Mn level (twofold) has been brought about with a 200-fold increase in dietary level (Thomas, 1970). Liver generally responds more to dietary treatments than other organs because it is the main storage organ (Papavasiliou *et al.*, 1966; Watson *et al.*, 1973). It appears that liver Mn changes readily up to a certain level (about double normal) and then resists further change (Carter *et al.*, 1974). Contrary to other tissues, hair Mn levels continue to rise as dietary Mn intakes increase. Costa Rican cattle consuming high Mn forages (> 100 ppm) had very elevated hair Mn levels compared to controls, 83.3 vs. 18.6, respectively (Lang, 1971).

Manganese deficiency signs. Clinical signs and conditions observed when the diet contains insufficient Mn include: suboptimal soft tissue and skeletal growth; decreased breaking-strength of bones; abnormal bone shape; ataxia; muscular weakness; excess accumulation of body fat; reduced tissue storage of Mn in bone, liver, hair, and ovary; reduced milk production; reduced level of Mn in milk; delayed, irregular, or absence of estrus; resorption of fetus; fetal deformities; aplasia or hypoplasis of pancreatic cells; diabetic-like blood glucose disappearance; decrease in liver arginase; and a decrease in bone and plasma alkaline phosphatase (Thomas, 1970).

The reproductive processes are particularly susceptible to lack of Mn. Bentley and Phillips (1951) reported that heifers raised on low Mn (<10 ppm) were slower to exhibit estrus and were slightly and consistently slower to conceive upon breeding than controls. The effect of Mn supplementation on cattle infertility in Great Britain was reported by Wilson (1965) in an experiment with 350 cows. Of those given Mn, 63% conceived after the first service compared with 51% of those not given it. Also, in Great Britain, Munro (1957) previously observed that conception rates were raised from 48 to 72% following Mn supplementation.

Anke *et al.* (1973) reported that cows on rations low in Mn weakly expressed estrus and the number holding to first insemination was 31%, as against 64% in the control herd. There was a significant prolongation of gestation from 287 to 290 days.

The nature and severity of the skeletal abnormalities that arise in Mn-deficient animals vary from a mild and generalized rarefaction of bone to gross and crippling deformities, particularly of the long bones (Underwood, 1966). Dyer (1961) suggested that calves born with congenital deformities may be a result of Mn deficiency of the dam. Rojas *et al.* (1965) fed pregnant cows rations containing 15.8 or 25 ppm of Mn. Calves born to cows fed the low-Mn ration were born with a general weakness and deformities characterized by enlarged joints, stiffness and twisted legs. Deformed calves had shorter humeri with the breaking-strength greatly reduced (Rojas *et al.*, 1965). The changes in epiphyseal cartilage of growing bones and developing fetus have led to studies showing a decrease in the mucopolysaccharide content and radioactive sulfur uptake of bone in Mn deficiency (Thomas, 1970).

Manganese toxicity. Experimental levels of 50 to over 4,000 ppm Mn in the diet is monogastric and ruminant animals have caused reduced hemoglobin, growth depression, abnormal bones, and other symptoms (Thomas, 1970).

Findings from Costa Rica suggest that Mn, when in excess, can be a limiting factor in animal production. Fonseca and Davis (1968) and Lang (1971) reported a close relationship between high forage Mn and low reproductive rates in regions characterized by volcanic soils. Dairy cattle that consumed high Mn forages (>100 ppm) had a lower calving percentage and required more services per pregnancy than controls (Lang, 1971).

Manganese deficiency in Latin America. Concentrations of Mn in forages is dependent on soil factors, plant species, stage of maturity, yield, pasture management, climate, and soil pH. Gomide *et al.* (1969), studying mineral composition in tropical grasses of Minas Gerais, Brazil, found significant year x species x age interaction in Mn content. Poor drainage conditions increase forage Mn (Mitchell *et al.*, 1957), while increasing soil pH decreases plant availability and uptake of Mn (Miller *et al.*, 1972; Cox, 1973). From the Brazilian Amazon Valley, Sutmöller *et al.* (1966) report a very high intake of Mn by Brazilian cattle on soils that are deeply flooded during a long period of the year, while low intake occurs on non-flooded or slightly flooded soils.

From Peru, Beeson and Guillermo-Gómez (1970) noted that Mn concentrations tended to be excessively high in forages grown on acid soils. Cox (1973) notes that in order to develop a Mn-deficient soil, soils must be leached of reduced forms of Mn and soils frequently are limed, often in excess of crop requirements.

In Brazil, Sutmöller *et al.* (1966) report a relationship between Mn content of soils and Mn intake by cattle. Soils of the semi-arid region of the state of Pernambuco, Brazil are characterized by adequate Mn with the chances of a Mn deficiency remote (Horowitz and Dantas, 1966). However, in soils near the coast, Zona de Mata, where most of the cattle are located, available Mn is much less than 20 ppm, which is considered deficient (Horowitz and Dantas, 1966; Dantas, 1971).

Forages usually fall within the range of 20 to 100 ppm Mn, but in this instance, it should be stressed that the content depends greatly on soil conditions, low concentrations being generally found in crops growing on well-aerated organic soils of high pH (Mills, 1969). In Latin America, there is a scarcity of data of Mn content of forages. Only 11.2% of 2615 forages in the 1974 **Latin American Tables of Feed Composition** (McDowell *et al.*, 1974) contained Mn values.

Of 293 average forage values from the 1974 **Latin American Tables of Feed Compositon** (McDowell *et al.*, 1974), 21% contained less than 40 ppm Mn while only 5.2% contained less than 20 ppm. Andreasi *et al.* (1968) reported adequate Mn concentrations of three common forages in the state of São Paulo, Brazil. Mean values taken from different locations ranged from a low of 89 to 326 ppm, while the distribution of all values was between 22 to 487 ppm. In Minas Gerais, Brazil, Gomide *et al.* (1969) reported the mineral composition of six tropical grasses and found the Mn species means to range from 64 to 248 ppm. From Guatemala, only 1 of 28 species had mean Mn values of less than 20 ppm (Scaillet, 1969). Blue *et al.* (1969) reported adequate Mn forage concentrations in four regions of Panama, with values ranging from 28 to 213 ppm. However, Chicco (1972) reported low average Mn concentrations (<20 ppm) for 7 out of 28 locations in Panama.

Detection and diagnosis of manganese status for ruminants. There is no single, simple diagnostic test that will permit the early detection of Mn deficiency in animals (Underwood, 1966). Van Koetsveld (1958, cited by Sutmöller *et al.*, 1966) and Egan (1975) considered liver Mn values below 10 ppm and 6 ppm, respectively, as indicating a deficiency.

Underwood (1966) believes that the level of Mn in liver is a useful but not entirely reliable indicator of Mn deficiency, unless the deficiency is severe. McDowell *et al.*, 1976 concludes that a Mn deficiency can best be detected by the combination of liver (<6 ppm) and diet (<20 to 40 ppm) analyses, while a toxicity is suspected when hair samples contain over 70 ppm Mn. The only certain way of detecting mild Mn deficiency is by measuring the response in reproductive performance, skeletal development and growth that occurs as a result of feeding a Mn supplement.

Prevention and control of manganese deficiency. Manganese-deficient soils have been discovered in many parts of the world upon which plant growth responses can be obtained from the application of Mn-containing fertilizer. In areas where Mn deficiency in crops has been demonstrated, attention should be given to the possible inadequancy of supplies of dietary Mn for ruminants.

In areas where Mn deficiency or "conditioned" Mn deficiency occurs in cattle, remedial measures could normally include a careful control of liming, the use of crop sprays or fertilizers containing Mn, and the inclusion of Mn-containing supplements in the ration. Supplementation of the feed with Mn sulfate at the rate of 4 g for cows, 2 g for heifers, or 1 g per day for calves is sufficient for either the prevention or the cure of the deficiency (Underwood, 1966). Underwood (1966) also reports that treatment of the pastures with Mn sulfate at the rate of 15 kg per hectare has been found completely effective under the conditions that exist in the Netherlands.

On the basis of the literature, it appears that 40 ppm of forage Mn would be considered adequate, 20 to 40 ppm borderline, and less than 20 ppm Mn deficient for ruminants. Nevertheless, it should be remembered that soil and water likewise provide Mn toward meeting the animal's requirement. Dyer (1961) reported that water from a ranch with normal calves contained 1.7 ppm while that from a nearby ranch with deformed calves contained .02 ppm Mn.

When roughages contain over 40 ppm Mn, it seems likely that most beef or dairy cattle rations would require supplemental Mn. It seems logical, as a preventive measure, to add 10 to 20 ppm of supplemental Mn to cattle diets, when forage analyses are routinely below 40 ppm. This level of Mn should be adequate to correct any likely borderline deficiency.

Zinc

Introduction. Zinc deficiency, under experimental conditions, has been produced by many workers. However, a deficiency under natural conditions was once thought unlikely. Nevertheless, reports from Guyana (Legg and Sears, 1960), Finland (Haaranen and Hyppola, 1961), Norway (Dynna and Havre, 1963), Venezuela (Perdomo, J. T., personal communication, 1975), Greece (Spais and Papasteriadis, 1974), and the United States (Mayland, 1975) have confirmed Zn deficiencies in grazing cattle when the ration contained less than 40 ppm.

Function of zinc. Zinc is essential in all animals, functioning in enzyme systems and being largely involved in nucleic acid metabolism, protein synthesis, and carbohydrate metabolism. Zinc has likewise been shown to be involved in vitamin A metabolism by maintaining normal concentrations of vitamin A in plasma (Smith *et al.*, 1973). These workers used animals deficient in both Zn and vitamin A and demonstrated that Zn is necessary for normal mobilization of vitamin A from the liver.

Zinc requirements. The minimum zinc requirement of ruminants varies with the chemical form or combination in which the element occurs with other components of the diet, and with the criteria of adequacy employed. The suggested Zn requirement for cattle is 10 to 50 ppm (NRC, 1976, 1971; ARC, 1965).

Nine to 14 ppm Zn has been found adequate for normal growth and Zn plasma levels in calves (Miller *et al.*, 1963; Miller *et al.*, 1967). In contrast, zinc deficiency has been reported under field conditions in different European locations when forage contained from 19 to 83 ppm Zn (Miller, 1970). For dairy cattle, Haaranen (1963) suggests that the requirement for Zn is 45 ppm when the ration contains .3% Ca and increased by 16 ppm for each .1% of additional Ca.

Zinc absorption, excretion, and storage. The small intestine is the main site of Zn absorption with the duodenum the most active site. Absorption is affected by dietary level, amounts and proportions of several other elements and dietary components, and by the chemical form in which Zn is ingested (Underwood, 1971). A high percentage of all Zn is excreted through the feces and very little by way of urine (Miller, 1970).

The most important factor affecting absorption is the Zn content of the ration. Stake *et al.* (1975b) reported that Zn absorption for calves and cows ranged between 47.2 and 53.4% when fed low Zn rations. Zinc absorption was directly reflective of the physiological demand for Zn in both calves and lactating cows (Miller, 1969; Stake *et al.*, 1975a). Zinc-deficient animals absorb a higher percentage of administered Zn. Zinc-deficient calves have a net absorption as high as 80% of an oral Zn dose (Miller, 1970). Neathery *et al.* (1973) reported that dairy cattle compensated for low Zn diets within one week by a 50% increase in percentage absorption of Zn, a decrease in milk Zn, and a decline in excretion of Zn in feces.

Zinc is widely distributed throughout the body, with substantial amounts in all tissues containing considerable protein or calcified material (Miller, 1970). The prostate, choroid, and the iris of the eye and pituitary accumulate particularly high concentrations of Zn.

Zinc occurs in the animal and is transported almost entirely combined with organic compounds (Miller, 1971). In absorption and transport, Zn is apparently passed from one binding protein to another. Zinc may be passed as a metallo-ligand complex with such compounds as amino acids or EDTA as the nonprotein ligands. Metabolism after absorption can be affected by the ligands involved (Miller, 1975).

When young ruminants are fed a very Zn-deficient diet, the Zn content of some tissues declines, but in others, there is little or no change. With a severe deficiency, there is limited Zn reduction in hair, bone, liver, lung, kidney, spleen, pancreas, and blood plasma (Miller, 1970). Neathery *et al.* (1973) reported that Zn tissue contents of first lactation dairy cows fed 16.6 ppm or 39.5 ppm Zn for 6 weeks were very similar. Of 25 tissues analyzed, only rib cartilage and rumen wall from cows given the low-Zn diet had significantly less Zn.

Animals have a limited capacity for storing Zn in a form which can be mobilized rapidly to prevent deficiency signs. With a very low Zn diet, there is an immediate share decline in plasma Zn, with reductions in feed intake and cessation of growth within less than one week (Mills *et al.*, 1967). Plasma Zn concentrations fall below .04 mg/100 ml within 24 hours of feeding a Zn-deficient diet. However, Spais and Papasteriadis (1974) reported plasma Zn between .04 and .06 mg/100 ml corresponding to severe Zn characteristic lesions, with .06 to .1 mg/100 ml related to slight Zn deficiency signs.

Practically all natural-occurring diets conain adequate amounts of Zn, but only small amounts of the element seem to be available to the animal. Therefore, factors must be present which reduce Zn absorption or impair its utilization in the animal. The nature of the diet has a marked effect on the amount of Zn required by monogastric animals. The metabolism of Zn may be influenced by interaction with other elements like Cd, Ca, Cu, Fe, Se, and Mn (Strain and Pories, 1970; Ivan and Grieve, 1975). The presence of chelating materials, phytic acid, levels of certain minerals, particularly Ca and many unknown factors affect Zn absorption in monogastric animals (Blackmon *et al.*, 1967). However, in most instances, the factors which may affect the requirements of ruminants are unknown. In normally fed ruminants, presently, there is lack of direct evidence that Ca, phytic acid, or other factors in plant proteins decrease Zn absorption (Mills *et al.*, 1967; Miller, 1970).

Zinc deficiency signs. Blackmon *et al.* (1967) summarized clinical signs of a zinc deficiency to include: (1) inflammation of the nose and mouth with submucous hemorrhages, (2) unthrifty appearance, (3) rough coat, (4) stiffness of the joints with soft edematous swelling of the feet in front of the fetlocks, (5) cracks in the skin of the coronary bands around the hooves, which later become deep fissures, (6) dry, scaly skin on the ears, (7) thickening and cracking of the skin around the nostrils, (8) development of horny overgrowths of the mucosa on the lips and dental pads, (9) gnashing of the teeth, (10) alopecia, (11), red, scabby and wrinkled scrotal skin, (12) bowing of the hind legs.

Early effects of Zn deficiency include reduced feed intake, growth rate, and feed efficiency, followed by skin disorders. The skin is rich in Zn and is a sensitive indicator of Zn metabolism. Zinc-deficient animals are unable to grow healthy epidermis and epithelial appendages (Pories and Strain, 1970).

From Guyana, Legg and Sears (1960) were the first to report a parakeratosis skin disorder in grazing cattle. In the more acute cases, parakeratosis spread rapidly over about 40% of the body surface. The skin and hair rapidly returned to normal after oral administration of Zn sulfate. Spais and Papasteriadis (1974) reported that 60% of 150 cattle herds in Greece had severe to mild symptoms of Zn deficiency, consisting mainly of unthrifty appearance, rough coat, loss of hair, eczematous lesions with thickening and folding in various parts of the skin.

Zinc deficient calves grow more slowly, are lethargic, their wounds heal very slowly, if at all, and they are highly susceptible to nonspecific secondary infections (Miller, 1970). Testicular growth and development are often retarded in a Zn deficiency. Inhibited testicular growth has been observed in Venezuela in cattle consuming low Zn rations (Perdomo, J., 1975, personal communication).

Although severe clinical Zn deficiencies in ruminants have been described in different regions of the world, this likely is of much less economic importance than borderline subclinical deficiencies. The possibility of a widespread, mild, or borderline deficiency of economic importance should be investigated. The first effects of a mild Zn deficiency would be expected to be decreased feed intake, growth, feed efficiency, milk production, resistence to infection and stress, and lower reproductive efficiency (Miller, 1970). A borderline Zn deficiency, which is more likely to occur, would be difficult to diagnose clinically. As an illustration, Mayland (1975) reported increased weight gains for cattle supplemented with Zn, in the absence of Zn deficiency signs.

Zinc toxicity. Zinc is relatively nontoxic to animals and a wide margin of safety exists between normal intake and those likely to produce deleterious effects (Underwood, 1971). Ott *et al.* (1966) observed no adverse effects from feeding 500 ppm of Zn to cattle, but at 800 ppm Zn, a reduction in feed consumption and weight gain occurred. Miller (1970) concludes that it is improbable, with adequate amounts of other nutrients, that problems would arise in cattle receiving dietary Zn below 400 or 500 ppm. However, Zn greatly in excess of requirements might aggravate a borderline deficiency of some other element such as Cu, Fe, or Ca.

Zinc deficiency in Latin America. Cox (1973) reports low levels of Zn in soil and plants throughout much of Latin America. A number of factors including soil, plant species, stage of maturity, yield, pasture management, and climate may affect the likelihood of a Zn deficiency for ruminants. Poor drainage increases forage Zn (Mitchell *et al.*, 1957), while increasing soil pH decreases plant availability and uptake of Zn (Miller *et al.*, 1972). In most circumstances, the level of Zn declines as plants mature (Underwood, 1966; Mayland, 1975). Gomide *et al.* (1969) reported significant differences in forage Zn concentrations between two consecutive years. Vast areas of the "Campo Cerrado" region of Brazil are severely deficient in Zn as evidenced by substantial increases in crop yields when Zn was applied to soils (Britto *et al.*, 1971; Pereira *et al.*, 1973).

Many investigators conclude that Zn deficiency is unlikely and satisfactory weight gains in cattle result when the ration contains at least 40 ppm Zn (Spais and Papasteriadis, 1974 and Ivan and Grieve, 1975). Of 177 forage averages in the 1974 **Latin American Tables of Food Composition** (McDowell *et al.*, 1974) 61.5% contained less than 40 ppm. Legg and Sears (1960) reported severe Zn deficiency lesions in Guyana when cattle consumed forages containing 18 to 42 ppm Zn. In 72 forage observations from Venezuela, the overall mean was 32 ppm (Perdomo, 1975). From Puerto Rico (Kayongo-Male *et al.*, 1974), 82% of the grass species studied did not meet established Zn requirements for cattle. Considering the Zn analyses of the different grasses of Panama, Chicco (1972) concluded that a marginal nutrition of this element occurs particularly during the rainy season.

Forage Zn levels in the state of Sao Paulo, Brazil (Andreasi *et al.*, 1969) generally appeared to be adequate. Also, Galvao *et al.* (1973) reported that Zn supplementation had no effect on milk production and live weight gains of Minas Gerais cattle. Nevertheless, Gomide *et al.* (1969) reported low Zn concentrations for six plant species of Minas Gerais, ranging from 26.4 to 34.7 ppm.

Detection and diagnosis of zinc status for ruminants. Zinc deficiency is difficult to detect in its early stages or in milder forms. Biochemical changes with the most promising diagnostic value are decline in Zn concentration of plasma, hair, and bone with a tissue decline of alkaline phosphatase (Blackmon et al., 1967). Under survey conditions for determining the likelihood of deficiencies for large numbers of ruminants, Zn concentrations of plasma (.04 mg/100 ml) and forage (<50 ppm) would be indicators (McDowell, 1976).

Prevention and control of zinc deficiency. Supplementary Zn can be provided either by injections of Zn salts such as sulfate, by feeding Zn in mineral salts containing 1 to 2 percent Zn or by treatment of the soils with Zn-containing fertilizers (Underwood, 1966). Australian research on Zn-deficient soils indicated that 5 to 7 ob. of Zn sulfate per acre every 2 or 3 years would maintain increased Zn concentrations in forage. Good sources of supplemental Zn include Zn oxide, Zn chloride, Zn sulfate, and Zn carbonate.

Little is known either about the frequency with which low Zn levels may occur in forages or the most suitable quantities to incorporate in dairy cattle rations as a supplement in cases of inadequacy. The Zn content of most feeds is variable, with data on most being unavailable and not readily obtainable. Of 2615 forages in the 1974 **Latin American Tables of Feed Composition** (McDowell *et al.*, 1974), only 6.8% contained Zn values. Under Latin American conditions, it seems logical to add 20 to 30 ppm of supplemental Zn to cattle diets, unless forage analyses suggest high levels of this element. This level of Zn should be adequate to correct any likely borderline deficiency. Much higher levels of Zn, although not directly toxic to cattle, might aggravate borderline deficiency problems with other essential elements. Ivan and Grieve (1975) reported that 100 ppm of supplemental Zn significantly lowered liver Cu to 38 ppm compared to 148 ppm for control calves.

The majority of trace mineral mixtures in Latin America contain Zn. Nevertheless, many commercial trace-mineralized salt mixtures which are widely distributed contain an insignificant amount of Zn relative to the requirements of animals. Even more alarming is that the majority of farmers further dilute the trace-mineralized salt mixtures with 2 to 25 (or more) parts of additional salt to 1 part of trace-mineralized salt.

Summary

Research from tropical regions often indicates that trace mineral supplements for ruminants should contain Co, Cu, I, and Se. The need for supplementing ruminant diets with Fe, Mn, and Zn is less certain. Iron supplementation is warranted for grazing livestock when forages contain less than 100 ppm Fe and/or if insects or parasite are causing substantial blood loss. Iron status of livestock can be evaluated by serum Fe, total Fe-binding capacity, transferrin saturation, hemoglobin and hematocrit values. Mineral supplementation with Mn or Zn is advised if tissue levels are low, when clinical signs are suggestive of deficiencies or if forage concentrations are less than 40 ppm. The only certain way of detecting mild Mn and Zn deficiencies is by measuring the response as a result of feeding supplements of these minerals.

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NEWLY DISCOVERED AND TOXIC ELEMENTS IN RUMINANT NUTRITION

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At present, there are 14 known essential trace elements—iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), cobalt (Co), iodine (I), molybdenum (Mo), selenium (Se), fluorine (F), chromium (Cr), tin (Sn), nickel (Ni), vanadium (V) and silicon (Si). Some of the trace elements, such as arsenic (As), lead (Pb), cadmium (Cd), and mercury (Hg) are frequently classified as toxic elements because their toxicity to man and animal is relatively high and their biological activity is largely confined to toxic reactions. However, all the trace elements can be toxic if consumed in large-enough quantities or for long-enough periods (Underwood, 1973). A further 20 to 30 trace elements occur regularly in feeds and animal tissue and it is unknown whether they serve some useful purpose or are merely contaminants. Schwarz (1974a) suggests that even Pb is essential and speculated that titanium might be found deficient if purified diets can be developed which contain lower levels of this element.

An attempt will be made in this review to briefly mention both the most recently established essential trace elements (Cr, Sn, V, Ni and Si) and toxic elements (As, Pb, Hg, Cd and Al) that are detrimental to both man and livestock.

Essential Trace Elements (Cr, Sn, V, Ni and Si)

Although markedly different in their chemistry, mode of action, and effective levels, the newer essential trace elements have in common that they were first known for their toxic effects and that the induction of a dietary deficiency is very difficult. The rapid sequence of discoveries identifying the essentiality of these elements was based on the concepts of improved procedures for purification of diets, the use of the metal-free isolator system for raising animals and advances in trace element analytical techniques. The most recent reviews of the newer trace elements are as follows: Cr (Mertz, 1974a), Sn (Schwarz, 1974a), V (Hopkins, 1974 and Schwarz, 1974a), Ni (Nielsen, 1974) and Si (Carlisle, 1974a and Schwarz, 1974a). Table 1 presents the discovery date and approximate requirement of the newer trace element.

Chromium. Experimental Cr deficiency results in impaired glucose tolerance, reduction of growth and longevity, elevated serum cholesterol levels, and a decreased sensitivity of peripheral tissue to insulin. Chromium was identified as the active ingredient of a dietary agent, glucose tolerance factor (GTF), which is required for maintenance of normal glucose metabolism (Mertz, 1974b). In its biological effects, Cr may be intimately related to insulin of which it may be

Table 1
NEWER ELEMENTS IN MINERAL NUTRITION

Element	Discovery Date[a]	Reference[a]	Requirement
Chromium	1959	Schwarz and Mertz	>.1 ppm[b]
Tin	1970	Schwarz, Milne and Vinyard	1.5 - 2 ppm[a]
Vanadium	1971	Schwarz and Milne Hopkins and Mohr	.1 ppm[a]
Fluorine	1972	Schwarz and Milne Messer, Armstrong and Singer	2.5 ppm (F-)[a]
Silicon	1972	Schwarz and Milne Carlisle	5 - 100 ppm[b]
Nickel	1973	Nielsen	.03 - 3 ppm[b]

[a]Schwarz (1974a)
[b]Mertz (1974a)

a cofactor (Mertz *et al.*, 1974 and Schwarz, 1974b). The first detectable sign for Cr deficiency in rats and monkeys is impairment of intravenous glucose tolerance which is preventable or reversible by oral Cr. More pronounced Cr deficiency results in slightly decreased growth rates and life span, increased serum cholesterol increased formation of aortic plaques and, under certain conditions, in a syndrome resembling diabetes *mellitus* (Mertz, 1974b).

The demonstration of beneficial effects of Cr supplementation in malnourished children suggests that this element is also essential for man and that deficiencies exist (Mertz, 1974a). Chromium supplementation almost immediately restored glucose tolerance to normal in these children. The fact that Cr supplementation can significantly enhance the rate of recovery from malnutrition points out the need to identify those areas of the world in which protein-calorie malnutrition is complicated by Cr deficiency (Mertz, 1974a).

Hexavalent Cr compounds are inactive; only those which are derived from trivalent Cr or Cr of lesser oxidation states show activity with trivalent Cr as the active ingredient of the GTF (Schwarz, 1974a). Mertz (1974a) concludes that there are at least two classes of Cr compounds: One category, including Cr salts, which is poorly absorbed and which has no access to physiologically important pools, and another category consists of organic complexes in which Cr acts as an essential elemtent.

The evaluation of Cr nutritional status is difficult and the requirements of man or animals have not yet been quantified. This is due in part to unresolved problems in Cr analysis of tissues and feeds with the resulting lack of reliable values. Mertz (1974a) concludes that it is not yet possible to recommend a dietary Cr intake which would supply the 7 to 15 μg of available Cr needed to compensate for the daily losses. When Cr exists in an organically bound form (GTF), it is absorbed better, has a different tissue distribution, and is available to the fetus (Mertz and Roginski, 1971). Animals, as well as man, have a limited capacity to synthesize inorganic Cr into the GTF; the rate of this synthesis, which probably occurs in the intestinal flora, may be a very important determinant of the Cr nutrition of individuals. Chromium concentrations of selected feeds and their relative biological values are presented in Table 2. Most animal products contain much of their total Cr in the form of GTF, whereas leafy plants do not (Toepfer *et al.*, 1973). This data indicates that determination of total Cr in any material gives little information about its biological value. Unfortunately, many reports of Cr values are also unreliable since samples can be easily contaminated, even with stainless steel utensils, and organic Cr (GTF) is readily lost at high-ashing temperatures (Wolf *et al.*, 1974).

Tin. Schwarz (1971) produced a Sn deficiency in rats raised in metal-free isolator systems and also in plastic cages outside the isolator, by feeding a purified amino acid diet which contained all the essential trace elements known at that time. The growth rate in rats was enhanced by nearly 60% if 1 to 2 ppm of Sn as stannic sulfate was added to the amino acid diet. Tin also has an effect on the pigmentation of teeth (Milne *et al.*, 1972).

The biological chemistry of Sn is largely unknown. Ingested inorganic Sn is very poorly absorbed and is excreted mostly in the feces, with little or no accumulation with age in any human tissue other than the lungs (Underwood, 1973). Tin could well contribute to the tertiary structure of proteins or other biologically important macromolecules such as nucleic acids. Tin also could function as the active site of metalloenzymes (Schwarz, 1974b).

Table 2.
OCCURRENCE OF ESSENTIAL TRACE ELEMENTS

Element	Source
Chromium[b]	Liver (1.77 ppm), Brewers Yeast (1.17 ppm), Corn meal (.11 ppm), Wheat germ (.24 ppm) and Wheat bran (.42 ppm). Relative biological value of these sources is 4.52, 44.88, 2.35, 4.05 and 2.21, respectively.
Tin[c,d]	Widespread in foods, feeds and tissues. Kidney (.23–.7 ppm), Liver (.35–1 ppm), Lung (.44–1.2 ppm), Corn meal (.11 ppm), Oats (2.28 ppm, wet weight) and Pasture herbage, Scotland (.3–.4 ppm).
Vanadium[d,e]	Liver, Spleen, Pancreas and Prostate (.02–.03 ppm), Lung (.6 ppm), Red clover (.03–.16 ppm), Rye grass (.03–.11 ppm), Barley (.028 ppm) and Wheat (.046 ppm).
Nickel[d,e]	Wheat (.08–.35 ppm), Tobacco leaves (.05–1 ppm), Pasture plants (.5–3.5 ppm), Fruits and tubers (.15–.35 ppm).
Silicon[c,d]	Blood (2 ppm), Liver, Muscle, Lung, and Brain (2–20 ppm), Nails (56 ppm), Hair (90 ppm), Epidermis (106 ppm), Prairie grass *(Fectuca scabrella)* (6.27%), Alfalfa (.39%).

[a]All values on a dry basis unless otherwise specified.
[b]Troepfer *et al.* (1973)
[c]Schwarz (1974a)
[d]Underwood (1971)
[e]Welch and Cary (1975)

Tin is similar to carbon in its tendency to form truly covalent linkages. Even stannic chloride is largely covalent in its chemical nature. Different Sn compounds have variable biological activities. The organism is capable of utilizing Sn covalently bound to carbon since not only inorganic, but also organic Sn compounds enhance growth. Organic Sn sources are presumably biologically more available than the inorganic sources since smaller dietary levels of the former are capable of producing toxic responses than the latter. These compounds are lipid soluble with commercial fats, good sources of tin (Schwarz, 1974b).

Trace amounts of Sn occur widely distributed in tissues and nutrients (Table 2). Schwarz (1971) notes that value reported in the literature for Sn are highly questionable if they are obtained with high temperature ashing methods. Ur der these conditions, losses of Sn could occur, especially if the element is present in the form of organotin compounds

Vanadium. Vanadium is an essential trace element for the chick and rat. A deficiency results in reduced body an feather growth, impaired reproduction and survival of the young, altered red blood cell levels and iron metabolism impairment of bone tissue metabolism, and altered blood lipid levels (Hopkins and Mohr, 1974).

Hopkins and Mohr (1974) indicate that the V requirement level may be between .05 and .5 ppm and this require ment may be higher when the V comes from natural feeds. Schwarz (1974a) suggests a requirement of .1 ppm as sodium orthovanadate and notes large differences in the potency of various V compounds at different oxidation states. Vanadium deficiencies have been induced in the rat with diets containing less than .1 ppm; for the chicken, a more severely deficient diet (less than .03 ppm) appears to be necessary (Mertz, 1974b). Analysis of a few feed samples indicates levels of less than .1 ppm V, thus raising the question of nutritional adequacy of the diet. If nutritional ade- quacy is a practical problem, the deficiency will probably show up in the form of altered blood lipid levels since it is well established that V alters lipid metabolism. Deficiency has been reported to decrease plasma cholesterol levels at an early age (2 to 4 weeks) and subsequently to increase them over those of supplemented controls. Plasma triglyceride levels are significantly increased in V deficiency (Mertz, 1974b). It is most likely that V functions as an oxidation-re- duction catalyst in the organism (Schwarz, 1974a).

Nickel. Nickel occurs regularly in soils and plants in concentrations substantially higher than those normally present in animal tissues and fluids. Various researchers have reported that Ni extracted from soils correlates highly with plant Ni concentration (Welch and Cary, 1975). Grains and vegetables appear to be good sources for dietary Ni (Schroeder *et al.*, 1962).

Nickel toxicity occurs to varying degrees in both plants and animals. Common pasture plants normally contain .5 to 3.5 ppm Ni (Underwood, 1971). However, Ni in plant tissues may be toxic at 40 to 60 ppm (Painter *et al.*, 1953). High Ni in plants reduces Fe and Mn concentrations (Hewitt and Smith, 1975). Normally, insoluble Ni compounds be- come soluble in soil of low pH, which causes Ni to accumulate in plants, but adding lime to Ni-treated soil counteracts the toxic effect on plant growth. O'Dell *et al.* (1970) report reduction of feed intake and growth rate in calves supple- mented with 250 ppm Ni. These workers report that even though calves fed 1000 ppm Ni had greatly reduced feed intake and lost weight during the 8-weeks treatment period, they were not emaciated and appeared to be younger than the others.

Within the past few years, Ni deficiency has been reported in four species (chicken, rat, pig, and goat). Chicks raised in a controlled environment free of trace metal contamination and fed a dried skim milk-ground corn diet containing 3 to 14 ppb Ni exhibited impaired liver metabolism and morphology (Nielsen and Ollerich, 1974). Nickel deficiency in chicks results in suboptimal liver functions as evidenced by an ultrastructure degeneration, reduced oxidase ability, increased lipid, and a decreased phospholipid fraction. Rats deprived of Ni also show a reduced oxidative ability in liver and abnormalities in the polysome profile. Supplemental Ni at a level of 3 ppm prevented the deficiencies (Nielsen and Ollerich, 1974). Callan and Sunderman (1973) indicated that larger amounts of inorganic Ni would be required to meet the requirement than that naturally bound to organic ligands.

Anke *et al.* (1974) report that male and female pigs and goats fed a low-Ni diet (.1 ppm) had significantly decreased rate of gain, with both sexes developing slower than the control animals fed 10 ppm Ni. About 20 to 30% of the baby pigs and young goats from the deficient group developed a scaly and crusty skin which was similar to parakeratosis. The change in Zn tissue levels in connection with parakeratotic changes on a low-Ni diet suggests that a Ni deficiency affects Zn metabolism.

Nickel like V appears to be involved in lipid metabolism as evidenced by elevated hepatic concentrations of total lipids, phospholipids and cholesterol for Ni-deficient chicks (Mertz, 1974b). Nielsen and Ollerich (1974) hypothesize that Ni has a role in the metabolism or structure of membranes and may have a role in nucleic acids or protein bio- chemistry.

Silicon. Silicon is, next to oxygen, the most prevalent element on earth. The high content of Si in soils, plants, and atmospheric dust maintains a high, although very variable, intake by animals and man, especially grazing ruminants. Silicon occurs in plants as monosilic acid and as solid silica. The amounts and proportions of these two compounds vary with the plant species and its stage of growth, and with the soil conditions under which the plant has grown. Cereal grains carry much lower concentrations of Si than leaves or stems of the same species. Whole grasses and cereals may contain 30 to 40% of their total ash or 3 to 4% or more of the whole dry plants as SiO_2 (Underwood, 1971). Even higher levels occur in some tropical grasses (Oyenuga, 1958).

The essentiality of Si is demonstrated in chicks and rats through marked effects on growth and skeletal development (Schwarz and Milne, 1972; Carlisle, 1974b). Long bone joints of deficient chicks were smaller, had reduced strength, and the bones had an altered chemical composition. In rats, Si deficiency resulted in growth retardation and changes in the structure of the skull.

Silicon has qualities which make it appear likely that it may function as a structural rather than a catalytically active entity in metabolism. Schwarz (1974b) discovered a highly important structural function for Si by showing that it is an

integral building block, an important cross-linking agent in connective tissue. Silicon is shown to be an integral component of mucopolysaccharide-protein complexes of connective tissue (Carlisle, 1974b). Deformities from Si-deficient rats and chicks support the view that the element is specifically associated with the ground matrix and structural elements of connective tissue, cartilage, skin and bone (Schwarz, 1974b).

Toxic Minerals. A recent review on the toxicity of eight minerals to domestic animals is available (Ammerman *et al.*, 1973). Table 3 summarizes the relative toxicity of As, Pb, Hg, and Cd. Examples of concentrations of toxic elements in supplemental mineral compounds are illustrated in Table 4.

Arsenic. Most feeds contain less than .5 ppm and rarely exceed 1 ppm on a fresh basis. Arsenic is not readily absorbed by plants from soils, even when the levels in the soils have been raised by continued use of arsenical sprays, but surface contamination of feeds with spray residues can raise their As concentrations well above the .5 ppm level of As (Underwood, 1973). Foods of marine origin contain higher levels of As and commercial fishmeals may contain 2 to 20 ppm.

Arsenic compounds have been used extensively in the past as insecticides, rodenticides, herbicides, and antihelmintic agents. The misuse of such compounds or the accidental exposure of animals to these materials has frequently resulted in toxicity. In research with growing lambs, Bucy *et al.* (1955) reported that arsanilic acid and potassium arsenite were more toxic than was 3-nitro-4-hydroxyphenylarsonic acid to the ruminant. In these studies, severe pathological damage occurred at the higher levels of arsenic without evidence of outward clinical signs of toxicity. Frost (1967) has stated that "the most toxic arsenicals are well tolerated at levels which supply 10 to 20 ppm arsenic in the diet. The least toxic arsenicals can be fed without injury at levels which contribute up to at least 1000 ppm arsenic in the diet."

The relative toxicity of different forms of As can be explained in part by the fact that the more toxic trivalent compounds, including arsenic trioxide, are retained in the tissues in greater amounts and are excreted more slowly than the less toxic. Arsenic in the forms in which it ordinarily occurs in feeds is well absorbed and rapidly eliminated, mainly in the urine. The As of organic compounds, such as arsanilic acid used as growth stimulants in the rations of pigs and poultry, is also well absorbed, disappears rapidly from tissues, and is excreted mostly in the feces (Underwood, 1973). A single dose of As clears the animal body in five days. Following withdrawal from repeated dosage, six weeks should lapse before slaughter of exposed animals for human consumption (Selby *et al.*, 1974).

Chronic As poisoning is endemic in the Cordoba province of Argentina. Arsenic concentrations in the drinking water of this region are as high as 1.4 mg/liter. This concentration is 10 to 100 times higher than that of most natural water supplies (Underwood, 1973). The biological significance of high As water supplies to human and livestock population needs further study.

Lead. Lead poisoning in farm stocks is well documented with two recent reviews on the subject (Ammerman *et al.*, 1973 and Clark, 1973). Lead is one of the most frequently observed causes of poisoning in farm animals, especially in cattle and it is believed that many more cases of Pb toxicity occur than are actually diagnosed. Lead poisoning in domestic animals is mainly one of acute toxicity rather than in accumulative Pb problem as occurs most frequently in young chickens with pica (NAS, 1972) or adult humans consuming "moonshine" whiskey.

Allcroft and Blaxter (1950) suggested that the actual loss of cattle in England due to Pb poisoning was on the order of thousands every year. Studies from Northern Ireland showed Pb poisoning to be responsible for 1.7% of the deaths of adult animals (over 300 pounds) and 4.5% of the deaths in calves (Todd, 1962). In a recent survey of U.S.-Canadian Veterinary laboratories, cattle had the highest incidence of Pb poisoning with three cases per 1000 animals tested for all causes (Priester and Hayes, 1974).

Ruminants are commonly most affected with Pb poisoning and this may be due in part to the tendency for particulate matter to settle in the reticulum and be converted to soluble Pb acetate by the action of the acid medium of the forestomach (Blood and Henderson, 1968). Morbidity is usually low (10 to 15%), whereas mortality is usually from 75 to 100% (Buck, 1970).

The natural curiosity and licking habits of cattle make any available Pb-containing material a potential source of poisoning. Livestock exposure from Pb is mainly derived from Pb in storage battery plates, water pipes, putty, linoleum, asphalt roofing, used gasoline, engine oil, feed containers, paints, insecticides, motor vehicle exhausts, and contaminated feeds in highly motorized urban communities (Ammerman *et al.*, 1973; Underwood, 1973; Fick, 1974). According to Clark and Clark (1967), Pb paint is by far the most important source of Pb to cattle. It may contain red Pb (triplumbic tetroxide, Pb_3O_4), white Pb carbonate ($2PbCO_3 \cdot Pb(OH)_2$) and, less commonly, Pb sulfate ($PbSO_4$) or Pb chromate ($PbCrO_4$).

Allcroft (1951) states that approximately 200 to 400 mg of Pb per kg of body weight ingested in any one day, as the acetate, basic carbonate or oxide, is sufficient to cause death in calves up to four-months old. Older cattle may require single oral doses of 600 to 800 mg/kg body weight to produce the same effect (Buck, 1970). Repeated smaller doses will accumulate to produce toxicity. A daily intake of approximately 6 to 7 mg/kg body weight appears to be the minimum dose that will eventually give rise to toxicosis in cattle (Hammond and Aronson, 1964).

Contamination of pasture with Pb may occur in the vicinity of smelters. Lead content of plants in Pb mining areas varies widely depending upon their proximity to the mines and mills, smelter, and ore-truck routes. Concentrations of Pb in plants along the ore-truck routes averaged 280 ppm on the road right of way, 34 ppm at 100 yards, and 11.6 ppm at 200 yards from the highway (Hemphill, 1974).

Table 3

RELATIVE TOXICITY OF CERTAIN MINERAL ELEMENTS FOR ANIMALS[a]

Form of element	Estimated % absorption of oral intake	Prevalence of sources	Efficiency of excretion of absorbed element at low dosage	"Tolerable" level for human consumption
Arsenic				
inorganic (As^{+3}, As^{+5})	±5-70%	Ambient air, industrial	Good; readily cleared from blood and tissues	Meat, .5 ppm As other, 2 ppm As
organic		Methylated arsenicals, natural or synthetic	" (Animals have a "taste" for contaminated forage)	" Moderate tolerance
		Little or no As transferred from soil to plants.		
Lead				
inorganic (Pb^{+2})	1-10%, adults 15-50%, young	Ambient air; dust, industrial, gasoline, inks, paints, batteries (alkyl lead of gasoline cleaved to Pb^{++})	18 to 50% retained. Lead is largely sequestered in skeleton. May accumulate in liver and kidney.	Controversial 300 μg/day, adult ? , young milk, up to .5 ppm
organic				
		Minimal accumulation of Pb in plants or aquatic biota. Levels may be increased by external deposition. Toxicity insidious, animals.		
Cadmium				
organic		Plant and animal tissues		
inorganic (Cd^{+2})	2-8%	Aquatic biota concentrate by x 10^2, 10^3, Concentrates in aerial portions, some plants largely in roots of others. Occurence is highly correlated with Zn. Source is mainly industrial.	Negligible excretion until acute toxicity, Tissue retention longer than Pb or Hg.	Little deposition in eggs, milk, or fetus.
		Toxicity: Accumulation in soft tissues, kidney, and liver. Turnover very slow. Major lesion is renal and intestinal epithelial destruction. Anemia and reproductive effects. Animals are Cu, Zn, and Fe deficient with time and low dosage.		
Mercury				
inorganic (Hg^{++}, Hg) (May be a metabolite *in vivo* of organic Hg)	±15%	Vapor, salt and dust from both natural and industrial sources. May be deposited on soil, plants, water.	Negligible excretion until acute episode. Animal ½ time retention, 80-150 days. (Vapor exhaled)	Little deposition in eggs, milk, or fetus. .02-.05 ppm Hg 100 μg/day.
organic		Phenyl and ethyl salts cleaved readily to Hg^{++}.	"	"
Methylmercury (CH_3Hg^+)	60-100%	Aquatic biota methylate Hg^{++} and CH_3Hg^+ accumulates. Present in fish protein concentrates up to 90% of Hg. (Formerly in grain fungicide dressings)	Hair and feathers, eggs and milk are routes of excretion. Animal ½ time retentions, about 20 days. C-Hg bond cleaved to Hg^{++} *in vivo* about 5%.	.5 ppm Hg (Se accumulates in fish at 1:1 molar ration with CH_3Hg; moderates toxicity).
		Toxicity: Mercuric ion, as for Cd. Methylmercury enters all tissues, crosses brain and placental "barriers;" is lipid soluble. Biliary Hg is reabsorbed 46% for protein-bound and 100% as cysteine dipeptide. There is a delay period of several weeks to months between exposure and acute episodes for both Cd and Hg toxicity, permitting, continued ingestion of the intoxicant.		

[a]Reviews of Ammerman *et al.* (1973), Flick *et al.* (1971), MacGregor and Clarkson (1974), NAS (1972), Petering (1974) and Selby *et al.* (1974).

Table 4

TOXIC ELEMENTS IN MINERAL SUPPLEMENTS[a]

Mineral Compound	Al %	Pb ppm	As ppm	Hg ppm	Cd ppm
Defluorinated Phosphate	0.86	2	<1	8	
Dical. Phosphate	0.82	4	5	6	
Dical. Phosphate	0.34	2	3	12	
Fe Carbonate	0.16	250	5		
Fe Carbonate	0.10	20	1		
Fe Oxide	0.61	70	30		
Fe Oxide	0.03	4630	23		
Cu Oxide		0	7		
Cu Oxide		100			
Zn Oxide		30	2		1290
Zn Oxide		100	6		1500
Zn Oxide		4770	9		170
Zn Oxide		30000	149		790
Mn Oxide	0.93	100	10		
Mn Oxide	1.52	2180	1400	.009	

[a]Data from International Minerals & Chemical Corporation, Skokie, Illinois.
These values represent individual sample analyses.

Recent evidence suggests that Pb absorption in newborn and very young animals may be higher than 50% of intake. However, in recent research with sheep, limited intestinal absorption of Pb was demonstrated by low values recorded for apparent absorption and net retention of stable lead (Fick, 1974). In these intravenous injection studies, ^{210}Pb was excreted in feces and urine in approximately equal amounts. In adult humans, food lead is also poorly absorbed (to the extent of about 5%) (Underwood, 1973). The Pb that is absorbed enters the blood and settles in the bones and soft tissues, including the kidney and liver, from which it is gradually excreted via urine and the bile into the small intestine and then eliminated in the feces. Lead has a marked affinity for bone, and levels between 5 and 20 ppm on the fresh basis have been reported (Underwood, 1973).

Mercury. Mercury has long been known as a toxic element associated with both ingestion and inhalation. Mercury is a volatile relatively common element and is widely distributed in nature. However, little is known of normal Hg intakes by farm animals. Underwood (1971) has summarized data indicating that soils contain .1 to .3 ppm and fruits, vegetables and cereal grains .005 to .035 ppm Hg. Lunde (1968, cited by Underwood, 1973) reported a mean Hg concentration of .18 ppm (range .03 to .4) for twelve commercial fishmeals from different sources. The edible portion of five species of fish analyzed by Kamps *et al.* (1972) contained Hg levels ranging from .04 to 2.6 ppm, most of which was in the form of methylmercury. The levels of Hg in feathers, hair, and erythrocytes are useful indications of the tissue Hg status of individuals and of their environment (Underwood, 1971). Since excretion is minimal, urine and feces do not reflect tissue Hg build-up with time.

Available information indicates that Hg is readily absorbed by way of the respiratory tract, gastrointestinal tract and through unbroken skin. Methylmercury is 60 to 100% absorbed in ruminants, fowls and humans. Mercuric ion is only about 15% absorbed. Mercury acts as a cummulative poison since it is very slowly excreted by the animal body (Nelson *et al.*, 1971, Lagerwerff, 1972). The property of Hg to combine readily with proteins is one reason for its high toxicity (Jakibowski *et al.*, 1970). Mercury has an influence on the absorption and transport of Cu, Zn and Cd. Acute and chronic Hg poisoning can result in renal failure and death. Fitzhugh *et al.* (1950) reported that as little as .5 ppm dietary Hg as phenylmercuric acetate caused histopathologic changes in kidney tissue but 160 ppm Hg was required to reduce survival time in a series of treatments which included 10, 40, and 160 ppm Hg in rats.

Particular interest has centered upon the levels of methylated forms of Hg such as methylmercury ($CH_3 \cdot Hg^+$). These compounds are more hazardous than inorganic forms of the element because they are nearly completely absorbed and enter a wider number of tissues with a more specfic effect upon the central nervous system (Friberg, 1959). It has been shown that inorganic mercuric chloride can be converted to the more toxic methyl-mercuric chloride by bacterial action (Underwood, 1971).

Environmental Hg compounds are derived from the burning of coal, from the use of organic Hg compounds as pesticides and fungicides in agriculture and industry and certain chemical industries. The use of these compounds in industry can result in sufficient Hg to produce increased Hg concentration in marine life of rivers, lakes, and in plant and animal products. From the use of Hg-containing fungicides, elevated levels of Hg have been found in pheasants and partridges collected in Southern Alberta where Hg seed-dressings were used extensively (Fimreite, 1970).

Little research has been conducted on ingested Hg in ruminant metabolism, but studies with other species suggest that methylmercury is metabolized differently than inorganic Hg compounds. Ansari *et al.* (1973) reported a far higher percentage of methylmercury (methylmercury chloride) absorbed than of mercuric chloride. Combined values for retention in the liver, kidneys, lungs, and heart totaled 6.5% for the organic methylmercury compound and only .42% for the inorganic mercuric chloride, suggesting a much higher absorption for the organic form.

Studies with goats (Howe *et al.*, 1972) indicate that inorganic Hg is poorly absorbed from the intestinal tract and that only a small fraction of the absorbed Hg is tranferred to milk. Radioactive methylmercury ($CH_3{}^{203}HgCl$) was administered as a single oral dose to lactating cows (Neathery *et al.*, 1973). Apparent absorption of the ^{203}Hg was 59% and in 14 days only .17% of the dose was secreted into milk. Examination of tissues revealed the highest percent of dose (^{203}Hg) in kidney, followed by liver, skeletal muscle, heart, smooth muscle, spleen and other tissues.

Selenium compounds protect against the toxicity of Hg compounds. Pathological changes typical for intoxication by inorganic Hg salts did not appear in animals given Se compounds (Parizek *et al.*, 1974). Rats given a high dose of Hg compounds lethal to controls survived when treated with compounds of Se.

Ganther *et al.* (1972) reported that increased dietary Se protected against methylmercury toxicity in rats and Japanese quail as measured by growth rates. This was confirmed in growth studies with rats by Potter and Matrone (1973) and in survival studies with Japanese quail by El-Begearmi *et al.* (1973). Japanese quail fed 20 ppm Hg as methylmercury in diets containing 17% tuna survived several weeks longer than quail given the same concentration of methylmercury chloride in a corn-soybean meal diet. The additional Se present in the tuna appeared to be responsible for the protective effect (Ganther *et al.*, 1972).

Cadmium. Cadmium poses a potential environmental hazard of major importance. The factors that affect the magnitude of normal intakes and the movements of Cd from soils and plants to animals and man have been little studied (Underwood, 1971). Cadmium-containing products such as plastics, pigments, batteries and alloys terminate in junk piles, creating a potential for biological injury through contamination of water supplies, air and ingested matter. Absorption of inhaled Cd has been estimated to be as high as 40% but only about 5% of ingested Cd is absorbed (Amnerman *et al.*, 1973).

Relatively large quantities of Cd are found in grains, commercial fertilizers containing phosphates and water in galvanized or black polyethylene pipes (Underwood, 1971, Flick *et al.*, 1971). Vegetables, nuts, and fruits are poor sources of Cd, with concentrations mostly ranging between .04 and .08 ppm.

A study on the uptake of Cd by oats showed roots accumulated Cd from industrially contaminated soil in relatively large amounts with smaller amounts accumulating in the above ground portions (John *et al.*, 1972). However, a study by Lagerwerff and Biersdorf (1971) on uptake and translocation of Cd in the radish showed higher concentrations in the leaves than in the roots. A review by Flick *et al.* (1971) presented data from Allaway indicating that Cd levels in forages were inversely related to distance from the highway. Concentrations of Cd in plants along a Pb-mining region averaged 1.51 ppm along the ore-truck route, .58 at 100 yards, and less than .5 ppm for a distance of 200 yards or greater (Hemphill, 1974).

Safe levels of Cd in water for human consumption and farmstead use in the U.S.A. have been set at .01 ppm (C.R.C., 1969). Surveys have indicated however, that many public water supplies exceed this level, particularly those where ground water is the local source. Levels of Cd in water varied geographically from 0 to .03 ppm (Flick *et al.*, 1971).

Some of the toxic and environmental health hazards of exposure to Cd reside in its antagonistic activity with respect to the metabolism of several essential elements, namely Cu, Zn, and Fe. Signs of Zn deficiency can be accentuated by high intake of Cd and the toxic effect of higher Cd intake can be ameliorated by increasing the Zn status of the diet. These findings imply a competition between Zn and Cd for protein-binding sites for transport across the intestinal wall, and probably for the Zn metallo-enzymes (Underwood, 1973). Feeding trials with Cd in ruminants, rats, swine and poultry have further documented the Zn-Cd relationship. A resemblance between the symptoms of Cd toxicity and Zn deficiency was observed in several species and it was found that supplemental Zn could overcome the toxicity (Amnerman *et al.*, 1973). Hill *et al.* (1963) suggest that Cd substitutes for Zn at the cellular level and this may be the basis of its toxic effects. Renal failure is a function of dose x time of exposure.

Among the more significant studies are implications that tolerance to Cd may be related to the Cu status of the animals. Low-level (3.5 ppm) exposure of newborn lambs to Cd resulted in highly significant declines in liver Cu and Zn (Mills, 1974). Recent studies with rats have examined the effect of diets providing as little as 1 ppm Cd when the Cu intake is marginal (2.8 ppm) and when Zn intake meets requirement or is higher (Campbell and Mills, cited by Mills, 1974). Exposure to 1 ppm Cd and 30 ppm Zn for 10 weeks promoted a 58% decline in ceruloplasmin activity, a reduction of cortical bone thickness in the femur, and a decline in liver and blood Cu content. These effects were exacerbated when the diet contained 5 or 15 ppm Cd and, particularly so, when Zn intake was also high (300 or 1000 ppm). The Cd/Cu relationship suggests that in specific situations a high risk may arise, as, for example, in ruminant animals already exposed to high intakes of Mo or in human infants maintained for long periods on diets based predominately upon dairy and cereal products low in Cu.

One aspect of the biological effects of Cd (and also Pb) may be linked to their effect on the biosynthesis of prophyrins, hemes, and cytochromes, and on the mobilization and release of Fe (Petering, 1974). Jacobs *et al.* (1974) report that the Fe concentration of the duodenum was decreased significantly in quail receiving 10 ppm Cd. Previous investigations at this laboratory showed inhibition of Fe absorption by Cd at much lower levels of Cd.

A review by Flick *et al.* (1971) suggested that little is known about Cd metabolism and toxicity, especially about the mechanism of intestinal absorption, transport, tissue deposition, interaction with other compounds, drugs and pesticides and its mode of causing toxic effects. Toxicology studies indicate that Cd preferentially deposits in kidney and liver tissue and it can cause kidney, testicular and prostatic damage and lesions of the central nervous system. Also Cd may be a hypertensive, carcinogenic and teratogenic agent (Flick *et al.*, 1971). Abundant human and animal evidence indicates that long-term exposure to Cd (and Hg) will cause renal tubular dysfunction. Acutely poisoned experimental ruminants have appeared unthrifty with edematous and shrunken scrotum, sore enlarged joints, impaired vision, body dehydration, rough hair, alopecia, dry scaly skin, and increased sensitivity to infection (Miller, 1971). In monogastrics which vomit, nausea, diarrhea, vomiting, respiratory difficulty and degrees of prostration are clinical signs of Cd intoxication (Flick *et al.*, 1971).

In a review, Ammerman *et al.* (1973) report that ascorbic acid, vitamin D, a Zn chelate, cysteine, glutahthione, Zn, Fe, and Se have demonstrated some protection against Cd toxicity. As with Hg toxicity, Se compounds are highly effective in decreasing Cd toxicity including full protection against all known specific effects of Cd related to reproduction (Parizek *et al.*, 1974). Relief of Cd and Hg toxicity by Se administration, however, increases concentrations of the three elements in liver and kidney tissues.

Aluminum. Little information is available on the toxicity of Al for man or livestock. Aluminum is present in highly variable concentrations in food of plant origin and even lower concentrations in animal tissues. The variability from sample to sample for forages is probably a result of ease of contamination from dust (Underwood, 1973). In a review, Underwood (1971) presents data noting concentrations of Al as high as 3000 to 4000 ppm for certain trees and ferns and 10 to 50 ppm Al in grasses and clover. These levels were high compared with the .5 to 5 ppm reported for a range of vegetables for human consumption.

No data is currently available on the potentially toxic levels of Al for livestock. In humans, ten times the amounts likely to be ingested can be tolerated without harmful effects. Nevertheless, large intakes may induce gastrointestinal irritation and produce rickets by interfering with P absorption (Deobald and Elvehjem, 1958).

Under tropical conditions, grazing livestock are suspected to consume extremely large intakes of Al. Moomaw *et al.* (1959) report that certain plants are classified as Al accumulators as evidenced by 13 of 23 Hawaiian species that contained more than 1000 ppm Al in the vegetative portions. From Guyana, high Al contents (over 1000 ppm) were obtained in forage samples from some pasture areas (Holder, 1972). Grazing livestock ingested large Al concentrations from direct soil consumption, due to soils in the humid tropics containing characteristically high percentages of Al. Under New Zealand conditions, annual ingestion of soil can reach 75 kg for sheep and 600 kg for dairy animals. (Healy, 1974). Measurements in southwest England indicated that soil ingestion by grazing cattle, over the winter months, varied from 140 to 1400 g/day (Thornton, 1974).

Plant species differ markedly in tolerance to excess soluble or exchangeable Al, a primary growth-limiting factor in many acid soils. Phosphorus deficiency is often a prominent sign of Al toxicity (Fox and Brown, 1964). The detoxification of Al by the addition of P, lime, or a synthetic chelating agent is closely associated with an increase in the P concentration of plants. (Rees and Sidrak, 1961). Aluminum binds P on root surfaces and cell walls and in the free space of plant roots, making P less available for metabolic activities within the cells (Clarkson, 1966). In addition, Clarkson (1966) also concludes that some Al apparently penetrates plant cells and interferes with cell division, respiration, DNA synthesis and sugar phosphorylation. Latin American soils are characteristically acid with high percentages of exchangeable Al which complexes with P making it unavailable to plants (Woodruff and Kamprath, 1965). The Campo Cerrado of Brazil and the Llanos of Colombia and Venezuela are examples. Aluminum is the predominant cation in acid mineral soils with a pH of 5 or lower while above pH 5.6, most soils have relatively small amounts of exchangeable Al.

In grazing cattle, the most prevalent mineral deficiency throughout Latin America is P (McDowell, 1976). Phosphorus deficiency is more of a problem in tropical vs. temperature regions because soils contain less P and acid soils contain high concentrations of Al and Fe which form insoluble phosphate complexes.

Much research needs to be undertaken with livestock to examine the effects of high Al intakes, which occur in tropical regions, on livestock performance. This line of research in ruminants is currently being undertaken at the University of Florida.

Discussion

Progress in discovering new essential trace elements has been closely linked to improved procedures for both purification of diets and for reducing environmental contamination. The exact number of required trace elements is not yet known. Since 1959, six new elements (Cr, Sn, V, F, Si, and Ni) have been shown to be essential, with 5 of these discovered since 1970. Only limited data are available on the practical nutritional importance of these newer essential trace elements. Analysis of a limited number of feeds in relation to the estimated requirements suggests that under some feeding conditions deficiencies of Cr, Sn, V, and Ni might occur. It does, however, seem highly improbable that grazing animals would consume inadequate supplies of Si. Nevertheless, the chemical forms of the trace elements can greatly determine their ability to meet animal requirements. To illustrate, total Cr in any material may give little information about its biological value.

Modern agricultural and industrial practices and the increasing motorization and urbanization of specific regions has increased the possibility of deleterious effects from Cd, Hg, Pb, and As. These toxic elements are frequently encountered in products such as insecticides, fungicides, batteries, paints, gasoline additives, phosphate fertilizers, etc. Toxic minerals are widely distributed in air, feed, water, and soil. Cattle may ingest up to 10 times the amount of Pb and As in the form of soil to that of herbage. In mining and smelting regions, agricultural soils may contain up to 2500 ppm As and 1700 ppm Pb (Thornton, 1974). Even mineral ores which are used in preparing mineral supplements can provide considerable and highly variable quantities of toxic elements (Table 4).

Toxic concentrations of As, Pb, Hg, and Cd are known to affect the metabolism of required elements. Mercury and Cd are particularly antagonistic to Ca, Cu, Zn, and Fe. Selenium is known to greatly modify the toxic properties of Hg and Cd. Recently, there have been a large number of world reports of Cu and Se deficiencies. In addition to the accepted reasons, could an additional explanation be found in environmental contamination of heavy metals including Cd and Hg, which increases the requirements for Se and Cu? In areas of geothermal activity (i.e. volcanic regions of Central America), natural effluxes of Hg and possibly other volatile heavy metals may provide environmental levels which exceed those of technology. In Hawaii, which exhibits high volcanic activity, fish were shown to accumulate CH_3Hg^+ from such sources of Hg vapor (Siegal and Siegal, 1975).

Although much less toxic on a molar basis, Al likely has a greater influence on adequate mineral nutrition for tropical regions than As, Pb, Hg, or Cd. In tropical countries, P deficiency is the most severe mineral limitation to grazing cattle. Over 35 tropical countries have reported P deficiencies (McDowell, 1976). Aluminum complexes with P making it unavailable for plants, thereby increasing the incidence and severity of P deficiencies in grazing cattle.

Summary

Chromium functions as a glucose tolerance factor and is associated with insulin. Tin is widespread in feeds and tissues and is necessary for growth of rats at a level of 1.5 to 2 ppm. Both Sn salts and organotin compounds are effective in preventing deficiencies. Compared with Sn, V is required in much smaller amounts and probably functions as an oxidation-reduction catalyst. Nickel is required at approximately .03 to 3 ppm, with a deficiency resulting in suboptimal liver function as evidenced by an ultrastructural degeneration, reduced oxidative ability, increased lipid, and a decreased phospholipid fraction. Silicon is a building block of connective tissues, serving as a cross-linking agent. Bone deformities develop as a result of Si deficiency. Whether a deficiency of Cr, Sn, V, Ni, and Si would ever be a practical problem for ruminants remains to be seen.

Industrial and technological development has increased the potential problem of toxicity from As, Pb, Hg, and Cd. Toxic minerals are often found in products such as insecticides, fungicides, etc. Contamination of soils and pastures with toxic minerals may occur in the vicinity of smelters and other industrial operations. Mercury and Cd are detrimental to the utilization of Cu, Zn, and Fe, with this toxicity modified by administration of Se. In tropical regions, high soil Al concentrations complex with P, thereby accentuating P deficiencies in grazing cattle.

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BIOLOGICAL AVAILABILITY OF MACRO-ELEMENTS[1]

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In the study of mineral metabolism, it is generally recognized that the total content of a mineral element in a particular compound or in a complete ration has little significance unless it is qualified by a factor indicating the biological availability of the element to animals. In other words, chemical analysis shows how much of a given mineral nutrient is present, but it does not indicate to what degree, if any, the nutrient is utilized when it is consumed by animals. No element is ever completely absorbed and utilized; some of it is always lost in the normal digestive and metabolic processes. Before a required nutrient can be of nutritional value, it must be in a form that can be digested, absorbed, and transported to the part of the body where it is utilized for its essential function.

In the literature there appears to be some confusion as to what constitutes "utilization" and "availability" of the major ions and how they should be expressed and applied in nutrition. As a result of biological availability studies of the major mineral ions over the years, a number of terms have been developed to define certain specific observations. These include percent utilization, percent apparent digestibility, percent true digestibility, percent absorption, percent net retention, percent apparent availability, percent true availability, biological availability, and others. It should be pointed out that obviously these terms do not necessarily mean the same thing and should not be used interchangeably. They should be considered only in the context suggested by the researcher.

In this particular presentation, the term biological availability will be used as a measure of the ability of the element or ion under consideration to support some physiological process. And, in this regard, where it has been possible to do so, biological availability data are reported in relative numerical terms in comparison with a previously selected reference standard. In most research, where nutritional requirements for the major mineral ions have been studied experimentally, relatively pure chemical salts, recognized for their nutritional value have been used, and subsequently these salts have become useful to others as reference standards.

Because of the large volume of research reported in the literature, information presented here will be confined primarily to the inorganic sources of mineral ions most commonly encountered in practical feed formulation, and except in certain cases the contribution of these elements from natural sources will be disregarded.

Phosphorus

There is a tremendous volume of literature on phosphorus nutrition and a large part of it pertains to the availability of phosphorus from various sources to animals. Much of this literature on availability deals with factors that influence the utilization of phosphorus in various ways. Another major portion relates to experimental techniques that have been developed to define more accurately the comparative or relative biological availability of phosphorus from various sources. Some of the factors that influence the utilization of phosphorus for the various species of animals are the type of ration fed, chemical form of the element, the calcium-phosphorus ratio, age of animal, sex, fat and energy levels, plane of nutrition, environment, hormones, disease and parasites, protein and trace element levels, interactions with other minerals and nutrients, chelating agents, the physical nature of phosphorus sources and other feedstuffs in the diet (especially particle size), feed processing and numerous others. Many of these factors have been investigated in detail and some of them have been found to influence the availability of phosphorus of one source to a greater degree than another, but in general the relative order of effectiveness of the various sources remains approximately the same under similar sets of circumstances.

[1] Original paper published in Journal of Animal Science, Vol. No. 35, No. 3, September 1972, pages 695-712.

Sheep. For sheep, the value of phosphorus of plant origin has been questioned for many years. Shortly after radioactive phosphorus became available for nutritional studies, Lofgreen and Kleiber (1954), using an isotope technique, found that 94% of the phosphorus in an alfalfa hay was utilized by sheep, indicating quite high biological availability from this source. It is realized now that this finding should have been expected, inasmuch as the leaves from good quality alfalfa contain little, if any, phytate phosphorus. Phytate phosphorus, as it occurs in plants, generally is regarded as being substantially less biologically available than most inorganic phosphorus.

In investigations with inorganic phosphate sources, Ammerman and associates (1957) found differences in biological availability using a balance technique. From their experiments it was concluded that the relative rank of the phosphate sources for their biological availability was dicalcium phosphate, Curacao Island phosphate, soft phosphate, and a defluorinated phosphate. Endogenous phosphorus excretion, however, was not completely accounted for in this work. In later studies, Lofgreen (1960) utilized a radioisotope dilution technique in which endogenous phosphate interference was eliminated in order to determine the true digestibility of several inorganic phosphate supplements and calcium phytate. The availability data from these studies are presented in table 1. By assigning dicalcium phosphate the value of 100, the biological availabilities of other phosphate sources on a relative basis were bone meal, 92%; soft phosphate, 28% and calcium phytate, 66%. The values determined on the inorganic phosphates using ruminant animals are in quite close agreement with values determined using monogastric animals.

Table 1
PHOSPHORUS ABSORPTION BY WETHERS[a]

Supplement	Phosphorus intake from supplement	Phosphorus absorbed from supplement	True digestibility	Biological value
	g/day	g/day	%	%
Dicalcium phosphate	3.43	1.71	50	100
Bone meal	3.86	1.76	46	92
Soft phosphate	3.76	0.52	14	28
Calcium phytate	3.91	1.29	33	66

[a]Lofgreen (1960).

In a more recent study, Chicco *et al.* (1965) determined the relative biological availability of three different crystalline forms of calcium and sodium phosphates, utilizing both *in vivo* and *in vitro* techniques. The biological availability values from these studies are shown in table 2. On a relative basis, calcium metaphosphate was only 70% as available as the normal calcium orthophosphate salt, and the calcium pyrophosphate was very poorly available, having a 54% value in the *in vivo* trial.

The *in vitro* cellulose digestion data follow the same order of availability as found in the *in vivo* trial, but with values of somewhat different magnitude. The sodium forms of the salts were utilized well in both the *in vivo* and *in vitro* trials. The findings of these experiments are particularly significant in that they indicate the detrimental impact that improper manufacturing processes and higher temperatures can have on the biological availability of calcium phosphates.

Beef Cattle. As with other ruminants, the supplements commonly evaluated in phosphorus availability studies with beef cattle have been reagent and feed grade dicalcium phosphates, bone meal, phosphoric acid, defluorinated phosphates and soft phosphate. In most studies with this species, dicalcium phosphate has been found significantly more available than soft phosphate. Relative availabilities between other inorganic phosphates, however, are less definite and in some experiments, statistically significant differences between many of the commonly used feed phosphates were not found. However, as shown in table 3, researchers from several stations (O'Donovan *et al.*, 1965; Arrington *et al.*, 1963; Ammerman *et al.*, 1965; Long *et al.*, 1956) utilizing different assay techniques report the order of biological availability rank for mineral supplements fed to beef cattle to be dicalcium phosphate, followed by defluorinated phosphate and bone meal, with soft phosphate having the least availability. Phosphoric acid has been reported to be essentially equal in availability to bone meal and to dicalcium phosphate. Johnson and McClure (1967) found ammonium polyphosphate solutions to be essentially equal to dicalcium phosphate in other feeding trials.

Table 2

UTILIZATION OF INORGANIC PHOSPHATES BY SHEEP[a]

Phosphate salt	Relative availability: In vivo absorption	Relative availability: In vitro cellulose digestion
	%	%
Calcium Ortho–$Ca(H_2PO_4)_2 \cdot H_2O$	100	100
Calcium Meta–$Ca(PO_3)_2$	70	78
Calcium Pyro–$Ca_2P_2O_7$	54	0
Sodium Ortho–$NaH_2PO_4 \cdot H_2O$	–	107
Sodium Meta–$NaPO_3$	97	98
Sodium Pyro–$Na_2H_2P_2O_7$	82	100

[a]Chicco *et al.* (1965).

Table 3

BIOLOGICAL AVAILABILITY OF VARIOUS PHOSPHATE SOURCES OF BEEF CATTLE

Source	Long[a]	Arrington[b]	Ammerman[c]	O'Donovan[d]
	%	%	%	%
Dicalcium phosphate	100	100	100	100
Defluorinated phosphate	–	71	95	93
Soft phosphate	17	68	88	–

[a]Growth response, Long *et al.* (1956).
[b]Net retention-isotope technique, Arrington *et al.* (1963).
[c]True absorption-depletion-repletion, Ammerman *et al.* (1965).
[d]True digestibility-balance trial, O'Donovan *et al.* (1965).

Numerous studies have been conducted using microbiological techniques based on the concept that phosphate depleted rumen bacteria will rapidly digest cellulose only when supplied with adequate amounts of available phosphorus. There seems to be reasonable agreement between the microbiological *in vitro* results and *in vivo* animal experimentation results in studies to determine the biological availability of phosphate compounds, although there are exceptions, especially when evaluating relatively insoluble compounds (Anderson, Cheng and Burroughs, 1956; Ammerman *et al.*, 1965; Raun, Cheng and Burroughs, 1956; Chicco *et al.*, 1964). Even though good information on phosphate availability is found from microbiological techniques, caution should be used in extrapolating artificial rumen results directly to the animal.

Dairy Cattle. A large volume of research has been reported on the need for and the utilization of phosphorus in dairy animals, but very little work has been reported on the comparative biological value of the various sources. Utilizing a ration in which approximately 53% of the phosphorus was from phytate. Mathur (1951), on the basis of phytate content of feces of mature cows, found the biological value of phosphorus from this source to be on the order of 50%.

Using dairy calves, Wise, Wentworth and Smith (1961) evaluated inorganic phosphate sources for their comparative value. Criteria studied in these experiments were body growth, bone growth, bone ash, blood serum phosphorus, and blood phosphatase levels. Of all the criteria evaluated in these studies, blood serum phosphorus was the most sensitive and most reliable biological availability measure. Although the data do not readily lend themselves to a relative biological availability calculation, the relative order of response in the two experiments was dicalcium phosphate, defluorinated phosphate, low fluorine rock phosphate and soft phosphate. These data are shown in table 4.

Table 4

EFFECT OF PHOSPHATE SOURCE ON TERMINAL SERUM PHOSPHORUS LEVELS[a]

Supplement	Terminal serum P: Experiment I	Terminal serum P: Experiment II
	mg %	mg %
Basal	2.83	4.69
Dicalcium phosphate	5.26	6.87
Defluorinated phosphate	4.13	6.44
Low F rock phosphate	4.12	6.18
Soft phosphate	3.07	5.87

[a]Wise *et al.* (1961)

In later studies using improvement in plasma phosphorus levels as a measurement of biological availability, Arrington *et al.* (1962) essentially confirmed the findings of Wise and associates (1961).

Calcium

The value of a feedstuff as a source of calcium depends not only upon its calcium content, but also on the amount that the animal can extract and retain for its own use. Results of numerous experiments have been reported describing the many factors that have an influence on the absorption and retention of calcium. Some of the major factors reported are age, vitamin D level, hormone blood level and balance, amount of calcium fed, composition of diet, calcium status of animal, and the form of calcium fed.

In spite of the volume of research conducted on calcium nutrition over the years, relatively little information has been developed on the comparative biological availability of calcium from different feed sources for animals.

Turner, Hardin and Hartman (1927), Lindsey and Archibald (1925) and Hayden, Monroe and Crawford (1930) found dicalcium phosphate to be as good a source of calcium as that from natural sources for cattle. Using body weight gains in the same species, Lantow (1933) found little difference between rations containing monocalcium phosphate, bone meal, dicalcium phosphate or calcium from natural sources. Radioisotope procedures, however, allowed Hansard, Crowder and Lyke (1957) to more accurately measure endogenous calcium excretion in cattle and thereby calculate the true absorption. Using these techniques, 109 individual balance trials were conducted on young and mature cattle, pair fed a basal ration to which calcium was supplied from 15 different organic and inorganic sources. Their comparative biological availability results are presented in table 5. True digestibility of calcium was greater in young cattle than in mature steers. Calcium from inorganic sources appeared to be utilized more efficiently than that from alfalfa, lespedeza or orchard grass hays. Differences in calcium availability were not considered large, but the sources tended to classify themselves into three groups with bone meal, monocalcium and dicalcium phosphates having the highest availability for calcium, and the hay sources the lowest in availability. The availability of calcium in ground limestone, defluorinated phosphate and calcium carbonate was intermediate. In subsequent studies with feed-lot cattle, Bushman *et al.*(1967) found no difference in a calcium availability between ground limestone or dicalcium phosphate as measured by weight gain, feed consumption, bone ash, blood level or carcass data. However, the basal ration probably was completely adequate in calcium since no response was obtained from any calcium level fed.

Magnesium

Magnesium has been recognized as an important dietary essential for many years, and under a number of feeding situations supplemental magnesium is required for optimum performance. Although needed by all species, the incidence of hypomagnesemia, or "grass tetany", especially in certain geographical regions, has stimulated special interest in the study of magnesium for ruminant animals.

Table 5

BIOLOGICAL AVAILABILITY OF CALCIUM FROM VARIOUS SOURCES FOR YOUNG AND MATURE STEERS[a]

Calcium source	True digestibility		Biological availability	
	Mature	Young	Mature	Young
	%	%	%	%
Calcium carbonate, C.P.	40	51	100	100
Bone meal (Imported)	55	68	138	133
Calcium chloride, C.P.	53	60	132	120
Dicalcium phosphate, C.P.	50	64	125	126
Monocalcium phosphate, C.P.	56	61	140	120
Dicalcium phosphate (A)	49	58	122	114
Dicalcium phosphate (B)	38	56	95	110
Dicalcium phosphate (C)	56	60	140	120
Dicalcium phosphate (D)	51	60	127	120
Dicalcium phosphate (E)	55	58	138	114
Defluorinated phosphate	40	55	100	108
Ground limestone	37	45	93	88
Alfalfa hay	31	41	78	80
Lespedeza hay	36	50	90	98
Orchard grass hay	39	51	98	100

[a]Hansard *et al.* (1957).

As with other nutrients, an understanding of the efficiency of utilization of magnesium from various sources is important to sound nutrition. Several dietary factors have been reported (Rook and Storry, 1962) to influence magnesium availability in various ways. Some of these factors are: composition of diet; magnesium status of the animal; various dietary ions such as calcium, phosphorus, sodium, potassium, manganese and citrate; phytic acid and chelates in natural feedstuffs; abrupt changes in feeding systems; age and genetic differences in animals; dietary fat and vitamin D levels; nitrogen level and season of the year for forages; and numerous other factors. Many of the factors studied appear to have a negative effect on magnesium absorption, but others such as processing by cooking and grinding of grains and hays have been reported to increase magnesium absorption.

Although most of the factors mentioned above, and others, have been reported to influence absorption and utilization of magnesium to one degree or another, it is assumed that these factors exert their influence to approximately the same degree on magnesium from various sources, and therefore, will have little bearing on the relative or comparative availability of magnesium from the various sources.

A number of criteria have been used to measure magnesium availability. Much of the early information on availability used apparent absorption and blood plasma levels as criteria. Other researchers have employed percent urinary excretions of magnesium intake as an indication of availability. These techniques have been questioned for a number of reasons and it is probable that more recent studies involving complete balance trial data have more meaning.

Employing balance trials with mature wether sheep, Stillings and associates (1964) found average values for apparent availability of magnesium from low nitrogen-containing grass forages to range from 18 to 24%, while those from high nitrogen-containing forage ranged from 11 to 16%. Field (1967) found the mean true availability of magnesium in mixed forages to range from 16 to 26% in grazing sheep trials. Again, using balance trials, Lomba *et al.* (1968) reported the mean apparent digestibility of magnesium in rations consisting variously of hay, straw and concentrates to be 23.1% for dry cows and 27.8% for lactating dairy cows. Other experiments reviewed by Rook and Storry (1962) indicate the availability of megnesium in hay samples to vary from 23.3 to 26.3%.

Magnesium availability in concentrate feeds has generally been somewhat higher ranging up to 40% (Rook and Storry, 1962). Blaxter and McGill (1956) estimated the average availability of magnesium in a complete ruminant ration without mineral supplementation to be about 33%. The availability of magnesium reported in hays, forages, and concentrates for ruminant animals is summarized in table 6.

Table 6
AVAILABILITY OF MAGNESIUM IN HAYS, FORAGES AND CONCENTRATES FOR RUMINANTS

Researcher	Species	Feedstuff	Availability
			%
Stillings *et al.* (1964)	Sheep	Low N hay	18-24
		High N hay	11-16
Field (1967)	Sheep	Mixed pasture	16-26
Lomba *et al.* (1968)	Dry cows	Mixed hays	23.1
	Lactating cows	Mixed hays	27.8
Rook *et al.* (1962)	Cows	Hays	23.3-26.3
Rook *et al.* (1962)	Cows	Grain	37.5
Blaxter and McGill (1956)		Concentrates	33

Values of a higher order have been reported for milk-fed calves the first few weeks of life (Smith, 1958). Subsequently, however, there usually is a marked decline in ability to absorb magnesium as age increases, so that older milk-fed calves will show values of only 30 to 50% of dietary intake (Blaxter and Rook, 1954).

Considerable variability has been observed in results from experiments conducted to determine the relative availability of magnesium from various salts. Huffman *et al.* (1941) without showing actual data, reported essentially equal availability from magnesium oxide, carbonate, chloride and phosphate salts. The efficiency of utilization of magnesium citrate, silicate, sulfate salts and of metallic magnesium, however, was markedly reduced for calves on whole milk rations. Blood plasma magnesium was used as the criterion of response in these studies. Storry and Rook (1963) compared the availability of a number of magnesium salts for dairy cows. In this case, the urinary loss of magnesium expressed as a percentage of magnesium in the supplement was given as the measure of availability. Their values ranged from 14.5% to 49.2%. Using magnesium oxide as the reference standard, the supplements had values of 54% for magnesium trisilicate on the low side up to 158% for magnesium citrate. In these studies blood magnesium levels were not found to be a suitable measure of availability. With beef steers on a magnesium low basal ration, Gerkin and Fontenot (1967) determined the availability of magnesium in dolomitic limestone to be 28% of that in magnesium oxide. Magnesium absorption based on excretion data was used as a measure of availability.

A recent report by Ammerman and associates (1972) compared the availability of several magnesium salts for sheep. Values were expressed as true net retention as determined in balance trials. Availability values ranged from 13.6% to 44.1% for the compounds tested. When reagent grade magnesium oxide was assigned a value of 100, the relative value of magnesium sulfate was 113% and that of reagent grade magnesium carbonate 86%. A sample of magnesite ore, a crude magnesium carbonate, was found to have too low an availability to calculate. In an extension of this work, feed consumption by magnesium deficient sheep was found to be useful as a measure of biological availability. Again, with reagent grade magnesium oxide employed as the standard, the relative availability for feed grade magnesium oxide was 85%, magnesium sulfate 65% and the carbonate 113%. In these studies the administration of the sulfate salt in a single daily dose may have been responsible for the progressive loss of appetite in the sulfate fed sheep. Data from the various relative biological availability comparison trials are presented in table 7.

The literature can be summarized by indicating that the availability of magnesium in forages ranges from 10 to 25% with a mean of approximately 20%. Grains and concentrates range from 30 to 40%. The experimental data on relative availability of magnesium from the various mineral supplements vary considerably and more research is needed to define more accurately their relative efficiencies.

Sulfur

Sulfur metabolism in animals has been studied extensively, with an excellent accumulation of information and references reported in a recent Symposium: Sulfur in Nutrition (Muth and Oldfield, 1970).

The ability of both ruminant and nonruminant animals to utilize sulfur-containing amino acids and inorganic sulfur compounds to various degrees has been recognized for many years. In the studies reported, methionine, elemental sulfur, and sodium sulfate have been the principle compounds used, although many other forms have been investigated. Very little information exists, however, on the comparative biological availability of the various forms of sulfur for animals.

Table 7

RELATIVE AVAILABILITIES OF MAGNESIUM IN VARIOUS SALTS

Researcher:	Huffman[a]	Storry[b]	Ammerman[c]	Ammerman[c]	Gerkin[d]
Animal:	Calf	Cow	Sheep	Sheep	Steer
Criterion:	Plasma Conc.	Urine loss % of supp.	Balance trial	Feed cons.	Absorption
	%	%	%	%	%
Oxide–R.G.	100	100	100	100	100
Oxide–F.G.	–	–	–	85	–
Sulfate	<	58	113	65	–
Carbonate	100	–	86	113	–
Magnesite	–	–	X	–	–
Dolomite	–	–	–	–	28
Chloride	100	90	–	–	–
Citrate	<	148	–	–	–
Acetate	–	107	–	–	–
Nitrate	–	97	–	–	–
Lactate	–	98	–	–	–
Silicate	<	–	–	–	–
Trisilicate	–	66	–	–	–
Phosphate	100	–	–	–	–
Mg-Metal	<	–	–	–	–

[a]Huffman *et al.* (1941).
[b]Storry and Rook (1963).
[c]Ammerman *et al.* (1972).
[d]Gerkin and Fontenot (1967).

Many of the studies have demonstrated that ruminants and nonruminant animals utilize sulfur from the various sources differently. Moreover, there is considerable evidence that sulfur from different sources may be utilized differently within the same species. For example, much of the sulfate fed to ruminants is rapidly converted to sulfide and absorbed through the rumen wall (Anderson, 1956; Bray, 1969a). Very little sulfate is absorbed in the rumen (Bray, 1969b) and also it apparently is poorly absorbed in the intestinal tract of ruminants (Bray, 1969a). In ruminants the intervention of rumen microorganisms can convert inorganic sulfur compounds and sulfur-containing amino acids to microorganismal amino acids which can be utilized by the host animal (Muth and Oldfield, 1970). Radioisotope studies (Pereira, Harper and Gould, 1966) indicate that labeled sulfur from supplemental methionine and sodium and barium sulfides appear principally in the protein fractions of milk but that sodium sulfate sulfur shows up mainly in

the non-protein fraction. In tissue sulfur distribution studies with lambs, more radiosulfur from methionine appeared in the lung and pancreas than from element sulfur or sodium sulfate and more of the sulfur in nose cartilage came from sodium sulfate than from the other compounds investigated (Johnson, Goodrich and Meiske, 1971) indicating that sulfur from sodium sulfate may have entered a different body pool from that of methionine and elemental sulfur. These observations showing that animals can utilize sulfur from various sources differently complicate a discussion on the comparative biological availability of sulfur compounds.

In studies with sheep, Ewan (1957), evaluated calcium sulfate and found it to be an available source of sulfur for lambs. When high levels of sulfur were fed to lambs (Johnson, Meiske and Goodrich, 1968) it was observed that 0.5% sulfur from sodium sulfate did not reduce gains to as great an extent as an equal amount of sulfur from calcium sulfate, indicating differences in utilization between the sources. Feeding a semi-purified diet to lambs and using weight gain as the criterion of response, Sparks *et al.* (1954) found 0.4% elemental sulfur, 1.10% sodium sulfate sources. On a sulfur basis, and assigning methionine a value of 100, the relative availabilities of the sulfur in sodium sulfate and elemental sulfur were 35.2% and 26.6%, respectively. In a similar biological availability trial based on weight gain in lambs, Albert *et al.* (1956) compared the effectiveness of sulfur from methionine, sodium sulfate and elemental sulfur. Five dietary levels of each compound were tested. Optimum daily gains were produced by 0.138% S from methionine, 0.29% from sodium sulfate and 0.47% S from elemental sulfur. Assigning a value of 100 to methionine gives relative biological availabilities of 47.7% and 29.4% for sodium sulfate sulfur and elemental sulfur respectively. More recently, Johnson *et al.* (1971) utilizing a radioisotope technique estimated the true digestibility and retention of the sulfur from elemental sulfur, sodium sulfate and L-methionine and determined the percentage of sulfur from each source that was available for incorporation into wool, muscle tissue, and several other tissues and organs. Results showed a true retention of 70.0% S from L-methionine, 56.0% S from sodium sulfate and 26.8% S from elemental sulfur. On a relative basis, the availabilities were 100 for methionine, 80.0% for sodium sulfate and 38.3% for elemental sulfur. The results from the three lamb trials are summarized in table 8. On the basis of these experiments, the biological value of the sulfur in sodium sulfate is 54% and that of elemental sulfur 31% as compared with methionine arbitrarily set at 100.

In vitro digestion trials using purified cellulose and corn-fodder diets indicated sulfur from sodium sulfate to be approximately equal to the natural sulfur (presumably from S-amino acids) in corn-fodder in promoting cellulose digestion (Barton and Bull, 1971).

Sodium

Very little information has been reported on the biological availability of sodium. Sodium salts are readily absorbed throughout the gastrointestinal tract, and generally the sodium from various sources has been considered fully available. However, recent research suggests that the chemical form in which sodium exists may influence its biological usefulness.

Table 8

BIOLOGICAL AVAILABILITY OF SULFUR FROM VARIOUS SOURCES

Researcher	Criterion	Methionine	Sodium Sulfate	Elem. S
		%	%	%
Sparks *et al.* (1954)	Weight gain	100	35.2	26.6
Albert *et al.* (1956)	Weight gain	100	47.7	29.4
Johnson *et al.* (1971)	True retention ^{35}S	100	80.0	38.3
	Average	100	54	31

Certain calcium phosphate feed supplements contain some sodium as a result of the manufacturing process. Nott and Combs (1969) compared the relative availability of the sodium in a defluorinated phosphate with that of sodium chloride. Using weight gain and feed consumption as the criteria of biological response, it was found that the sodium in the defluorinated phosphate sample investigated was 83% as available as the sodium from sodium chloride. The sodium in most defluorinated phosphates is present predominately as a calcium sodium phosphate complex (approximately $Ca_6Na_3(PO_4)_5$).

Potassium

As with sodium, little work has been reported on the comparative biological availability of potassium from different sources. Large differences in availability probably should not be expected in view of the solubility and rapidity of absorption of the usual forms of potassium found in an animal's diet.

Roberts and St. Omer (1965) conducted a series of experiments involving yearling steers for the purpose of determining the potassium requirement for this species. Sources of potassium varied between experiments, and no direct comparisons were made, but the fact that essentially the same level of potassium from either KCl or K_2CO_3 was required for optimum weight gain and feed consumption may be an indication that these two sources are approximately equal in availability for yearling steers.

Shelton and Ellis (1965) fed 1, 2 and 3% $KHCO_3$ and equivalent amounts of potassium from KCl to growing lambs on an all concentrate ration based largely on sorghum grains. Both forms of potassium appeared to be equal in promoting growth, but only the KCl was found to be helpful in preventing urinary blockage from calculi.

Solid evidence is lacking, but it would appear that KCl, K_2CO_3, $KHCO_3$, K_2HPO_4 and $K_3C_6H_5O_2 \cdot H_2O$ are approximately equal as sources of potassium for the various animal species studied and that the potassium from grass and legume hays also appears to be efficiently utilized.

Summary

The major metal ions required in animal nutrition are those of phosphorus, calcium, magnesium, sulfur, sodium and potassium. Some level of these elements occurs naturally in various forms in most feedstuffs. In addition, they also are added as supplements to feeds to balance dietary requirements. The supplements are chiefly chemical compounds of varying purity and composition, processed natural ores and by-products from various industrial processes. The forms in which these elements are present in feeds may vary widely in biological availability and thereby greatly influence their nutritional worth. The term biological availability is used as a measure of the ability of the element form under consideration to support some physiological process in relative numerical terms in comparison to a reference standard.

Phosphorus

Numerous factors influence the utilization of phosphorus, but in general the relative order of biological effectiveness of the various sources of phosphates, regardless of technique employed, remains approximately the same under similar sets of circumstances. Although certain species of animals respond differently to certain of the phosphate sources, a review of comparative utilization studies of sources for various species indicates the following general order of rank: The soluble phosphates such as sodium phosphate, phosphoric acid and monocalcium phosphate are approximately equal having the highest biological availability, followed closely by dicalcium phosphate. These are followed by defluorinated phosphate and steamed bone meal, then low fluorine rock phosphate and finally soft phosphate. Phytate phosphorus is intermediate in biological availability for ruminant animals and adult poultry, but is very low in biological availability for young poultry and swine.

Calcium

Ruminant animals appear to be more sensitive to differences in calcium sources than poultry or swine. For the ruminant bone meal, monocalcium phosphate and dicalcium have the highest biological availability with hay sources of calcium the lowest. The availability of calcium in limestone, defluorinated phosphate and calcium carbonate is intermediate.

Magnesium

Most biological availability studies on magnesium have been conducted with ruminant animals. The availability of magnesium in forages ranges from 10% to 25% and that in grains and concentrates from 30% to 40%. Reagent grade and feed grade magnesium oxide, magnesium sulfate and magnesium carbonate appear to be well utilized by the ruminant animal whereas the magnesium in dolomite is poorly utilized.

Sulfur

Methionine, sodium sulfate, potassium sulfate, calcium sulfate, and elemental sulfur are the usual sources of sulfur investigated for ruminant and nonruminant animals. For ruminants, on a relative basis, the biological availability of sulfur in sodium sulfate is 54% and for elemental sulfur is 31% as compared with 100% for methionine sulfur.

Sodium

Most sodium salts are highly biologically available to animals.

Potassium

Little work is reported on the comparative biological availability of potassium compounds. Potassium in the form of chloride, sulfate, phosphate, carbonate, acetate and that present in natural feedstuffs is well utilized.

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BIOLOGICAL AVAILABILITY OF MICRO-ELEMENTS[1]

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The mineral ions to be considered in this review are iodine, iron, copper, cobalt, zinc, manganese and selenium. Each of these elements may be required as a dietary supplement for grazing ruminants in certain areas of the world (Underwood, 1971). In general, the mixed grain diets fed to swine and poultry are less likely to be deficient in these elements. Other minor elements either suggested or considered to be essential for normal function of tissue include chromium, vanadium, tin, nickel, bromine, fluorine, and molybdenum (Mertz, 1970; Underwood, 1971). These elements, however, do not appear necessary as dietary supplements for domestic animals on the basis of present evidence.

The relative biological availability of the desired element in a compound or supplement is one of the major considerations in the selection of a suitable source of the element. Sources of many of the supplemental minerals are natural ores or by-products of industry which usually contain many mineral elements. Some of these are potentially toxic and the level of those which may be harmful must be considered. Other factors of importance in the selection of a suitable source include handling and mixing properties, dependability and uniformity of supply, and relative cost per unit of biologically available element.

The research to be reviewed will relate almost entirely to the biological availability of minerals in compounds and ores[2] which have been used or have been proposed for use as dietary supplements. Numerous dietary factors including protein source and level, interrelationships among the mineral ions, and certain chelating agents influence the utilization of mineral ions. These factors have been considered by Scott *et al.* (1969), Miller (1970) and Underwood (1971) and will not be examined in the present review.

Iodine

Many of the early positive responses from supplemental iodine were obtained with either sodium iodide (NaI) or potassium iodide (KI) (McClendon, 1927). Research with calcium iodate was prompted by the observation that, unless properly protected, potassium or sodium iodide lose iodine when mixed with other minerals or when subjected to adverse storage conditions involving moisture, heat or sunlight. Hixson and Rosner (1957) fed day-old chicks to 6 weeks of age a goitrogenic diet supplemented with either potassium iodide or calcium iodate [$Ca(IO_3)_2 \cdot H_2O$] at an iodine level of 0.594 ppm. Based on maintenance of normal thyroid weight and histological examination of the thyroid, calcium iodate and potassium iodide gave similar responses.

Supplemental iodine is provided frequently to livestock as iodized salt in the form of blocks which may be exposed to atmospheric conditions. Thus, to be effective, an iodine source used in salt blocks must be both physically and nutritionally available. Iodine can become physically unavailable by leaching or by migration of the iodine compounds from the surface of blocks as a result of absorbed atmospheric moisture. Davidson and Watson (1948) showed that potassium iodide was unstable in salt blocks except in dry, dark storage and in further research, Davidson *et al.* (1951) found that diiododithymol and potassium iodate (KIO_3) were stable in salt blocks tested under practical feeding conditions. Shuman and Townsend (1963) tested the physical stability of potassium iodide, clacium iodate, and 3, 5-diiodosalicylic acid (DIS) ($C_7H_4I_2O_3$) when added to salt blocks. The salt samples were exposed to high humidity, simulated rainfall and tested under field conditions. Potassium iodide and calcium iodate were lost rapidly from the surface layer of the salt while DIS remained in the surface layer. Potassium iodide was highly soluble in water or sodium chloride brine while DIS and calcium iodate were relatively insoluble. On the basis of these findings, it would seem desirable to have an insoluble iodine source that would not be leached by exposure to moisture but that would be of high biological availability. Diiododithymol [$C_6H_2 \cdot CH_3 \cdot OH \cdot C_3H_7)_2$] is relatively insoluble in water and brine and research by Baldwin *et al.* (1947) showed that its iodine was available to the rat. In addition to this compound, the availability of iodine from cuprous iodide (Cu_2I_2), DIS, and potassium iodide was found equal for rats (Mittler and Benham, 1954).

Diiodosalicylic acid, as a source of iodine for ruminants, was investigated by Aschbacher *et al.* (1963). Dairy calves were dosed orally with ^{131}I as either $D^{131}IS$ or iodide ($^{131}I^-$). As precent of oral dose, the urinary excretion of activity from $D^{131}IS$ was approximately twice that (83.2 vs 46.1%) of the activity from the iodide ($^{131}I^-$). When expressed in a similar manner, thyroid uptake of radioiodine averaged 5.5% for $D^{131}IS$ and 26.8% for $^{131}I^-$. Following further research (Miller *et al.*, 1964) yielding similar results, the authors suggested that absorbed DIS is cleared rapidly from the animal's system by urinary excretion as DIS or as a corresponding salicyluric acid. Rats were shown to have

[1]Based on a paper published originally in the Journal of Animal Science 35:681, 1972.

[2]Chemical composition and purity vary among compounds and ores used to supply supplemental minerals. The identifications or chemical descriptions presented in the paper cited are given in this review.

a greater ability than cattle to remove iodine from DIS (Aschbacher and Feil, 1968) explaining the effectiveness of DIS shown with rats (Mittler and Benham, 1954). Radioiodine given orally as $D^{131}IS$ to pregnant cows was not as available to either the maternal or fetal thyroid and did not cross the placenta as readily as radioiodine administered as iodide (Aschbacher *et al.*, 1966).

Miller *et al.* (1968b) and Moss and Miller (1970) showed that iodine from calcium iodate or pentacalcium orthoperiodate (PCOP) $[Ca_5(IO_6)_2]$ was as well utilized as that from sodium iodide in meeting the iodine needs of cattle. The nutritional and physical availability of PCOP was investigated by Kuhajek and Andelfinger (1970). This compound was equal to either sodium iodide or calcium iodate $[Ca(IO_3)_2]$ in maintaining normal thyroid weight when fed at a dietary iodine level of 0.15 ppm to weanling rats. Salt blocks containing 0.008% iodine as PCOP showed essentially no loss of iodine in surface samples after a four-week exposure. Acute oral toxicity studies with rats revealed similar LD_{50} values for calcium iodate and PCOP.

Ethylenediamine dihydroiodide ($C_2H_8N_2 \cdot 2HI$) has been used at relatively high dietary levels for veterinary purposes including the prevention and treatment of footrot and soft tissue lumpy jaw in finishing cattle (Miller and Tillapaugh, 1966).

Injectable forms of iodized oils including iodized poppy seed oil, have been effective source of iodine in the reduction of endemic goiter in human populations (Hennessy, 1964; Buttfield *et al.*, 1965; Kevany *et al.*, 1969). Sheep in areas of borderline iodine deficiency in New Zealand (Myers and Ross, 1959) were injected with a similar material. The iodized oil injections were equal to oral potassium iodide as determined by histological examination of the thyroids. Injected iodized oil was effective also in reducing goiter and neonatal mortality in lambs born to ewes consuming plants with goitrogenic activity (Andrews and Sinclair, 1962).

Iron

Extensive research on the biological availability of various iron sources has been conducted in recent years. This research has been stimulated by renewed interest in the availability of iron compounds used in fortifying foods for human consumption. Fritz *et al.* (1970) and Underwood (1971) have reviewed numerous publications concerning the availability of iron sources and an extensive bibliography has been included in a paper by Pla and Fritz (1970). Only those reports relating specifically to domestic animals or to iron sources used for domestic animals will be reviewed in the present paper.

Elvehjem and Hart (1929) demonstrated that anemia in chickens fed a milk diet was corrected by feeding ferric chloride ($FeCl_3$) or ferrous sulfate ($FeSO_4 \cdot 7H_2O$) but not by feeding ferric oxide (Fe_2O_3). Based on hemoglobin and red blood cell regeneration in anemic rats, Nesbit and Elmslie (1960) found ferrous carbonate to be relatively unavailable when compared to ferrous sulfate. In recent studies (Willingham and Hill, 1970), iron from several sources was added to a low-iron diet and fed to chicks. Based on body weight and hemoglobin levels at 21 days of age, reagent grade and feed grade ferrous sulfate were well utilized as a source of iron while ferric oxide, either reagent or feed grade, and feed grade ferrous carbonate were relatively unavailable. Using hemoglobin response in both the weanling rat and day-old chick. Fritz *et al.* (1970) determined the relative biological availability of iron from various sources. Compounds classified as good sources of iron, when compared with the standard ferrous sulfate ($FeSO_4 \cdot 7H_2O$), included ferric ammonium citrate, ferric chloride, ferric sulfate, ferrous ammonium sulfate and ferrous fumarate. Iron sources yielding a poor response included ferric oxide, ferric orthophosphate, ferrous carbonate and sodium iron pyrophosphate.

Iron from ferric oxide was shown to be relatively unavailable to young pigs (Pickett *et al.*, 1961). In the same study, USP ferrous sulfate ($FeSO_4 \cdot 2H_2O$) resulted in the highest gains and hemoglobin values, while the response to iron carbonate was intermediate between that for ferrous sulfate and that obtained for USP ferric oxide (Fe_2O_3). Ferric ammonium citrate was equal to ferrous sulfate for baby pigs based on hemoglobin values and weight gains (Harmon *et al.*, 1967). Harmon *et al.* (1969) compared a feed grade ferrous carbonate, which had been separated magnetically from a siderite ore, with USP grade ferrous sulfate as iron sources for young pigs Supplemental ferrous carbonate which provided about 130 ppm iron failed to promote hemoglobin levels greater than those obtained with the basal diet. Three feed grade ferrous carbonates, which were predominately siderite, were tested by Ammerman *et al.* (1974) with pigs weaned at 14 to 21 days of age. The pigs were fed an iron depletion diet (30 ppm iron) for 14 days and then fed diets containing a total of 100 ppm iron for 42 days. The response to the ferrous carbonates varied as measured by hemoglobin levels with the most available carbonate yielding a response similar to that of reagent grade ferrous sulfate. The effectiveness of the carbonates was related to their solubility in 0.4% HCL.

The effectiveness of intramuscularly administered iron dextran in preventing anemia was demonstrated in baby pigs (Barber *et al.*, 1955; Brownlie, 1955; Rydberg *et al.*, 1959; Ullrey *et al.*, 1960). Maner *et al.* (1959) found that 100 mg iron as iron dextran injected at 3 days and again at 10 days of age produced body weights and hemoglobin levels at 24 days equal to those of pigs whose dams' udders were sprayed with a ferrous sulfate solution. In this study, injected iron was more effective than orally administered iron as ferrous sulfate.

Relatively little research has been done concerning the utilization of iron compounds by ruminants. Ammerman *et al.* (1967) used calves and sheep to determine the relative biological availability of radioiron administered orally in the form of freshly synthesized ferric oxide (Fe_2O_3), ferric chloride ($FeCl_3$), ferrous carbonate ($FeCO_3$) and ferrous sulfate ($FeSO_4 \cdot XH_2O$). The sulfate, chloride and carbonate forms were not significantly different when compared on the basis of tissue ^{59}Fe deposition. Based on either serum or tissue ^{59}Fe uptake, iron from ferric oxide was of very limited

availability. In studies by Perry *et al.* (1967), the injection of 500 mg of iron dextran in calves at birth was without effect on body weight or hemoglobin levels at weaning. In another phase of the same study, 500 mg iron in the same form was not beneficial to cattle under feed lot conditions. Further studies by Getty *et al.* (1968) confirmed the hemoglobin response to injectable iron dextran by young calves and the earlier observations that no increase in weight gain occurred.

Copper

Studies with inorganic copper sources have been conducted both with ruminants and nonruminants. Based on hemoglobin regeneration in anemic rats, Sherman *et al.* (1934) found that copper as cupric sulfate was readily utilized while that as cupric sulfide was relatively unavailable. In more recent studies, cupric sulfate was absorbed more efficiently by pigs than cupric sulfide (Barber *et al.*, 1961; Bowland *et al.*, 1961). Copper as the sulfate ($CuSO_4$) or pyrophosphate was readily utilized for hemoglobin regeneration in anemic rats (Schultze *et al.*, 1936). In studies with mature rats, Nesbit and Elmslie (1960) fed copper oxide, copper pyrophosphate, copper concentrate (74.1% Cu) and copper sulfate at dietary levels of 250 and 500 ppm copper. Using liver copper storage as the criterion, copper oxide, copper concentrate and copper pyrophosphate were approximately 25, 33 and 50% as available, respectively, as was copper sulfate. In research with chicks, cupric sulfate ($CuSO_4$) resulted in similar body weight gains but significantly higher hemoglobin levels at 21 days of age than occurred with cupric oxide (CuO) when both sources were fed at a supplemental level of 10 ppm copper (Willingham and Hill, 1970).

Radioactive copper in the form of cupric carbonate, cupric sulfate or cupric oxide was administered as a single dose to pigs averaging 25 kg in body weight and consuming a diet containing 15 ppm copper (Buescher *et al.*, 1961). Based on serum uptake of ^{64}Cu and fecal and urinary availabilities of the three forms of copper for swine were similar. Weanling pigs were fed 250 ppm supplemental copper as $CuSO_4$, CuO or $CuCO_3$ for 42 days (Bunch *et al.*, 1961, 1965). Liver copper concentrations expressed on a dry weight basis were 218 and 32 ppm for $CuSO_4$ and CuO, respectively, in one study and 89 ppm for $CuCO_3$ in a similar experiment.

Several copper containing compounds have been tested as dietary supplements of this element for ruminants. Lassiter and Bell (1960) reported greater blood uptake of radioactive copper in sheep when radioactive cupric chloride ($CuCl_2$) was given orally than when cupric sulfate ($CuSO_4$) or cupric nitrate [$Cu(NO_3)_2$] were administered. Copper from cupric oxide needles (CuO) was less well absorbed and copper in copper wire (metallic copper) was essentially unavailable. In another phase of the same study, cupric carbonate ($CuCO_3$) was better utilized than cupric oxide (CuO) or cuprous oxide (Cu_2O). In similar research in which radioactive compounds were administered to steers (Chapman and Bell, 1963), the copper from cupric nitrate, cupric sulfate, or cupric chloride was absorbed into the blood stream from powdered cupric oxide than from the same compound in needle form. The authors concluded, from both the physical characteristics of the compound and the biological value of the copper, that cupric sulfate was the most suitable source of those tested for use as a dietary copper supplement. It could be suggested that high bioavailability can also be significant to mineral toxicity should accidentally high dosages be given.

Injectable forms of copper-containing compounds have been effective in preventing copper deficiency in ruminants. Allcroft and Uvarov (1959) published studies in which copper glycinate was injected subcutaneously in cattle. These studies indicated a fairly wide margin of safety with this method of copper administration and suggested that two or three injections yearly could maintain normal copper nutrition, even under grazing conditions of severe copper deficiency. Similar positive responses in cattle have been obtained with injectable copper glycinate in other countries including the United States (Dunkley *et al.*, 1963; Donaldson, 1964; Cook *et al.*, 1966; Clawson *et al.*, 1972), Australia (Alexander *et al.*, 1967) and New Zealand (Cunningham, 1959). Injectable copper as copper glycinate, CuCa-EDTA, or copper methionate was effective in maintaining normal blood and liver copper in pregnant ewes (Hemingway *et al.*, 1970). The injectable Cu-EDTA complexes have resulted in less localized reaction than occurred with copper glycinate but appear to have a greater toxicity potential than the glycinate form (Ishmael *et al.*, 1970).

Cobalt

A critical evaluation of the relative biological availability of cobalt from various sources to ruminants has not been made. In early studies, the initial positive responses to supplemental cobalt were obtained with the natural ore, limonite (Underwood, 1971). Oral cobalt sulfate and cobalt carbonate relieved deficiency in sheep (Keener *et al.*, 1950) and radioactive cobalt administered orally as cobalt carbonate (Keener *et al.*, 1951), as cobalt chloride (Monroe *et al.*, 1952) or as cobalt oxide (Mittler, 1954) was absorbed well by sheep. The carbonate, chloride, sulfate and nitrate forms of cobalt have been proposed as satisfactory dietary sources of the mineral (Smith and Loosli, 1957; Cunha *et al.*, 1964; Becker *et al.*, 1965; Jones and Anthony, 1970). Because of desirable physical characteristics, cobalt carbonate is frequently the cobalt source of choice in the feed industry.

Dewey *et al.* (1958) described an orally administered heavy pellet made of cobalt oxide and clay which remains in the reticulorumen for several months. Dairy cattle treated with cobalt pellets increased in milk production (Skerman *et al.*, 1961), and ewes treated similarly during pregnancy produced colostrum and milk higher in vitamin B_{12} than that produced by untreated ewes (O'Halloran and Skerman, 1961). Improved performance, when pellets were administered

to beef cattle grazing cobalt-deficient areas, has been observed by Skerman *et al.* (1959) and Chapman and Kidder (1964). However, the pellets may be lost frequently through regurgitation or become ineffective because of the formation of a surface coating (Skerman *et al.*, 1959; Owen *et al.*, 1960). Connolly and Poole (1967) have designed a pellet containing layers of cotton gauze bandage impregnated with cobaltic oxide which does not coat over and thus remains effective for a longer period of time.

Zinc

Although supplemental zinc is used extensively in practical feeding situations with poultry, swine and ruminants, critical evaluation of the biological availability of different inorganic sources has been undertaken only with poultry. Edwards (1959) used chick growth at 14 days of age as the cirterion for utilization of zinc from seven ores and five compounds. The results of the studies indicated that zinc in reagent grade zinc sulfate, zinc carbonate ($ZnCO_3$) zinc metal (Zn), and zinc oxide (ZnO); in technical grade zinc oxide (ZnO); and in the mineral ores, willemite [Zn_2SiO_4 (^+Mn)], smithsonite ($ZnCO_3$), hemimorphite ($2ZnO{\cdot}SiO_2H_2O$ and zincite (ZnO) was relatively available to the growing chick. The zinc in sterling black and brown crude ore was of lower availability and zinc in the ores sphalerite (ZnS) and franklinite [$(Fe, Mn, Zn, FeO_2)_2$] was relatively unavailable.

Since turkeys have a higher zinc requirement than chickens (NRC, 1971), the poult may provide a more critical assay model than the chick for determining zinc availability. Sullivan (1961) added 20, 30 or 40 ppm zinc from various sources to a basal diet containing about 14 ppm zinc and fed day-old poults to 28 days of age. Based on growth, survival, bone development and incidence of deficiency symptoms, the zinc in technical grade zinc carbonated and USP grade zinc sulfate ($ZnSO_4{\cdot}7H_2O$) was readily available to starting poults. Zinc in reagent grade zinc chloride ($ZnCl_2$) was slightly less well utilized than that in zinc carbonate and zinc sulfate. Zinc oxide (ZnO) and zinc sulfate ($ZnSO_4{\cdot}H_2O$), both technical grade, were relatively unavailable sources of dietary zinc for poults.

Various zinc containing compounds have been effective for other species. In general, however, only one supplemental zinc source was used in each study and critical tests of biological availability were not made. Forbes and Yohe (1960) fed $ZnCO_3$ in determining the zinc requirement of the rat. In studies with swine, $ZnCO_3$ and ZnO (Conrad and Beeson, 1957), USP ZnO (Smith *et al.*, 1958), reagent grade $ZnSO_4{\cdot}7H_2O$ (Hoekstra *et al.*, 1967), and technical grade $ZnSO_4{\cdot}H_2O$ (Miller *et al.*, 1968) have been fed. Zinc as ZnO (Miller *et al.*, 1963; Ott *et al.*, 1965; Perry *et al.*, 1968) or as $ZnSO_4$ (Mills *et al.*, 1967; Underwood and Somers, 1969) has been effective in ruminants.

Manganese

The need for supplemental manganese in practical diets was first recognized with poultry (Wilgus *et al.*, 1936) and it appears that almost all of the biological availability research with inorganic manganese sources has been conducted with poultry.

Schaible *et al.* (1938) added various levels of manganese from different sources to a diet containing 11 ppm manganese which was fed to chicks from 1 day to 5 weeks of age. Based on reduction in incidence of perosis with 30 ppm supplemental dietary manganese, the sulfate ($MnSO_4{\cdot}2H_2O$), chloride ($MnCl_2{\cdot}2H_2O$), carbonate ($MnCO_3$), and dioxide (MnO_2) forms of manganese and potassium permanganate ($KMnO_4$) were equally effective. In addition, natural oxide ores including manganite (Mn_2O_3), pyrolusite (MnO_2), psilomelane (MnO_2) and hausmannite (Mn_3O_4) gave results equivalent to those obtained with the reagent grade compounds. Manganese in the form of rhodonite ($MnSiO_3$) or rhodochrosite ($MnCO_3$) was much less effective in preventing perosis. In similar studies, Gallup and Norris (1939) tested the effectiveness of chemically pure $MnCl_2{\cdot}4H_2O$, $MnSO_4{\cdot}4H_2O$, $KMnO_4$, $MnCO_3$, and MnO_2 in chicks and reported that all manganese sources were equally effective in preventing perosis.

Studies to compare the biological availability for chicks of natural carbonate ore (rhodochrosite) and precipitated manganese carbonate ($MnCO_3$) were made by Bandemer *et al.*, (1940). The precipitated $MnCO_3$, when added at dietary level of 30 ppm manganese, was completely effective in protecting against the perosis occurring with the basal diet. Rhodochrosite, however, was ineffective at levels up to 125 ppm manganese. Roasting the ore or dissolving in acid rendered the manganese available to the chick.

In more recent studies (Watson *et al.*, 1970, 1971), several manganese sources were tested with chicks fed to 28 days of age. A semi-purified diet containing 5 ppm manganese was fed and the manganese sources were added to provide 10 ppm supplemental manganese. Reagent grade manganese sulfate and manganese carbonate resulted in the least severe leg abnormality. Feed grade manganese oxides varied significantly in degree of biological availability of manganese. Biological availability of natural carbonate ore was low.

Although biological availability assays have not been conducted with ruminants, manganese as the chloride or sulfate has been shown to be an effective source of manganese for cattle (Bentley and Phillips, 1951; Dyer *et al.*, 1964; Rojas *et al.*, 1965).

Selenium

The direct addition of selenium to ruminant diets or mineral supplements except under experimental conditions has not yet been permitted in the United States. In 1974, the U.S. Food and Drug Administration gave approval for the oral administration of supplemental selenium as either sodium selenite or sodium selenate to certain classes of swine and poultry. Similar approval in the United States for ruminants will require additional information, particularly with regard to the influence of dietary intake on concentrations of selenium in tissue and milk in beef and dairy animals.

Positive responses have been obtained in grazing ruminants given supplemental selenium in the form of sodium selenite (Na_2SeO_3) or sodium selenate (Na_2SeO_4) in either oral dosage or injections (Muth *et al.*, 1967; Underwood, 1971). Trace mineralized salt containing 132 ppm selenium as sodium selenate and offered *ad libitum* to pregnant ewes prevented muscular dystrophy in the lambs and improved lamb weight gains when compared with lambs from ewes offered salt without selenium (Paulson *et al.*, 1968). The addition of 0.5 or 1.0 pprm Se as sodium selenite to the diet of growing-finishing pigs increased selenium levels in the tissues and prevented pathological tissue lesions typical of Se and/or vitamin E deficiency (Groce *et al.*, 1971).

Organic selenium compounds are of higher availability than selenite or selenate for several species (Ammerman and Miller, 1975). Tests with chicks, (Cantor *et al.*, 1975) compared the utilization of selenium in various feedstuffs with that in sodium selenite. Based upon prevention of exudative diathesis and glutathione peroxidase activity, the biological availability of selenium in feedstuffs was 60-90% for those of plant origin and 25% for those of animal origin. Sodium selenate and selenocystine were of high availability and selenomethionine, selenoethionine, selenopurine, and selenium sulfide were low.

An approach to selenium supplementation for ruminants similar to that for providing cobalt has been considered. Kuchel and Buckley (1969) tested heavy pellets for grazing sheep which were composed of finely divided metallic iron and either calcium selenate, barium selenate or elemental selenium. In this study blood and tissue levels of selenium remained elevated for periods up to 12 months after administering the pellets. Because of physical stability and resistance to coating with calcium phosphate, the pellet containing finely divided iron and elemental selenium was considered to be the pellet of choice. Results confirming the effectiveness of a selenium-containing pellet, when placed in the reticulorumen, have been obtained with sheep by Handreck and Godwin (1970).

Summary

Sources of the minor mineral ions customarily used to supply adequate dietary levels include reagent grade chemicals, natural ores and by-products from industrial processing. These may vary greatly in chemical purity, in amount of dietary mineral supplied, and in biological availability.

Iodine. Sodium and potassium iodide are well utilized as sources of iodine but lack physical stability. Calcium iodate, diiododithymol and pentacalcium orthoperiodate are less water soluble, have greater physical stability and are similar to sodium or potassium iodide in availability. Dilodosalicylic acid is readily absorbed by ruminants but is excreted with little release of iodine from the cyclic structure. Studies with rats have indicated a more efficient use of the iodine in this compound than occurred with ruminants. Injectable forms of iodized oils have been effective in supplying supplemental iodine to sheep.

Iron. Dietary iron as the sulfate or chloride is well utilized by either ruminants or nonruminants while iron as ferric oxide is essentially unavailable. Feed grade ferrous carbonates have ranged from low to intermediate in availability in several experiments. In studies with rats or chicks, ferric ammonium citrate, ferrous ammonium sulfate and ferrous fumarate were well utilized; ferric orthophosphate and sodium iron pyrophosphate were poorly utilized. Intramuscularly injected iron dextran is effective in preventing anemia in baby pigs.

Copper. In general copper as cupric sulfate has been found the most available form for rats, swine, poultry and ruminants. Ruminants responded similarly to cupric nitrate and cupric sulfate. Copper as cupric oxide was absorbed to a lesser degree than cupric sulfate by sheep, cattle, chicks and rats. In experiments where tested, cupric carbonate was intermediate in response between the oxide and sulfate forms of copper. Injectable forms of copper including copper glycinate and copper-EDTA have been effective in preventing copper deficiency in ruminants.

Cobalt. Critical tests of the biological availability of cobalt compounds for ruminants have not been made. The carbonate, chloride, sulfate and nitrate forms of cobalt have been effective in providing supplemental cobalt for ruminants. Orally administered heavy pellets made of cobalt oxide and clay which remain in the reticulorumen for several months have been found effective in supplying cobalt to cattle and sheep. Problems have been encountered with regurgitation and with coating of the pellets.

Zinc. Few studies on the availability of various zinc sources have been made and these have been conducted with chicks or poults. The results obtained among experiments have not been in close agreement. Experiments with chicks indicated that zinc as the metal, sulfate, carbonate, oxide and in several natural ores was relatively available. In a study with poults, technical grade zinc carbonate and USP grade zinc sulfate were readily available, but reagent grade zinc chloride was less available and technical grade zinc oxide or zinc sulfate were relatively unavailable.

Manganese. The biological availability of manganese sources has been determined primarily with poultry. Reagent grade manganese sulfate, chloride, carbonate and oxide were equally effective in preventing perosis in chicks. Certain feed-grade manganese oxides were less effective and the natural manganese carbonate ore was ineffective in preventing perosis.

Selenium. Although critical biological availability assays have not been made, sodium selenite and sodium selenate as either oral doses or injections have prevented the symptoms of selenium deficiency in both ruminant and monogastric animals. Under proper storage conditions, both sources are stable in mixed feeds (Ammerman and Miller, 1975).

In general, chemically pure compounds are of higher biological availability than natural ores containing the same element. Natural ores may contain the element in different chemical forms as well as carry other minerals; thus, it is important that the chemical and physical properties of the ore be described. X-ray diffraction analyses and solubility

tests may assist in obtaining this information and in predicting biological availability. In addition, the physical and chemical characteristics of a compound or an ore may limit its use under certain conditions even though it may have high biological availability.

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SOIL, PLANT AND ANIMAL TISSUE AS PREDICTORS OF THE MINERAL STATUS OF RUMINANTS

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Introduction

All plants depend upon the soil for their supply of mineral nutrients and grazing ruminant animals obtain the majority of their mineral nutrients from plants grown on these soils. The soil-plant relationship is direct in that the plant must obtain all mineral nutrients from the specific soil with which it has contact. In contrast, animals that range freely over wide areas will obtain their minerals from a variety of soil types, plant species and different botanical parts of plants. Restricting animal movement makes these animals dependent on narrow ranges of soil types and plant species. The soil-plant-animal relationship becomes even more complex than either the soil-plant to the plant-animal relationship. The fact that animals suffer various disorders when consuming specific plants or when restricted to some areas has been recognized for centuries. Marco Polo (ca. 1295) made references to a poisonous plant growing in the mountains of western China which, when eaten by beasts of burden, caused their hooves to drop off. Now we recognize that seleniferous vegetation will produce this phenomenon in cattle and horses.

Tremendous progress has been made during the past 50 years in identifying and correcting these mineral deficiencies and toxicities. However, in the major ruminant livestock producing areas of the world, relatively little is known about the mineral status of soils, vegetation or animals. Mineral analyses are complicated and expensive. Therefore, we are interested in selecting and analyzing the minimum number of tissues which are most indicative of the mineral status of the animal.

Factors Affecting Levels of Mineral Nutrients in Plant Tissues

Plant materials provide the primary source of mineral nutrients to grazing ruminants. Concentrations of minerals in plants are dependent on at least four basic, interdependent factors. These are (1) genetic differences depending on genus, species, or strain of plant, (2) the type of soil on which the plant has grown, (3) the climatic or seasonal conditions during growth, and (4) the stage of maturity of the plant.

Genetic Differences

Selenium accumulator plants provide an excellent example of genetic differences. Several species growing on seleniferous soils which contain 5 to 10 ppm of selenium develop selenium concentrations between 1,000 and 3,000 ppm. Another example is cobalt. Black gum *(Nyssa sylvatica)* has been shown to contain about 100 times more cobalt than broom sedge *(Andropogon glomeratus)* growing on the same soils of the coastal plain in the eastern United States (Beeson *et al.*, 1955). Substantial species differences have been reported between grasses. Beeson *et al.* (1955) reported cobalt concentrations to range from 0.05 to 0.14, copper from 4.5 to 21.1, and manganese from 93 to 815 ppm (dry basis) when 17 grass species were grown together on a sandy loam soil and sampled at the same time. Furthermore, strains of rye grass *(Lolium perenne)* grown on similar soils have been found to have iodine levels which were 10 times different.

Soil Effects

Soil composition is a basic factor determining the level of mineral nutrients in plants. This composition is influenced primarily by the nature of the rocks from which the soil is derived. In early studies on cobalt deficiency in New Zealand, Kidson (1937) estimated the amount of cobalt soluble in concentrated hydrochloric acid and found the deficiency prevalent when soils contained less than 2 ppm cobalt. Healthy animals were found on soils containing an average of 6 to 20 ppm of cobalt, but same soils low in cobalt had healthy animals. Bryan and Becker (1935) found that deficient mineral soils had generally lower iron and copper contents than healthy soils, but that high organic matter peat soils produced deficiencies even though they contained 12 and 42 ppm copper.

Effect of Season and Stage of Maturity

The marked decline of phosphorus and potassium as plant mature is not paralleled by comparable declines in trace minerals. Whole plant concentrations of trace minerals may increase, decrease or show no consistent change with stage of growth, the plant species and the soil or seasonal conditions. Changes in trace mineral concentrations of forages related to season and stage of growth are of greater significance to the animals in areas where marginal levels are present.

Tissues Most Indicative of the Mineral Status of Grazing Ruminants

An analysis of the mineral content of plants consumed by grazing animals can be helpful in predicting the mineral status of grazing ruminant animals. However, tremendous variations occur in the mineral content of these plants. Most animals consume many different plant species at different stages of maturity which are grown on different soil types. Consumption, digestibility, absorption and secretion of mineral elements are complex and controlled by many factors.

Grazing ruminants are in close and continuing contact with the soils on which the plants grow. Soils often contain many times the levels of minerals which are found in the plants which grow on these soils. Mitchell (1963) reported that soil contained 20 to 1,000 times the Co and Fe content that was found in pastures grown on a particular soil. Recent measurements in southwest England indicate that soil ingestion by grazing cattle varied from 140 to 1,500 g per day (Thornton, 1974). Soil as a percentage of dry matter intake varied between 1 and 11 percent. These recent studies confirm other reports that appreciable amounts of soil may be involuntarily ingested.

Ideally, animal scientists would like to determine the mineral status of an animal by measuring the mineral content of one tissue which is readily available from a live animal. However, this is not possible for many reasons. Fortunately, the mineral metabolism of each important mineral has been studied in great detail and these studies indicate which tissues are the most indicative of the mineral status of the animal. Animal, plant and/or soil analyses, in conjunction with clinical, pathological and intake data, are valuable measurements.

Eleven essential minerals which are of major importance have been selected. These are briefly discussed and the tissues are indicated which have been found to have major diagnostic importance. Three excellent references on this subject are by Underwood (1971), Miller and Stake (1974), and the Netherlands Committee on Mineral Nutrition (1973). A summary of the tissue analyses of greastest value in assessing the mineral status of grazing ruminants is presented in Table 1.

Calcium (Ca)

Calcium is required in large quantities for skeletal development, and approximately 99.5 percent of the body Ca is found in the bones. Calcium requirements are highest during periods of rapid skeletal development and during periods of lactation since milk contains approximately 0.12 percent Ca. Although osteogenesis constitutes the major demand for Ca, it also has several regulatory functions.

Calcium nutrition has been intensively studied and its metabolism is better understood than many of the other minerals. Grazing ruminants obtain a major part of their requirements from the forage they consume. Legumes contain an excess and many grasses contain adequate levels of Ca. The requirement for beef cattle is 0.25 percent and 69 percent of the 1,128 forage entries in the **Latin American Tables of Feed Composition** contained more than 0.30 percent Ca (McDowell *et al.*, 1974).

A deficiency results in lowered serum Ca values, but physiological mechanisms regulating them are more effective than those for P and most other minerals. The symptoms of milk fever in lactating cows are accompanied by low serum Ca, but milk fever is not caused by a dietary Ca deficiency. A Ca deficiency reduces the quantity of milk produced, but not the Ca content of the milk.

Table 1

ANALYSES OF GREATEST VALUE IN ASSESSING MINERAL DEFICIENCIES IN RUMINANTS

Element	Soil	Diet	Liver	Blood Plasma	Saliva	Milk	Urine	Other
Ca		Ca		Ca				
P		P		P				
Mg		Mg, K, N		Mg			Mg	
Na		Na			Na, K			
Co	Co	Co	Co, Vit B_{12}					Serum B_{12}
Cu			Cu	Cu**				
Fe				*				Hb*
I						I		
Mn		Mn, Ca, P	Mn					
Se			Se	Se				Kidney cortex
Zn		Zn		Zn				

Underlined indicates greatest value.
* Percent saturation of transferrin, hemoglobin and hematocrit of blood.
** Also plasma ceruloplasmin.

Young and lactating animals are able to utilize large amounts of Ca from the skeleton to meet their nutritional demands. This results in lowered bone breaking strength, bone density and bone ash, although the Ca to P ratio in bone ash is not greatly affected.

Gross abnormalities in bones and teeth are not specific for Ca since P, Vitamin D, Mn, Cu and excess F can produce similar effects.

Many of the tissues mentioned have value in determining the Ca status of animals. However, a determination of dietary levels and a comparison between Ca intake and the requirement are recommended to determine the Ca status of the grazing ruminant animal.

Phosphorus (P)

Phosphorus deficiency is the most widespread and economically important mineral problem affecting grazing ruminants unless P supplementation is provided. It is also the most expensive mineral supplement in the diet because of the amount required and its comparatively high price.

Approximately 80 percent of the P is found in the osseous tissue where it constitutes about 16.5 percent of the bone ash. The remaining 20 percent, found in the soft tissues, has vital metabolic roles in carbohydrates metabolism in the formation of hexosephosphates, creatine phosphate and adenylic acid, and in protein metabolism where it is present in nucleo-proteins and phosphoproteins.

A decrease in serum inorganic P below normal levels--6 mg % for adults and 6 to 8 mg % for young--is an early sensitive biochemical measure of a P deficiency. Plasma phosphatase values increase. The mineral content of bones decreases and becomes fragile. Furthermore, joints become stiff, lameness may develop, and fractures may occur. Upon postmortem examination, the articulating joints appear to be eroded.

Anorexia is one of the first clinical symptoms of P deficiency, but is not specific for P. Pica develops in which the animals chew and ingest rocks, soil, wood, bones and hair, but this is not specific since it may occur with a Na or K deficiency. Phosphorus deficiency reduces gain and milk production and it often accompanied by reduced fertility in females.

Most research groups consider serum inorganic P to be sufficiently sensitive and recommend it for diagnosing P deficiencies. However, it is significant that the Netherlands Committee on Mineral Nutrition (1973) recommends forage analyses because studies have shown that earlier and more detailed information can be obtained. It is apparent that both serum inorganic P and forage analyses are effective in determining the P status of grazing ruminants and that either or both can be used.

Magnesium (Mg)

A magnesium-dependent condition, known diversely as grass tetany, grass staggers, hypomagnesium tetany, lactation tetany and wheat pasture poisoning, is frequently a problem in ruminants grazing an excellent, high quality pastures. It occurs during the fall and spring months when temperatures range between 40 and 60°F. Clinical signs are relatively characteristic, but serum Mg determinations are very useful in confirming the diagnosis.

The most characteristic change observed in grass tetany is a sudden drop in serum Mg. Normal serum Mg levels are between 1.8 and 3.2 mg %. In cases of tetany, the level may decline to 0.5 mg % or less.

There has been a tremendous amount of research on grass tetany, but the etiology of this metabolic disorder is not completely understood. Papers by Burns and Allcroft (1967a, 1967b) are excellent reviews on this subject.

Biochemical and gross characterization of the diet are useful in predicting Mg deficiency. Grass tetany normally occurs in cool weather in lactating animals grazing excellent pastures fertilized with N and K. Analyses of forage for Mg, N and K can aid in diagnosing a grass tetany problem, but these analyses are less reliable than serum and urine Mg values. Higher N and/or K and lower Mg indicate greater probability of grass tetany. Magnesium availability is lower in young, highly digestible forage. Lactation increases Mg requirements.

Sodium (Na)

Sodium is of major importance in the metabolic processes of all animals. Sodium apparently makes a greater contribution to pH, buffering systems and maintenance of physiological desirable osmotic pressure than do many other inorganic nutrients. In ruminant animals, inadequate Na intake is presumed to be the most important factor contributing to a Na deficiency although diarrhea may be a factor in young animals. Ruminants must have their diet supplemented with Na since plants generally have a small amount of this element. Plants also have a high K content which causes an increase in Na excretion.

As a Na deficiency develops, the Na content of plasma, saliva and other fluids is decreased and the K content is generally increased. Denton (1956, 1957) demonstrated that a Na deficient diet in sheep has a marked effect on the Na and K content of parotid saliva and that a salivary fistula contributed to producing a Na deficiency if the secreted saliva was not returned to the sheep. He found that the Na concentration in the parotid saliva was about 180 meq/1 with a normal diet and 60 meq/1 on a deficient diet. Phillips and Sundaram (1966) studied Na depletion in pregnant ewes with parotid fistulas and found that the Na content of saliva declined from 173 to 38 meq/1 while K content rose from 5 to 96 meq/1. Plasma Na content declined from 150 to 135 meq/1 and K declined from 4.6 to 4.2 meq/1.

Skydsgaard (1968) suggested that analyses of salivary Na and K can be used to diagnose Na deficiency in cattle. He found the normal Na to K ratio in saliva to be from 17:1 to 25:1, and suggested that, if it is between 10:1 and 15:1, Na deficiency can be suspected.

Currently, the Na to K ratio in the saliva is the most sensitive and reliable indication of the Na status of the ruminant. The Na to K ratio of the rumen liquor shows marked diurnal fluctuations. Urine Na varies widely, fecal excretion of Na is variable and milk Na is only slightly decreased with low Na intake.

Copper (Cu)

Experience in the Netherlands, where Cu deficiency is rather common, shows that Cu deficiency at the end of the grazing season cannot be distinguished on the basis of the Cu content in herbage or soil. However, a close correlation was found between Cu content in liver and concentration in blood serum. Animals are able to store large reserves of Cu in the liver. Normal blood Cu levels do not indicate the size of the liver reserves. However, liver Cu permits an evaluation of the actual situation and allows an estimate of the Cu reserves which are available for future critical periods. Therefore, the Cu content of the liver gives more reliable and detailed information on the Cu status of the animal than the blood value. Because of the comparative ease of taking samples, blood plasma Cu is frequently used (Hartmans, 1974).

The Cu status of plasma from cattle and sheep can be readily determined from serum ceruloplasmin activity. Ceruloplasmin, a true oxidase enzyme (ferroxidase) synthesized in liver, usually contains eight Cu atoms per mole. A high percentage of the plasma Cu exists as cerulopasmin with high correlations between serum Cu and ceruloplasmin activity. Some of the advantages for using ceruloplasmin values as a screening method for Cu deficiency are high enzyme specificity, enzyme stability at room temperature, only 0.1 ml of blood required and ease of determination.

Mean liver Cu values for mature cattle on normal diets are reported to be 200 ppm as compared to 11 ppm on Cu deficient diets (Cunningham, 1946). The normal range of blood plasma Cu for sheep and cattle is 0.6 to 1.5 μg/ml, while values consistently below 0.6 μg/ml indicate Cu deficiency (Underwood, 1971).

Cobalt (Co)

A Co deficiency is primarily an area problem and severe deficiencies occur in grazing ruminants in many countries. Soil Co is considered by the Dutch to have good diagnostic value. When Co is extracted with acetic acid (2.5 % v/v), more than 0.3 ppm indicates adequate Co, whereas, less than 0.1 ppm is considered low. Co content of herbage is also helpful in determining the Co status of the animal. Under most conditions, mean pasture values of 0.10 ppm Co or more supply sufficient Co to prevent a deficiency. However, if the herbage consistently contains less than 0.08 ppm Co, a deficiency can be predicted with a relatively high degree of confidence.

The concentration of Co in the livers of sheep and cattle is sufficiently responsive to changes in Co intake to have some value in the diagnosis of Co deficiency. Most studies indicate that cattle and sheep liver Co levels below 0.1 ppm on a dry basis are low to deficient while levels between 0.15 and 0.30 ppm are normal for healthy animals.

Liver vitamin B_{12} concentration is a more sensitive and reliable criterion than liver Co concentration. Vitamin B_{12} contains four percent Co and is the primary function of this element.

Andrews (1960) determined that the following vitamin B_{12} values were indicative of the Co status of sheep and that they can tentatively be applied to cattle.

Vitamin B_{12} in fresh liver (ppm)	Cobalt status of animal
< 0.07	Severe Co deficiency
0.07 to 0.10	Moderate Co deficiency
0.11 to 0.19	Mild deficiency
> 0.19	Sufficiency

There are a number of biological tissues that are helpful in diagnosing the Co status of grazing animals. Clinical signs of Co deficiency in grazing ruminants are not specific. The best clinical method of diagnosing a deficiency is to administer a Co supplement and, if a deficiency exists, improvement in the animals will occur with a few weeks.

Iron (Fe)

Iron deficiency is a commonly occurring deficiency disease in swine and humans, but is rarely found in ruminants except where precipitated by chronic blood loss. Iron deficiency results in hypochromic, microcytic anemia with low serum Fe, increased total serum Fe binding capacity and a decreased transferrin saturation. Low hemoglobin and hematocrit values are not sensitive indicators of early Fe deficiency because they do not occur until Fe storage is severely depleted.

Many consider percent saturation of transferrin to be the most practical means of detecting Fe deficiency in its early states (Underwood, 1971). The Fe content of transferrin reflects available circulating Fe at the hemoglobin synthesis site. Serum Fe and total Fe binding capacity, the basis for calculating percent transferrin saturation, can be determined simultaneously and by a completely automated procedure (Friedman and Cheek, 1971).

Iodine (I)

Iodine deficiency is easy to prevent by the use of iodized salt, but it is still widespread in grazing ruminant animals. Goitrogenic substances occur frequently and increase the animal's requirement for I. Consequently, the I content of the diet has limited value in diagnosing a deficiency problem. Iodine deficiency causes enlarged thyroids which are relatively easy to detect by manual palpation in young calves and lambs. However, in early deficiency stages, a glandular enlargement is not pronounced and methods other than visual inspection and palpation should be used.

Several methods of estimating thyroid secretion rates have been used successfully. One of the most accurate methods is obtained by using radioactive thyroxine to determine the rate of disappearance, but radioactive substances are limited to experimental animals (Swanson and Miller, 1973).

Milk analyses have been used successfully to determine the I status of lactating dairy cows. Binnerts (1954) found the following mean differences between goitrous and non-goitrous regions in the Netherlands: summer milk, 9.7 and 11.1 μg/liter and winter milk, 20.6 and 83.5 μg/liter, respectively. Iodine in the milk has been adopted by the Netherlands Committee on Mineral Nutrition to indicate I status.

Manganese (Mn)

The Mn content of most body tissues is remarkly resistent to low intakes. Reductions occur in liver, bones, and hair or feathers. High levels of Mn result in only moderate increases in liver Mn. Experimentally, the Mn content of hair, feathers and wool can be increased, but, due to wide variations, these are not regarded as reliable diagnostic measures for Mn.

Manganese deficiency decreases blood and bone alkaline phosphatase, but this decrease is not specific for Mn. Reserve stores of manganese do not occur in the livers of newborn ruminants and the liver concentration varies little with age or species. Livers of normal cattle and sheep contain 8 to 10 ppm. It is apparent that liver Mn levels are of limited value in assessing the Mn status of ruminants.

Dietary Mn levels of 25 ppm have been found to meet the requirement for cattle under most conditions. Determining the Mn in the diet is the most reliable indicator of the Mn status of ruminants.

Selenium (Se)

Selenium deficiency is widespread in ruminant animals throughout the world. The most universal manifestation of Se deficiency is muscular dystrophy, often referred to as white muscle disease in calves and lambs. Selenium occurs in all the cells and tissues of the body in concentrations that vary with the tissue and with the level of Se in the diet. Kidney cortex is by far the highest in Se concentration, followed by the pancreas, the pituitary and by liver. The muscles, bones and blood are relatively low in Se.

Muscular dystrophy can be diagnosed by gross and histological examination of the affected muscles. However, it is possible to measure serum glutamic-oxalacetic transaminase (SGOT) which is markedly elevated in calves and lambs with white muscle disease. The units of the enzyme per ml ranged from 295 to 3,460 for lambs and calves with white muscle disease and only 22 to 191 in normal animals (Blincoe and Dye, 1958).

Selenium levels in sheep tissues were presented in detail by Hartley, (1967). All values were expressed as mcg/gm of wet tissue for organs and mcg/ml for whole blood.

The kidney cortex and the liver are the most sensitive indicators of the Se status of the animal and the Se concentrations in these organs can provide valuable diagnostic criteria. Data by Hartley (1967) and Andrews *et al.* (1968) suggest that Se levels of less than 0.25 ppm (fresh basis) in the kidney cortex and of 0.02 ppm in the liver are indicative of marked Se deficiency in sheep. Concentrations greater than 1.0 ppm Se in the kidney cortex and 0.1 ppm in the liver are considered normal.

The concentration of Se in the blood is very responsive to changes in the Se level of the diet. Blood Se levels of 0.05 mcg/ml in sheep are considered satisfactory.

Zinc (Zn)

Zinc deficiency in grazing ruminants is not a major area problem like Cu, Co and Se. The occurrence of Zn deficiencies under practical conditions has been primarily with swine and poultry.

Under experimental conditions, many biochemical changes have been identified in severely Zn deficient animals. Those with most promising diagnostic value are plasma, serum, hair and bone (Blackmon, 1967). Zinc levels in these tissues can be markedly reduced by severe Zn deficiency, but their practical diagnostic value is limited.

Serum or plasma Zn is rapidly and markedly reduced with severely deficient diets. However, they are not greatly influenced by marginally deficient diets. Studies with calves and lambs suggest that plasma Zn may be a valuable aid, but only if values are repeatedly below 0.3 ppm (Mills *et al.*, 1967).

Hair Zn is slowly reduced when a deficient diet is fed for a period of time. However, hair Zn is affected by many factors and, under practical conditions, its diagnotic value is severely limited. Its diagnostic value has been more successful in identifying Zn deficiency in humans than in animals.

Determination of dietary Zn in combination with a response to supplemental Zn has greatest value in determining a Zn deficiency.

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CURRENT STATUS OF MINERAL RESEARCH IN LATIN AMERICA

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Nutritional inadequacies can occur in almost any area of the world and result in inefficient animal production. In Latin America, the cattle industry is often restricted by mineral deficiencies, imbalances and toxicities. This is particularly true of the minerals in which severe or borderline deficiencies sometimes occur in widely scattered areas.

Cattle in Latin America depend almost exclusively on forages to obtain mineral elements. A low intake or imbalance of the mineral elements from forages can adversely affect fertility, weight gain, milk production and in general, the health of the animals. Only rarely can Latin American forages completely provide all mineral requirements of grazing cattle. Therefore, the determination of the chemical composition of forages and mineral supplementation are important to supply cattle with adequate levels of the minerals they need.

The purpose of this paper is to compile available literature on mineral research in Latin American and Caribbean countries. Emphasis was placed on mineral studies related to grazing ruminants. The authors are aware that many worthwhile research publications are not included because these are not readily accessible to libraries and abstracting journals.

Mineral Deficiencies and Toxicities in Cattle

Mineral deficiencies or excesses are found and reported to some extent from almost all countries in Latin America and the Caribbean. Due to lack of information, it is not generally appreciated how extensive the areas affected are. Mineral problems are closely associated with geographical areas. Aliman and Hamilton (1949) gathered information from various parts of the world on locations of livestock nutritional deficiencies. Information on mineral deficiencies and toxicities for livestock in Latin America has been updated by Phillips (1956) and De Alba (1971). Recently, McDowell (1976) compiled a list of mineral deficiencies and toxicities in cattle in the developing countries of the world. Table 1 compiles our present knowledge on the occurrence of cattle mineral deficiencies and toxicities in Latin American and Caribbean countries. It includes both confirmed as well as highly suspected geographical areas of mineral deficiencies and toxicities in cattle. Obviously, this constitutes a very generalized approach with important geographical omissions inevitable but it does indicate the scope of the problem. The term "deficient or toxic area" is used to denote a region in which deficiencies or toxicities can be readily found, but it does not imply that all plants or animals in that area are, in fact, in deficient or toxic states. It does not even imply that certain elements are in short or abundant supply, because, imbalances can occur due to natural conditions or induced by unsuitable agricultural practices.

Table 1
GEOGRAPHICAL LOCATIONS OF MINERAL DEFICIENCIES OR TOXICITIES IN CATTLE OF LATIN AMERICAN AND CARIBBEAN COUNTRIES.

Required elements	
Calcium	Argentina (6, 194, 198); Brazil (176); Colombia (6, 86, 198, 217, 258); Costa Rica (20); Guatemala (105); Guyana (6, 97, 141, 198, 252); Mexico (45); Panama (198, 264); Peru (99, 100, 123, 149); Surinam (93); Venezuela (66, 85, 114, 198).
Magnesium	Argentina (21, 77, 87, 94, 179, 194, 198, 215); Brazil (229); Chile (198); Colombia (170); Costa Rica (20, 85, 86, 260); Guatemala (220); Guyana (141); Haiti (198); Honduras (198); Jamaica (198); Peru (7, 22, 255); Surinam (229); Trinidad (202); Uruguay (205).
Phosphorus	Antigua (198); Argentina (6, 18, 36, 48, 77, 90, 91, 131, 156, 165, 198, 203, 259, 263, 264); Brazil (6, 8, 16, 80, 81, 82, 95, 123, 125, 126, 147, 148, 176, 177, 178, 198, 211, 229, 239, 245, 249, 262, 269); Chile (19, 75, 86, 210); Colombia (6, 38, 39, 198, 217, 258, 261); Costa Rica (20, 41, 161, 240, 241, 257, 265); Cuba (5, 110, 133); Ecuador (198); Guatemala (105, 220); Guyana (6, 97, 141, 168, 198); Haiti (198); Honduras (198); Jamaica (198, 264); Mexico (45, 83, 85, 135, 267); Nicaragua (198); Panama (65, 207, 213, 251); Paraguay (198, 201); Peru (1, 11, 23, 25, 86, 99, 100, 101, 129, 130, 149, 150, 166, 198, 225, 236, 237, 238, 254, 255); Surinam (86, 93); Uruguay (4, 6, 86, 117, 189, 198, 227, 228); Venezuela (66, 85, 114, 116, 138, 198).
Potassium	Brazil (132, 229); Haiti (198); Panama (65); Venezuela (114).
Sodium	Brazil (14, 211, 229); Colombia (170); Guatemala (220); Panama (65); Surinam (93); Venezuela (114, 197).
Sulfur	Brazil (211); Ecuador (198).

Cobalt	Argentina (60, 62, 77, 119, 120, 121, 182, 183, 198); Brazil (8, 15, 49, 71, 72, 73, 74, 79, 85, 122, 144, 157, 164, 198, 211, 219, 239, 244, 246, 248); Colombia (104, 258); Costa Rica (85, 198); Cuba (5); El Salvador (198); Guyana (141, 198); Haiti (154, 198); Mexico (6, 198); Nicaragua (198); Peru (98, 100, 128, 149, 225, 255); Surinam (93); Uruguay (228).
Copper or molybdenum toxicity	Argentina (32, 33, 34, 35, 53, 54, 55, 58, 59, 60, 61, 77, 103, 192, 200); Brazil (122, 164, 178, 198, 211, 219, 239, 243, 244, 247, 248, 250); Colombia (209); Costa Rica (161); Cuba (5, 109, 111); Guyana (141); Haiti (154); Mexico (127); Panama (65); Peru (6, 11, 22, 25, 98, 99, 100, 128, 129, 136, 149, 150, 186, 198, 225, 235, 236, 237, 238, 255); Surinam (93, 198); Uruguay (189, 228).
Iodine	Antigua (142, 198); Argentina (189, 199); Bolivia (6, 198); Brazil (6, 56, 167, 174, 175, 198); Chile (137); Colombia (86, 258); Costa Rica (198); Ecuador (152, 198); Guatemala (198); Haiti (198); Nicaragua (198); Paraguay (198); Peru (6, 22, 152, 198, 255, 268); Uruguay (190); Worldwide (69, 70, 112, 152, 223, 224).
Iron	Brazil (124); Costa Rica (161); Panama (65).
Manganese	Argentina (198); Brazil (229); Costa Rica (161); Panama (65).
Selenium	Bahamas (93); Brazil (184); Costa Rica (161); Ecuador (44, 226); Guyana (141); Honduras (185); Mexico (139); Paraguay (42); Peru (242, 266); Uruguay (155).
Zinc	Argentina (192); Brazil (13, 132, 211); Guyana (141, 162); Costa Rica (161); Panama (65); Peru (11); Puerto Rico (151); Venezuela (197).
Toxic elements	
Fluorine	Argentina (6, 77, 198); Guyana (198); Mexico (6, 198).
Manganese	Brazil (211); Costa Rica (9, 113, 160); Peru (129, 130); Surinam (198).
Selenium	Argentina (6, 163); Brazil (153); Chile (6, 163, 198); Colombia (12, 26, 27, 214); Ecuador (198); Honduras (92); Mexico (6, 47, 106, 107, 108, 134, 146, 198, 216); Peru (6, 22, 163, 198); Puerto Rico (146); Venezuela (30, 89, 145, 146, 153, 193).

Calcium and Phosphorus

A deficiency of calcium or phosphorus or both will cause a decrease in efficiency of production and eventually may result in the fracture of skeletal bones. Either one or both elements may be deficient under grazing conditions in certain geographical areas although phosphorus is the element most likely to be deficient. Forages tend to be higher in calcium and lower in phosphorus while grains are generally lower in calcium and higher in phosphorus.

McDowell *et al.* (1977) summarized the mineral concentrations of 2615 Latin American forages (tables 2 and 3), reported in the 1974 edition of the **Latin American Tables of Feed Composition** (McDowell *et al.*, 1974). Average calcium values were reported for 1123 (42.9%) forage entries and average phosphorus values for 1129 (43.2%) forage entries (table 2). For these forages, 31.1% of the calcium values and 72.8% of the phosphorus values were 0.3% or less (table 3) which may be borderline to deficient in these elements for most classes of cattle. Phosphorus deficiency has been reported in parts of most Latin American countries (table 1). Low forage phosphorus has been found in Argentina (Kraemer and Mufarrege, 1964; Bingley *et al.*, 1965a, b; Díaz, 1965a; Culot *et al.*, 1967; Vonesch and De Riveros, 1967-1968; Villalba Palacios, 1973), Chile (Ares Rojas, 1947; Rogers, 1952), Colombia (Villamil, 1942; Vergara, 1967; Blasco Lamenca and Bohórques Ampudia, 1967, 1968; Salazar de Buckle and Medina Ramírez, 1970), Costa Rica (Arrea Baixench and Muñoz Sandoval, 1954; Velasco, 1961; Tergas, 1968; Blue and Tergas, 1969; Wills, 1971; Lang, 1974), Cuba (González, 1942; Alba Gómez *et al.*, 1967; Figueroa and Sutherland, 1969), Guatemala (Fernández *et al.*, 1971), Guyana (Duthie, 1939; Mayers, 1969; Holder, 1972), Mexico (De Alba, 1950; González, 1966; Zavala and Galván, 1973), Panama (Rosas *et al.*, 1969; Ríos Araúz, 1972; Chicco, 1972), Paraguay (Ramírez, 1954), Peru (Gómez *et al.*, 1967; Mantari, 1968; Gómez *et al.*, 1969; Echevarría *et al.*, 1970b; Kalinowski *et al.*, 1970b; Talavera, 1970), Uruguay (Fynn, 1940; Nores, 1944; Spangenberg, 1944; Spangenberg and Sanchez González, 1952) and Venezuela (Grünwald *et al.*, 1947; Chicco and French, 1959; French and Chaparro, 1960; French and Chicco, 1961b). Blood serum (plasma) phosphorus is reasonably sensitive to variations in dietary phosphorus levels and thus has value as a diagnostic tool in determining phosphorus adequacy. Reduced serum (plasma) phosphorus concentrations in cattle have been noted in Argentina (Kraemer and Mufarrege, 1964; Bingley *et al.*, 1965a), Chile (Ares Rojas, 1947), Colombia (Villamil, 1942), Costa Rica (Lang, 1974), Cuba (Figueroa and Sutherland, 1969), Mexico (Zavala and Galván, 1973), Panama (Rosas *et al.*, 1969; Chicco, 1972; Ríos Araúz, 1972) and Venezuela (Chicco and French, 1959; French and Chicco, 1961b). Compared to phosphorus inadequacies, calcium is rarely a problem in grazing cattle with the exception of cows lactating large quantities of milk or those on acid, sandy or organic soils in humid areas where the herbage consists mainly of quick-growing grasses and is devoid of legume species (Underwood, 1966). On the basis of low calcium levels in forages, deficiencies of this mineral have been reported in areas of Colombia (Vergara, 1967; Salazar de Buckle and Medina Ramírez, 1970; De Alba, 1971), Costa Rica (Arrea Baixench and Muñoz Sandoval, 1954), Guatemala (Fernández *et al.*, 1971), Guyana (Underwood, 1966; Holder, 1972), Mexico (Buller *et al.*, 1960-1961), Panama

Table 2

PERCENTAGE OF LATIN AMERICAN FORAGES (2615) ANALYZED FOR VARIOUS MINERALS[a]

Mineral	Percentage
Calcium	42.9
Cobalt	5.4
Copper	9.0
Iron	9.8
Magnesium	11.1
Manganese	11.2
Molybdenum	5.1
Phosphorus	43.2
Potassium	7.8
Sodium	5.6
Zinc	6.8
Other minerals	<1.0

[a]McDowell *et al.*, 1977.

Table 3

AVERAGE MINERAL CONCENTRATIONS OF LATIN AMERICAN FORAGES[a,b,c]

Calcium (1123 averages)	Concentrations, %	0–0.30	Over 0.30
	% of total	31.1	68.9
Cobalt (140 averages)	Concentrations, ppm	0–0.10	Over 0.10
	% of total	43.1	56.9
Copper (236 averages)	Concentrations, ppm	0–10	Over 10
	% of total	46.6	53.4
Iron (256 averages)	Concentrations, ppm	0–100	Over 100
	% of total	24.1	75.9
Magnesium (290 averages)	Concentrations, ppm	0–0.20	Over 0.20
	% of total	35.2	64.8
Manganese (293 averages)	Concentrations, ppm	0–40	Over 40
	% of total	21.0	79.0
Molybdenum (133 averages)	Concentrations, ppm	0–3	Over 3
	% of total	86.4	13.6
Phosphorus (1129 averages)	Concentrations, ppm	0–0.30	Over 0.30
	% of total	72.8	27.2
Potassium (198 averages)	Concentrations, %	0–0.80	Over 0.80
	% of total	15.1	84.9
Sodium (146 averages)	Concentrations, %	0–0.10	Over 0.10
	% of total	59.5	40.5
Zinc (177 averages)	Concentrations, ppm	0–50	Over 50
	% of total	74.6	22.4

[a]Mineral concentrations expressed as dry matter basis.

[b]The approximate requirement (National Research Council, 1970, 1971 and Agriculture Research Council, 1965) of specific minerals for cattle is as follows: Calcium (0.1[illegible]–0.60%), Cobalt (0.05–0.10 ppm), Copper (4–10 ppm), Iron (10–100 ppm), Magnesium (0.04–0.18%), Manganese (20–40 ppm), Molybdenum (0.01 ppm or less), Phosphorus (0.18–0.43%), Potassium (0.50–0.80%), Sodium (0.1%) and Zinc (10–50 ppm).

[c]McDowell *et al.*, 1975.

(Williamson and Payne, 1965), Peru (Gómez *et al.*, 1967; Echevarría *et al.*, 1970b; Kalinowski *et al.*, 1970b) and Venezuela (De Alba and Davis, 1957 and French and Chaparro, 1960). Blood serum (plasma) is practically insensitive to dietary calcium and thus has limited value in evaluating the calcium status of the animal. However, assuming that serum (plasma) values of 8 mg % calcium or less are borderline to deficient, areas in Argentina (Ovejero, 1964) and Venezuela (Chicco and French, 1959) are considered deficient in this mineral.

A widespread occurrence of massive cardiovascular calcification, "enteque seco," has been found in cattle and sheep in the Buenos Aires Province in Argentina (Carrillo and Worker, 1967). The principal clinical change in cattle and sheep has been a rapid elevation of calcium and phosphorus in the blood followed by metastatic ossification of the elastic fibers of the cardiovascular system. The symptoms are loss of weight and general condition and if animals are left in problem areas, they continue to lose condition and eventually die. An estimated 1,600,000 cattle manifest the condition annually (Paoli, 1971a, 1971b). Bingley (1964), Bingley *et al.* (1965a, 1965b), Landó *et al.* (1967, 1968) studied the calcium and phosphorus blood levels in affected animals. Although a phosphorus deficiency was noted in animals in affected areas, it was independent of the disease itself. Controlled studies with cattle, sheep and laboratory animals by Camberos and Davis (1969), Reinoso Castro (1970), Camberos and Davis (1970), Camberos (1971) and Carrillo (1973) have demonstrated that relatively small amounts of the leaves of *Solanum malacoxylon,* "duraznillo blanco," either fresh or dried, will result in a deranged calcium and phosphorus metabolism.

Probably the most important economic loss in the cattle industry in Latin America due to mineral deficiencies is the decreased reproductive efficiency resulting from a phosphorus deficiency. Improved growth and reproductive performance in cattle with phosphorus supplementation and pasture fertilization has been reported in Panama (Ríos Araúz, 1972), Uruguay (Schiersmann, 1965; De León Lora, 1963) and Peru (Echevarría *et al.*, 1974). Novoa Barreto and Trujillo Ortiz (1968-1969) and Molina *et al.* (1969) reported adequate phosphorus levels in serum in cows that presented reproductive problems.

Buller *et al.* (1960-1961), in Mexico, supplemented grazing steers with salt, salt plus cottonseed meal and salt plus cottonseed meal and bone meal. Weight gains were increased with the cottonseed meal treatment but no further improvement in weight gains were observed with bone meal supplementation. Echevarría *et al.* (1973) obtained weight gains of 0.59 kg in steers supplemented with dicalcium phosphate and 0.27 kg for controls. Esteves Cancino (1960) reported increased milk production (up to 24%) with bone meal supplementation in farms that had phosphorus deficient soils and when cows grazed *Hyparrhenia rufa.*

Information on phosphorus and calcium availability in tropical forages is limited. In some tropical forages average true digestibilities of 71.1% and 32.9% for calcium and phosphorus have been determined with sheep, respectively (Perdomo, 1975). Butterworth (1966) reported that the true mean absorption of phosphorus contained in various Venezuelan forages was 53% and the excretion of fecal endogenous phosphorus was 26.7 mg per kg liveweight.

Cobalt

Cobalt deficiencies under grazing conditions have been observed in many regions of Latin America (table 1). Marginal or deficient concentrations of cobalt in forages have been found in Argentina (Morandi, 1954, 1955), Colombia (Vergara, 1967), Guyana (Holder, 1972), Haiti (King and Price, 1966), Surinam (Dirven, 1963), Peru (Gómez *et al.*, 1967); Echevarría *et al.*, (1970b), Uruguay (Spangenberg and Sanchez González, 1952). McDowell (1975) reported that of 2615 Latin American forages analyzed for minerals, only 5.4% presented cobalt values (table 2) and 43.1% had concentrations of .10 ppm cobalt or less (table 3).

Insúa *et al.* (1964) reported values of 30 and 35 μg % cobalt in serum of normal cattle and sheep, respectively. The concentrations of cobalt in the liver has received special attention because of its possible value in diagnosing cobalt deficiency in the field. Corrêa (1957) in the state of São Paulo, Brazil found .058 and .201 ppm cobalt in liver samples of animals from deficient and adequate cobalt areas, respectively. Probably the best way of verifying the deficiency is by feeding cobalt and observing a positive response. In Colombia, cobalt supplementation significantly increased forage consumption and milk production (Estevez Cancino, 1960). Vargas (1964) in Mexico, supplemented cobalt to cattle and observed a non-significant increase in weight gain. In Costa Rica, the low intake of some tropical forages was not related to cobalt deficiency (De Alba, 1951).

Cattle and sheep grazing *Phalaris tuberosa* in areas of Argentina presented the symptoms of the disease known as "Phalaris staggers" on "Tembleque del falaris" (Gaggino *et al.*, 1963a; Gaggino and Carrillo, 1964; Gaggino and Carrillo, 1965). Cobalt supplementation has been shown to alleviate the condition (Gaggino *et al.*, 1963b and Carrillo *et al.*, 1963).

Copper and Molybdenum

Lack of copper is probably the most severe mineral limitation to grazing cattle in Latin America, with the exception of phosphorus and possibly cobalt (table 1). Copper deficiency is induced by low concentration of copper in forages. However, "conditioned" copper deficiency also occurs where normal copper concentrations in forages are inadequate due to interrelationships with molybdenum, sulfate and other factors (Russell and Duncan, 1956). Nine and 5.1% of the total Latin American forages were analyzed for copper and molybdenum, respectively (table 2). Copper averages were deficient or borderline to deficient in 46.6% of the forages, and 13.6% of 133 forage analyses had molybdenum concentrations over 3 ppm (table 3).

Low copper levels in forages have been reported in Cuba (Figueroa and Sutherland, 1968, 1970), Guyana (Holder, 1972), Haiti (King and Price, 1966), Panama (Chicco, 1972), Peru (Culot *et al.*, 1967; Gómez *et al.*, 1969; Echevarría *et al.*, 1970a, b; Kalinowski *et al.*, 1970b; Talavera, 1970), Surinam (Dirven, 1963) and Uruguay (Nores, 1944; Spangenberg and Sanchez González, 1952). Areas in Peru (Goyzueta *et al.*, 1972) and Argentina (Culot *et al.*, 1967; Pizzi *et al.*, 1964; Camberos *et al.*, 1965, 1967; Núñez, 1969) have been observed to contain normal copper levels but high molybdenum concentrations in forages. Camberos *et al.* (1965, 1967) in Argentina, reported high levels of sulfate in the water and Pizzi *et al.* (1964) high sulfate levels in forages. Regions in Peru, also have high levels of sulfate in forages (Goyzueta *et al.*, 1972). Perdomo (1975) noted that maximum intake of copper in forages by sheep (.89 mg/day/kg body weight) approached levels reported to be toxic. The overall mean true digestibility of copper in several tropical grasses was 82.6%.

A copper deficiency in the animal can be reasonably well verified by taking a liver biopsy and determining the copper content of that tissue (Carrillo and Bingley, 1964a, b). Plasma copper levels of 50 μg % or less are indicative of low liver copper levels (Claypool *et al.*, 1975). Ancasi *et al.* (1973) reported low serum copper in cattle in Peru. On the basis of copper concentration in the liver areas in Argentina (Epstein *et al.*, 1971) Costa Rica (Lang, 1974), Panama (Ammerman *et al.*, 1974) and Peru (Narvaez and Terri, 1964) are deficient in this mineral. Deficient concentrations of copper in both blood and liver have been observed in Argentina (Bingley *et al.*, 1964a, b; Camberos *et al.*, 1965; Carrillo *et al.*, 1964a, b; Bingley and Carrillo, 1966) and Cuba (Figueroa and Sutherland, 1968, 1970).

Copper deficiency and molybdenum toxicity are corrected by providing additional copper to the animal. Good results have been obtained using copper injections in Argentina (Bingley *et al.*, 1964a, b), Cuba (Figueroa and Sutherland, 1968) and Peru (Narvaez and Terri, 1964). Improved animal condition by adding copper to the diet has been observed in Cuba (Alba Gomez *et al.*, 1967) and Argentina (Camberos and Figueiras, 1969).

Tabusso (1941a, b, c; 1942 a, b, c) in Peru, observed the symptoms of "Renguera Peruana" which is a copper deficiency. The symptoms described are similar to those recognized in Australia by Bennetts and Chapman (1937) as "Enzootic ataxia" or "Lamkruis" in South Africa by Schulz *et al.* (1951). In Argentina, "Enzootic ataxia" in ovines has been described by Epstein *et al.* (1971). Barúa (1966) indicated that "Renguera Peruana" was prevented with copper supplementation.

The condition of cattle known as "Muerte Súbita" occurs in Cuba with appreciable frequency. It is characterized by collapse and death of apparently healthy animals when exposed to stress. Incidence is seasonal and restricted to specific areas. The condition resembles "Falling disease" associated with copper deficiency in Australia (Bennetts *et al.*, 1941) and in Florida (Becker *et al.*, 1965). Cases of sudden death (Muerte súbita) in cattle in a pasture in the northeast area of Camaguey (Cuba) have been studied in relation to the metabolism of copper (Figueroa and Sutherland, 1968) and of sodium, potassium, calcium, magnesium and phosphorus (Figueroa and Sutherland, 1969). No deficiency or changes in the blood and tissue levels of these minerals were found that could explain the etiology of "Muerte súbita." Valdivia *et al.* (1974) reported that in the region of Pucallpa, Peru, animals suddenly die when exposed to stress. Incidence is highest at the beginning of the rainy season. During the rainy season, 37.4% of the cattle had low levels of magnesium (>1.8 mg%) while during the dry season only 13.9% presented low serum levels of this element. The authors feel that the low serum magnesium values alone may not cause "Muerte súbita" and are studying the mineral status of plants and animals as well as other factors, such as toxic substances that may cause this condition.

Sodium and Chlorine

In most circumstances, all cattle whether grazing or in dry lot require supplemental dietary sodium. This requirement is generally met by supplying sodium chloride or "common salt" as 0.5 percent of the total ration for full-fed cattle or as a free-choice supplement for cattle on pasture on range. Sodium appears to be the essential nutrient in salt and evidence of a naturally-occurring dietary deficiency of chlorine, as distinct from sodium has not been established (Underwood, 1966).

The National Research Council (1970) recommends 0.1% sodium for cattle. About 60% of 146 forage averages in the 1974 **Latin American Table of Feed Composition** (McDowell *et al.*, 1977) contained mean sodium values of 0.1% or less (table 3). Natural forages low in sodium have been reported in Colombia (McCormick, 1966), Panama (Chicco, 1972), Surinam (Dirven, 1963) and Venezuela (French and Chaparro, 1960; Perdomo, 1975). Dirven (1963) and Underwood (1966) suggest that under tropical or hot semi-arid conditions where large losses of water and sodium occur in sweat, the sodium requirement may be higher.

Salt has been incorporated in self-feeding protein and/or energy supplements to regulate intake and has been demonstrated to be practical for grazing steers (Chicco *et al.*, 1971).

Iodine

Iodine deficiency is one of the most prevalent deficiency diseases that has been shown to occur in almost every country of Latin America. A list of iodine deficiency reports in man and farm animals as endemic goiter is presented in table 1. Follis (1966) and Kelly and Snedden (1960) have illustrated in a map the most prevalent areas of endemic goiter in Latin America.

Iodine deficiency in domestic animals has been observed in regions of Antigua (Hutson, 1952), Argentina (Mazzocco and Arias Aranda, 1929; Piazza, 1937), Chile (Gruebler, 1951), Colombia (Vergara, 1967; De Alba, 1971), Ecuador (Kelly and Snedden, 1960), French Guyana (Hidiroglou and Prevost, 1958) and Peru (Zuñiga, 1960; Kelly and Snedden,

1960; Barúa, 1966; Valdivia *et al.*, 1974). Nores and Rossi Stajano (1948) reported a possible iodine deficiency in forages in areas of Uruguay. Probably, the most complete and detailed studies of iodine deficiency as goiter in domestic animals observed in Latin America have been reported in Brazil (Martins, 1946; Megale, 1947, 1949 and Cardim, 1948).

The widespread use of iodized salt and iodine additions to mineral mixtures has reduced significantly the incidence of iodine deficiency in Latin America.

Magnesium

It appears that simple, uncomplicated magnesium deficiency in cattle rarely occurs under normal feeding programs. Countries where forages low in magnesium have been reported include Colombia (McCormick, 1966) and Costa Rica (De Alba and Davis, 1957; Arrea Baixench and Muñoz Sandoval, 1954). Slightly over one-third of 290 Latin American forages contained 0.2% magnesium or less (table 3).

A condition in cattle referred to as "Grass tetany," "Grass staggers" and perhaps other terms has been related to abnormal magnesium metabolism. It is a seasonal problem; and typical cases involve cattle grazing small grain, winter pasture. Latin American countries where magnesium tetany is encountered are listed in table 1. Grass tetany or hypomagnesemia tetany has been studied extensively in Argentina where a considerable number of animals die annually due to this condition (Ovejero, 1964; Culot and Fernández Tuñón, 1967; Ruksan *et al.*, 1967; De La Fuente, 1968; Barberis and Mizuno, 1969; Mizuno and Barberis, 1969). Hypomagnesemia tetany responds favorably to magnesium therapy. In Peru, magnesium deficient cattle are treated successfully with intravenous or oral administrations of magnesium sulfate (Barúa, 1966; Alvarado *et al.*, 1970).

Selenium

Most of the information available from Latin America on selenium is related with toxicity. Selenium poisoning is often associated with consumption of selenium accumulator plants (i.e., *Astragalus spp.*) which may contain up to several thousands ppm selenium. Table 1 presents Latin American countries where selenosis is encountered and includes Argentina (Lemley, 1943), Chile (Lemley, 1943), Colombia (Ancizar Sordo, 1947; Benavides and Silva Mojica, 1965), Mexico (Byers, 1937; Figueroa, 1938; Figueroa, 1942a, b), Peru (Lemley, 1943; Barúa, 1966). Benavides and Silva Mojica (1965) described the regions and economic importance of selenium toxicity in Colombia. Based on the analyses of feeds over 3 ppm selenium, there are reported seleniferous zones in Venezuela and Puerto Rico (Jaffé *et al.*, 1967, 1969; Bermudez de Cruces, 1967; De Mondragón and Jaffé, 1971).

The concept of selenium as an essential element is relatively recent and just a few countries in Latin America have been reported to have deficient areas. Latin American countries with confirmed or suspected selenium deficiencies are listed in table 1. Lang (1974) reported borderline to deficient selenium concentrations in 33% of the livers analyzed from beef cattle slaughtered in Guanacaste, Costa Rica. Low selenium concentrations have been reported in forages in areas of Chihuahua, Mexico (Gutierrez *et al.*, 1974) and Guyana (Holder, 1972). In Peru, Terry (1964) reported a condition in ruminants resembling selenium vitamin E deficiency. When the animals were treated with selenium vitamin E injections, about 70% recovered from the condition.

According to Underwood (1971), the total areas of the world affected by selenium deficiency are far greater than those afflicted with selenium excess.

Fluorine

Reported incidences of fluorosis in Latin American countries are listed in table 1. Culot *et al.* (1967) reported fluorosis in grazing cattle in the districts of Tapalgue, Azul and Tandil, Argentina. Animals presented development of exostoses of the long bones with thickening of joints. Teeth were modified in shape and color, becoming mottled and pitted often with the pulp cavities being exposed. The cases of fluorosis were related to the high content of fluorine in the water (2 to 6 ppm). De Alba (1971) indicated that persons from Aguascalientes and Altos de Jalisco, Mexico have mottled teeth, but this condition has not been observed in cattle.

Manganese, Zinc, Iron, Potassium and Sulfur

Concentrations of manganese, zinc, iron, potassium and sulfur available from forages are generally adequate to meet cattle requirements under grazing conditions. However, decreased levels in forages and cattle deficiencies have been reported for some of these minerals in restricted areas of Latin America.

Of 2615 Latin American forages analyzed for minerals, only 11.2, 6.8, 9.8 and 7.6% reported analysis of manganese, zinc, iron and potassium, respectively (table 2). Borderline or deficient concentrations of manganese, zinc, iron and potassium were found in 21.0, 74.6, 24.1 and 15.1% of the total Latin American forages analyzed for these elements, respectively (table 3). Manganese, zinc, iron, potassium and sulfur deficiencies confirmed or suspected in Latin American countries are listed in table 1. Average true digestibility for potassium and iron in *Digitaria decumbens, Panicum maximum, Cynodon plectostachyum* and *Brachiaria decumbens* were 87.3 and 57.8%, respectively (Perdomo, 1975).

Lang (1974) reported that approximately 21, 63, and 24% of the total cattle livers examined in western Costa Rica were borderline to deficient in iron, manganese and zinc, respectively.

Forages containing low levels of manganese have been reported in Panama (Chicco, 1972). In a region of Costa Rica, characterized by volcanic soils, high manganese in forages have been observed which resulted in low reproductive rates of cattle (Fonseca and Davis, 1968; Amadeo Macia, 1971; Lang, 1971). In Peru, high manganese levels in forages have been reported by Gómez *et al.* (1967, 1969).

Legg and Sears (1960) found parakeratosis skin disorder in cattle of Guyana which were consuming forage containing 18 to 42 ppm zinc. Low levels of serum zinc were noted in cattle from Andahuaylas, Huancayo, Arequipa and Oxapampa, Peru. (Ancasi *et al.*, 1973). Latin American countries where forages contain low levels of zinc include Guyana (Legg and Sears, 1960; Holder, 1972), Panama (Chicco, 1972) and Venezuela (Perdomo, 1975).

Iron deficiency is of practical concern in grazing cattle in circumstances involving blood loss or parasitic infestation. Forage analyses from Panama indicate adequate iron concentrations to meet grazing cattle needs (Blue *et al.*, 1969). Another report from Panama suggests that *Hyparrhenia rufa* in certain locations is marginal in iron in relation to cattle requirements (Chicco, 1972). The author points out, however, that animals may supplement their intake with iron from soil.

French and Chicco (1961a) in Venezuela, found that 14.5, 5.7 and 15.2% of the cows, bulls and calves examined had hemoglobin levels of less than 8 g per 100 ml of blood, respectively. Highest deficiencies were found in the states of Táchira and Mérida. Newborn calves receiving iron injections had increased hemoglobin concentrations and slightly higher gains (Acosta and Waugh, 1967; Botero and Franco, 1972).

Forages containing low level of potassium have been reported in Panama (Chicco, 1972), Venezuela (French and Chaparro, 1960) and Brazil (Gomide *et al.*, 1969).

Sulfur may be lacking to Ecuador livestock as has been indicated by improvement observed following its administration in sulfurized salt blocks (Phillips, 1956).

Mineral Supplementation

Direct administration of minerals to cattle is the most economical method of supplementation. Cunha (1971) noted that self feeding trace mineralized salt is low cost insurance against deficiencies.

Table 4 presents a survey of mineral supplements supplied in cattle ranches of the north coast of Colombia (Rivas Ríos, 1974). Sixty-six percent of the farms surveyed provided mineralized salt to cattle, 30% supplemented only salt and the remaining 4% did not provide any type of mineral supplement. Eighty-one percent of the farms in the coast of Bolívar supplemented mineralized salt while the regions of savannahs of Bolívar (south), Lower Sinú and César River Valley had the lowest percentage (57) of farms that supplemented mineralized salt. Common salt was widely used as a mineral supplement in these areas.

In Colombia, Salazar and Waugh (1967) reported that a control group without any mineral supplement obtained better daily gains than heifers on pasture supplemented with salt. Gains were highest, however, on animals receiving a supplemental mineral mixture. In the native savannahs of Colombia, large growth responses were obtained by complete mineral supplementation but only in the rainy season. In the dry season, there was no difference between the supplemented and non-supplemented herds. The most dramatic improvement was obtained in breeding performance. Average conception in four months for the herds receiving complete mineral supplementation was 70% whereas it was 24% for the herds not receiving minerals (Anonymous, 1973). Improved weight gains and reproductive performance with mineral supplementation have been reported in Paraguay by Romero *et al.* (1973), Cattebeke *et al.* (1973) and Boggino *et al.* (1973). Improved weight gains with mineral supplementation have also been reported in Peru by Echevarría *et al.* (1973).

Table 4
MINERAL SUPPLEMENTS SUPPLIED BY GEOGRAPHICAL AREA ON CATTLE RANCHES IN THE NORTH COAST OF COLOMBIA[a]

Geographical areas	Common salt		Mineralized salt		No supplement		Total	
	No. of ranches	%	No. of ranches	%	No. of ranches	%	No. of ranches	%
Middle Sinú	13	42	18	58	0	0	31	100
Savannahs of Bolívar (south)	18	43	25	57	0	0	43	100
Lower Sinú	13	37	20	57	2	6	35	100
Mompós-Magdalena River Depression	13	37	22	60	0	0	35	100
Savannahs of Bolívar (north and central)	13	21	49	78	1	1	63	100
Coast of Bolívar	5	11	39	81	4	8	48	100
Coast of Atlántico	6	17	21	60	8	23	35	100
Lower Magdalena	26	31	56	66	3	3	85	100
Cesar River Valley	35	42	48	57	0	0	83	100
Gulf of Morrosquillo	5	17	23	79	1	4	29	100
Total	147	30	321	66	19	4	487	100

[a]Rivas Rios, 1974.

Ríos (1974) measured mineral consumption by heifers, yearling bulls and pregnant and open cows under grazing conditions. Average consumptions were 27, 35, 36 and 44 g per animal per day, respectively. It was noted that maximum mineral intake was obtained during the rainy season. Holder (1972) reported average mineral consumption of 81 and 74 g per head per day for bulls and heifers grazing pangola grass, respectively.

Agency for International Development–University of Florida Mineral Project

The department of Animal Science is engaged in a contract with the Agency for International Development entitled "Determination of Mineral Deficiencies and Toxicities for Cattle in Latin America." The research proposal has four principal objectives: 1) To experimentally determine the locations of mineral deficiencies, adequacies and toxicities in selected areas of Latin America where grazing livestock predominate, 2) To establish, by experimentation, the biological response and economic benefit of mineral supplementation to grazing animals, 3) To experimentally evaluate methods of mineral feeding and supplementation for grazing cattle, and 4) To publish and distribute information in order to stimulate the widespread use of mineral supplements. Previous research on mineral concentrations of soils, forages and animal tissues in addition to reports of clinical signs of plant and animal mineral deficiencies are evaluated to determine the areas where mineral deficiencies or toxicities are likely.

The research proposal can conveniently be divided into a (1) Tissue Collection and Analysis Phase and (2) Mineral Supplementation Phase. Animal and plant tissues obtained from specific cattle ranches will be analyzed for mineral concentrations. On the basis of the tissue concentration of each mineral, specific mineral deficiencies and toxicities will be established for selected cattle producing regions. Information from a number of ranches in many areas will be compiled and, by use of a mapping technique, research data will provide evidence of mineral deficiencies and toxicities in large cattle grazing areas. During the mineral supplementation phase, the production and economic benefits of mineral supplementation to grazing cattle will be clearly established. The combined mineral studies utilizing a tissue collection and analysis phase and a mineral supplementation phase will make it possible to obtain a comprehensive impression about the occurrence of mineral deficiencies, toxicities and imbalances in grazing livestock and they will also provide the methodology for improving cattle production through improved mineral nutrition.

At the present, research is being initiated in several Latin American countries which include Brazil, Colombia, Costa Rica, Guatemala, Ecuador and Venezuela.

Summary

An attempt is made to review mineral research data from Latin America. The most widespread mineral deficiency for grazing livestock is that of phosphorus. Calcium deficiencies are rare under grazing conditions. This fact is especially important since many old texts used in Latin America have given a greater importance to calcium than experimental evidence indicates.

Copper and cobalt deficient areas are likely to extend over wide areas of Latin America, but their limits are hard to define at present. Inadequacies of magnesium, sodium, iodine, selenium and zinc and toxicities of molybdenum, selenium, and fluorine are also encountered in areas of Latin America.

Forages rarely provide all the mineral requirements of grazing cattle, therefore, it is a good general practice to provide adequate mineral mixtures to assure the necessary intake of the elements needed.

The University of Florida, with assistance of a grant from the United States Agency for International Development, is cooperating with Latin American Institutions to initiate and establish mineral research.

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DISEASES CAUSED BY MINERAL DEFICIENCIES IN CATTLE RAISED UNDER RANGE CONDITIONS IN BRAZIL

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In cattle kept under range conditions are known to occur deficiencies of phosphorus, magnesium, sodium, chlorine, copper, cobalt, iodine, and selenium. The few references on the occurrence of other deficiencies, especially manganese and zinc in some countries, need further confirmation.

Mineral deficiencies may vary from severe deficiencies, with more or less characteristic disorders, to slight deficiencies with non-specific symptoms, such as slow development, low fertility, low body weight at slaughter and low milk yield. They are confined to certain areas. When they are severe, they may be responsible for the general poverty which exists in these regions. Mild deficiencies may also cause serious economic loss as they reduce the productivity of the animals and provide an obstacle to improvement of the cattle population over large areas.

Diagnosis of Diseases Caused by Mineral Deficiencies in Cattle Raised under Range Conditions.

In diagnosing mineral deficiencies, as in the diagnosis of any disease, it is necessary to study the different manifestations of the condition, so that conclusions may be drawn from all the available data.

In most of the more severe mineral deficiencies the history of the herd may give an indication of a specific deficiency. In some mineral deficiencies, clinical examination of the cattle reveals characteristic manifestations. Post-mortem examinations and histopathological studies also help in the establishment of the diagnosis. Phosphorus deficiency can be safely diagnosed by the very characteristic osteophagia, the severity of which may indicate the degree of the deficiency, and by the occurrence of rickets and osteomalacia. Iodine deficiency can easily be diagnosed by the observation of endemic goitre in calves. The definitive diagnosis of the other mineral deficiencies has to be confirmed by chemical analysis and/or experimentation. Chemical determinations must be done on tissues and body fluids of animals from the region involved. Information on the mineral levels in soil and pasture are useful in aiding the investigation of mineral deficiencies in animals. Analyses of animal material will allow the direct identification of the existing deficiencies with the use of relatively few samples. The results of pasture and soil analyses generally are not so easy to interpret as there are many factors in the soil and in the pasture which may influence the assimilation of mineral elements by the plant and the animal. Beside this, in many regions the collection of representative pasture samples of material actually eaten by the animals is difficult or even impossible, and moreover the mineral content of pasture samples varies considerably according to the growing stage of the plants. There is also the fact that pasture samples are variably contaminated by soil particles.

Experiments with mineral supplementation may seem to be the easiest method of diagnosing a mineral deficiency, but often it is difficult to conduct well performed experiments in cattle under range conditions, because of many natural limitations in deficient areas.

Studies on Mineral Deficiencies Affecting Range Cattle in Brazil

In Brazil, mineral deficiencies were suspected as the cause of several diseases of unknown etiology in cattle. In many of these diseases mineral deficiency have been confirmed. In this review the diseases due to mineral deficiencies are grouped together under the mineral involved. In the etiology of some of the diseases there is more than one mineral involved. These conditions are included under the mineral which is responsible for the most conspicuous symptoms observed in that disease.

For the purpose of this review the results of chemical analyses of plant and soil samples made independently of studies of possible mineral deficiency diseases in cattle are omitted, because this isolated data is difficult to interpret.

Phosphorus Deficiency. Giovine (1943) made a clinical study of phosphorus deficiency in cattle in Minas Gerais. He concluded that phosphorus deficiency affected a great number of cattle in different areas, mainly in the northern, central, and western regions of this state. The more severely affected animals were cows after the first and second calving. The clinical signs were depraved appetite, manifested mainly by osteophagia, skeletal defects ("caranga"), emaciation, decreased milk yield, temporary supression of estrus, decreased fertility, and slow growth of the calves. There was a significant decrease in serum inorganic phosphorus levels while calcium levels were normal or slightly decreased. Administration of phosphorus supplements resulted in a clinical recovery.

In a supplementary paper, Menicucci (1943) gave the results of phosphorus determinations on blood samples (probably serum) from cattle in Minas Gerais. He considered 3.5 mg of inorganic P/100 ml of blood (serum) as a normal value, and found that only 39.6% of the animals were normal, and that all the other animals suffered from varying degrees of phosphorus deficiency. Unfortunately the author did not give information on the season of the year when the blood samples were taken, the procedure of sampling, or the age and sex of the animals sampled. One hundred and forty-three soil analyses were made and these showed a maximum value of 0.41% of P_2O_5, just traces as a minimum value, and a mean of 0.09% of P_2O_5. Based on data obtained from other countries suggesting that phosphorus deficiency occurs in cattle when the soil values are below 0.27% of P_2O_5, and that there is no such deficiency when the values are above 0.55% of P_2O_5, he concluded that phosphorus deficiency probably occurs in most of the cattle population in Minas Gerais.

Villares and Silva (1956), between 1951 to 1953, determined during the various months of the year, the inorganic phosphorus content of whole blood from 37 Guzerá cows held on semi-range conditions at the Fazenda Experimental de Criação, Sertãzinho, São Paulo. The average inorganic phosphorus content was 4.17 (± 1.56) mg per 100 ml of blood (694 analyses). This annual average is almost at the lower limit of the normal physiological variation. The inorganic phosphorus content varied during the year and clearly showed a rhythmical curve which had a normal segment with an average of 5.19 (± 1.11) mg and a deficient segment with an average of 3.30 (± 0.54) mg. The 1.89 (± 0.54) mg difference between these means is highly significant and indicates a periodic phosphorus deficiency. The phosphorus deficient period corresponded to the dry season and the period of adequate phosphorus to the wet season. Lactating cows had phosphorus deficiency both in the dry and rainy seasons, with blood values of 2.58 (± 0.89) and 3.30 (± 1.03) mg of inorganic phosphorus, but at the end of lactation, phosphorus levels rapidly rose to normal. The non-milking cows were deficient only during the dry season.

Bauer *et al.* (1964), studying in the county of Vitória do Palmar, Rio Grande do Sul, a disease with neuromuscular signs in cattle which had allotrophagia, including osteophagia—which may be botulism—performed phosphorus analyses on blood serum, and copper and cobalt determinations on liver samples of cattle from this region. All phosphorus values were low; of the 40 samples analyzed, 77.5% had values below 4.0 mg of inorganic P/100 ml of blood serum. From six liver samples analyzed, four were deficient or marginally deficient for copper and three marginally deficient for cobalt.

Grunert and Santiago (1969) studied the influence of supplemental bone meal on the fertility in beef cattle in Rio Grande do Sul. The test was performed on 7,590 heifers and cows grazing on pasture. A total of 2,511 control animals received only salt in addition to pasture. An increase in the conception rate was noted, especially in lactating cows. In the control group only 25.6% of the lactating cows conceived, whereas 33.4% of all cows suckling a calf became pregnant after a small addition of bone meal and 47.3% after a larger amount. Non-lactating animals showed an improvement of 6.0% in fertility when the proportion of bone meal was more than 50% in the bone meal—salt mixture. It was not possible to demonstrate any influence of the bone meal on the fertility of the heifers.

Tokarnia *et al.* (1970a) studied a disease of cattle which occurs in the "chapadas" or "agreste" (cerrado) regions of Piauí, in northwestern Brazil. The clinical signs of the disease are stunted growth, rough hair-coat, low carcass weight at slaughter, reduced calf production, low milk yield, a weak and deformed skeleton with enlarged joints, lordosis and frequent bone fractures; the animals show ostephagia which causes choking of the mouth and throat. "Entreva" is the popular term for the most severe form of the disease, in which the skeletal lesions are so pronounced that the animal has a stiff gait. The main post-mortem findings were softening of bones, which could be broken more easily than normal bones and sometimes could even be cut with a knife. On histological examination, rickets and osteomalacia were diagnosed. Calcium analyses on blood serum from 51 bovines were normal. The inorganic phosphorus values were low. Twenty-five bovines had less than 4.0 mg inorganic P/100 ml of blood serum, in 14 others, the phosphorus values were between 4.0 and 5.0 mg, and in only 12 animals were the values above 5.0 mg. The blood samples were taken in March, during the rainy season when there was plenty of green pasture. Based on the history, the clinical picture, post-mortem findings, histopathological changes and inorganic phosphorus determinations on the blood serum, a diagnosis of phosphorus deficiency was made. Secondarily to phosphorus deficiency, there is the occurrence of epizootic botulism (Tokarnia *et al.*, 1970b). In addition, copper deficiency was also found in this region; from 26 liver samples, collected from cattle and sheep, it was found that 9 were deficient[1] and 8 marginally deficient in copper, while only one marginally deficient cobalt value was found (Tokarnia *et al.*, 1971).

Guimarães and Nascimento (1971) made an experimental study in beef cattle on the Island of Marajó, Pará, to determine the effects of common salt, phosphorus, calcium, copper, and cobalt on the calving percentage. Three herds, of about 50 cows and 2 bulls each, received a mineral supplementation which consisted for the first herd of common salt, bone meal, copper sulphate and cobalt sulphate; for the second herd of common salt and bone meal; and for the third herd of just common salt. A fourth herd did not receive any supplementation. The grazing was continuous. The

[1] In the papers published by Tokarnia and co-workers the following criteria, based on data found in the literature (Tokarnia *et al.*, 1968), was adopted in the interpretation of analytical data of liver copper and cobalt values. Liver copper values from 0 to 50 parts of the element per million (ppm) of dry matter indicate deficiency, from 50 to 100 ppm marginal deficiency, and above 100 ppm adequate copper in cattle and sheep of all ages. Liver cobalt values below 0.05 ppm indicate deficiency, from 0.05 to 0.12 ppm marginal deficiency, and above 0.12 ppm adequate cobalt in cattle, 9 months and older, and in sheep, 3 months and older, below 0.06 ppm indicate deficiency, from 0.06 to 0.10 ppm marginal deficiency, and above 0.10 ppm adequate cobalt.

calving percentage in these four herds was respectively 68.00, 72.22, 54.90, 49.06. The first two herds were significantly superior to the control group; the third herd, which received just common salt, did not show any significant difference when compared with the control herd. It was concluded that copper, cobalt and common salt did not significantly affect the calving percentage. Bone meal was the responsible factor for the increase in the calving percentage in the area.

Dayrell *et al.* (1973) studied young male cattle kept under range conditions in four "cerrado" areas of Brasília (Sobradinho, Planaltina, Formosa and Luziânia) for a period of 14 to 21 months. Serum inorganic phosphorus values were determined at monthly intervals during this period. Analyses of phosphorus levels in grass samples of *Mellinis minutiflora, Hyparrhenia rufa,* and *Aristida sp.*, and soil analyses were also carried out. The results of the serum inorganic phosphorus estimations from cattle in the areas of Sobradinho and Planaltina were in agreement with the herd histories, which indicated that the Sobradinho area was not deficient in phosphorus. But the Planaltina area was deficient. In the areas of Formosa and Luziânia, the serum inorganic phosphorus levels were intermediate, and were in agreement with the herd histories, which indicated a moderate phosphorus deficiency. There was a significant correlation between the phosphorus values in the blood serum and the values of the three grass species with the exception of the area where there was the most severe phosphorus deficiency. There was a correlation between the phosphorus values of the soil and the yearly average serum inorganic phosphorus value of the cattle from all four areas. No correlation was found between the rainfall and inorganic phosphorus levels in the blood serum in phosphorus deficient areas, but in areas where there was not a phophorus deficiency there was a close correlation between increased rainfall and increased inorganic phosphorus in the blood serum.

Clinical pictures of severe phosphorus deficiency with prone-eyed osteophagia were observed in western and southern Minas Gerais (Megale, 1949a, b), in the "fronteira" and "serra" areas of Rio Grande do Sul (Santos and Pereira Neto 1963, and personal observations), on the "lavrados" of the Roraima Territory, on the "campos altos" of Marajó Island, on the "chapadas" of Maranhão and northern Goiás, on the "cerrados" of northern Mato Grosso, on the sandy soils of the eastern pantanal and in certain other areas in southern Mato Grosso, in various regions of Bahia, in the region of Linhares in the State of Espírito Santo and in areas of the northern part of the State of Rio de Janeiro; in southern Maranhão and northern Goiás, secondary epizootic botulism was diagnosed, and in some of the southern Mato Grosso areas, the disease also appears to occur (personal observations).

Iodine Deficiency. Megale (1949b) described cases of congenital goitre in calves, in western and southern Minas Gerais. Histopathological examinations revealed a diffuse parenchymatous goitre. The administration of mineral mixtures containing iodine to the cows prevented the birth of goitrous calves. Calves treated with iodine recovered.

Iodine deficiency in cattle was also diagnosed on observation of goitre in newborn calves in many areas of northern and southern Mato Grosso, and in southern Goiás (personal observations).

Cobalt Deficiency. Corrêa (1955, 1957) studied a disease in cattle with the popular names "peste de secar," "sablose," "Mal da areia," "mal das cabeceiras," and "mal do colete" in the State of São Paulo. It was characterized by lack of appetite, slow and progressive loss of condition, cachexia, lethargy, pica, anemia, long and rough haircoat, decreased milk yield and low fertility. It occurs more frequently from December to May, i.e., during the rainy reason. Liver samples from 22 healthy cattle from an area considered to be sufficient in minerals and from 20 sick cattle from a deficient area, were analyzed for cobalt and copper. In the healthy animals; the average value for cobalt was 0.201 (± 0.016) and for copper 198.24 (± 23.72) parts per million of dry matter. In the sick animals, the average value for cobalt was 0.058 (± 0.006) and for copper 175.00 (± 24.07) ppm. The cobalt values of the sick animals indicated cobalt deficiency. Analyses of pasture and soil samples confirmed the cobalt deficiency. In pasture samples from areas where the disease does not occur average levels of cobalt were 0.334 (± 0.030) and of copper 14.36 (± 0.96) ppm of dry matter, whereas in samples from areas where the disease occurs, the values were 0.046 (± 0.005) and 14.23 (± 2.23) respectively. Soil samples gave average values of 20.37 (± 3.16) and 22.77 (± 2.98) ppm of dry matter for cobalt and copper respectively in areas where the disease does not occur, whereas in areas where it occurs the values were 0.797 (± 0.246) and 18.25 (± 1.05) ppm.

"Mal do fastio," a disease of cattle which occurs in the sugar cane plantation area of the Serra da Ibiapaba, in Ceará, was studied (Tokarnia *et al.*, 1961, 1968). Every year during the rainy season all the cattle are taken to the lower "sertão" area, and are taken back to the Serra only at the beginning of the dry season. If this is not done, the animals are affected by "mal do fastio." This happened in 1958, when because of severe drought in all northeastern Brazil, and especially in the "sertão," very few cattle could be moved down from the Serra. Five sick and three healthy animals which had been in the region for over a year, were examined. The signs of the disease were lack of appetite, rough body hair coat, dry feces, loss of condition, anemia and finally death. Post-mortem examinations and histopathologic studies revealed lipoidosis of the liver and hemosiderosis of the spleen and kidney. Liver cobalt values of four animals with "mal do fastio" were deficient, and in a fifth marginally deficient. Liver copper was deficient in one of them, and marginally deficient in two others, and normal in two. In two of the three healthy animals liver cobalt was deficient and in one there was a marginally deficient copper value. It was concluded from the history, clinical picture, post-mortem and histopathological findings and from liver analyses, that "mal do fastio" is a disease primarily due to cobalt deficiency and that there is also copper deficiency.

A cattle disease causing mortality in the forest area of the region of Macapá, in Amapá, was studied and the main characteristics of the diseased animals were their poor condition and lack of appetite. (Tokarnia *et al.*, 1971). Liver cobalt values were deficient in one and marginally deficient in four animals, liver copper values were deficient in three, marginally deficient in two and normal in one animal. It was concluded that there is a combined cobalt and copper deficiency.

Tokarnia *et al.* (1971) studied a chronic disease of cattle, which occurs north of the Doce River, in Espírito Santo, and which is called "toque" or "toca." The disease is observed when animals stay for a period longer than 60 to 180 days on certain pastures. Sick animals isolate themselves from the rest of the herd, are apathetic, show loss of appetite, rough haircoat, dry feces, and they loose body condition. If the animals are not moved from the pasture, they will die; but if they are taken to a pasture where the disease does not occur, the animals will recover quickly. Clinical examination of three bovines affected by "toque" revealed poor condition and rough haircoat. At post-mortem and histopathological examinations liver lipoidosis was found in one animal. Cobalt values in liver samples from two animals were deficient and marginally deficient in a third; copper values were normal. In four animals from the same region, not affected by "toque," the liver cobalt values were deficient in one and marginally deficient in a second; copper values were only marginally deficient in one animal. It was concluded that "toque" or "toca" is a disease primarily caused by cobalt deficiency.

Diseases called "toque" or "toca," which have the same or similar history as a condition with the same names identified as cobalt deficiency in northern Espírito Santo (Tokarnia *et al.*, 1971), occur in other regions of Brazil; in the São Francisco river valley in western Bahia (Macedo, 1952), in the Urucuí and Gurguéia river valleys in southeastern Piauí (Iglesias, 1951) and in the "chapada" regions of Maranhão (Tokarnia *et al.*, 1968). There is also an indication of cobalt deficiency in the Bragança region in Pará (Soares, 1963), and in several areas of northern and southern Mato Grosso (personal observations).

Copper Deficiency. Tokarnia *et al.* (1960, 1968) investigated the cause of a poor condition of cattle, and specifically of a disease called "ronca" (roaring disease), in the Parnaíba delta, in Piauí and Maranhão. The animals of this region were undernourished and had rough and often scarce body haircoat, which in some animals seemed bleached. Most of the animals were easily excitable, many had diarrhea which was due neither to lush pasture growth at the beginning of the rainy season nor to worm infestation. The animals with "ronca" had in addition a noisy inspiration. A normocytic and hypochromic anemia was found in both sick and apparently healthy animals. Post-mortem examinations and histopathological studies revealed haemosiderosis in the livers of all animals with "ronca" and in the spleen and lymph nodes of most of them. In animals not affected by "ronca" hemosiderosis of the spleen and lymph nodes was rare and was not seen in the liver. Liver copper values were deficient in three animals with "ronca" and in five others not affected by "ronca" from which liver samples were collected. Liver cobalt values were normal with the exception of one which was marginally deficient. It was conicuded that there was a copper deficiency in the Parnaiba delta, but the simultaneous occurrence of other deficiencies or factors could not be excluded, especially as no explanation could be found for the roaring.

Near the coast of Piauí, on sandy soils, there occurs a disease in newborn or young lambs which is locally known as "escancho" (Tokarnia *et al.*, 1966, 1968). Incoordination of the hind quarters is the most characteristic symptom. In severe cases paraplegia is observed. The disease is non-febrile, the appetite remains normal, and the condition may be either acute or chronic. Most of the affected lambs die. In nine animals post-mortem examinations revealed no abnormalities but histopathological studies revealed demyelination of the spinal cord. Copper determinations on liver samples revealed deficient values in all nine animals, whereas cobalt values were normal. It was concluded that "escancho" is identical to "enzootic ataxia," a disease associated with copper deficiency, described in other countries.

Sutmoller *et al.* (1966) found low liver copper values in cattle from the Marajo Island, the coast of Amapa Territory and the low-lands of the Lower Amazon Region.

Nine of ten liver samples collected from cattle on the Marajó Island, Pará, had deficient values for copper. Cobalt values were all normal. (Tokarnia *et al.*, 1968).

In the coastal area of the northern part of the State of Rio de Janeiro, the same roaring disease of cattle as occurs in the Parnaíba delta, is observed. The clinical data, post-mortem and histopathological findings are identical. In two animals affected by the disease the liver copper values were deficient, and in one of them a deficient cobalt value was also found. Another bovine, not affected by the disease, and one sheep from that area also had deficient copper values. (Tokarnia *et al.*, 1971).

It was thought that the cattle should be in better condition in the southern part of the State of Rio de Janeiro than they actually were, so a mineral deficiency was suspected. Seven deficient and seven marginally deficient liver copper values out of a total of 35 animals examined were obtained; as for cobalt there were only three marginally deficient values (Tokarnia *et al.*, 1971).

In northern Santa Catarina, Tokarnia *et al.* (1971) found deficient copper values in 12 of 14 bovines examined. The cobalt values were all normal. These animals were from higher areas between the Serra do Mar and the Atlantic coast. Here, "enzootic hematuria" and carcinomas of the upper digestive tract of cattle are prevalent and overshadow all other problems (Tokarnia *et al.*, 1969). In southern Santa Catarina between the Serra do Mar and the Atlantic, where there is

Fig. 1. Cobalt (Co), copper (Cu), iodine (I), and phosphorus (P) deficiencies in cattle in Brazil; not confirmed cobalt deficiency (Co?).

no "enzootic hematuria" but where cases of carcinomas of the upper digestive tract occur, there is a disease characterized by loss of condition and weakness. Two animals examined were cachetic and anemic. Liver copper values were deficient in both, whereas the cobalt values were normal. In another animal, an apparently healthy sheep, the liver copper value was deficient, and in two bovines, one was marginally deficient and the other normal. Liver cobalt values were normal with the exception of one which was marginally deficient.

In the region of Rondonópolis, in northern Mato Grasso, there is a chronic disease called "cara inchada." It affects up to 50% of the calves around weaning time and mineral deficiency was thought to be the cause. There were periodontal lesions, particularly in the premolar regions. Liver copper values from six affected calves were deficient, whereas cobalt values were normal. The cause of the disease, and the role of copper deficiency in its pathogenesis are unknown. (Döbereiner *et al.*, 1974; Tokarnia *et al.*, 1971).

Sodium and Chlorine Deficiencies. Imai *et al.* (1965/66) did not observe any significant difference in growth rate between eight heifers with access to salt supplementation and eight others without this supplement during 851 days on *Pannicum maximum* pasture at the Experimental Station of Sertaozinho, São Paulo.

Discussion

From the existing studies on diseases caused by mineral deficiencies in cattle in Brazil (Fig. 1), one can conclude that mineral deficiencies are important in this country.

Phosphorus deficiency is certainly the most important mineral deficiency of cattle in Brazil. In addition to the areas where pronounced phosphorus deficiency has been diagnosed, there probably occurs in large parts of Brazil a seasonal phosphorus deficiency, as studied in Sertãozinho, São Paulo, by Villares and Silva (1956), together with protein and energy deficiencies.

Cobalt deficiency seems to come second in importance.

Copper deficiency seems also to be quite common, but the presence of this mineral deficiency cannot be ascertained from disease histories and by the collection of clinical data. Copper deficiency in cattle is less characteristic than the other mineral deficiencies mentioned above and it can be seen from this review that it sometimes occurs associated with other deficiencies which dominate the clinical and pathological picture of copper deficiency.

Iodine deficiency in cattle has been observed only in Minas Gerais and Mato Grosso.

As yet there are not data on the occurrence of deficiencies of sodium, chlorine, magnesium, selenium, manganese, and zinc in cattle in Brazil.

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DESIRABLE RESEARCH INFORMATION NEEDED BY MANUFACTURERS OF MINERAL MIXTURES

by
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Calculated at 85.2 million head in 1972, the present bovine population in Brazil does not exceed 90 million. From this large number of animals, Brazil scarcely produced 2.04 million tons of carcass meat in 1972. Because 9.5 million head were slaughtered for this production, the percent slaughtered* was little more than 12%. For every cow existing in Brazil, only 25 kg of carcass meat was produced and this production corresponds to only 20 kg of meat per person.

The low production rates observed in the cattle industry have not permitted an annual herd growth rate greater than 1.3-1.5%. A large deficit in Brazilian beef production will be present during the next few years if this situation continues and present consumption levels persist.

During the next 25 years the human population of Brazil should, at least, double the population of 1975. For a population that is predicted to have 220 million inhabitants by the year 2000, Brazil will need to produce 5.7 million tons of carcass meat in order to be able to maintain the same present levels of beef consumption.

If the national herd maintains the current low production rates, 28.5 million head will need to be slaughtered at the beginning of the next century from a total herd of 237 million head. In order for this number to be attained in the next 25 years, the herd in Brazil would have to increase a minimum of 5% per year from 1975 which is approximately 2.5 times the current rate of increase. This growth in the national cattle population will hardly be achieved. In order to meet the increasing demand for beef for internal consumption and still be able to offer part of the production to the international market, the only alternative is to substantially increase cattle production per head.

$$\text{*Percent slaughtered} = \frac{\text{No. slaughtered}}{\text{No. of existing animals}} \times 100$$

Presently in Brazil there is an area of approximately 147 million hectares of natural and improved pastures, with a stocking rate of 0.5 head per hectare. With 147 million head of cattle (1 head per hectare) Brazil would succeed in doubling its meat production. Even if that number cannot be attained in the next 25 years, the present herd offers conditions for doubling and even tripling production, if effective changes in the methods of raising animals are implemented by means of the application of basic technical knowledge designed to a) improve the calving rate, b) reduce the mortality rate, and c) reduce the slaughter age of the animals.

These three conditions, high calving percentage, low mortality, and less time for animals to reach slaughter age, are closely associated with the nutrition of the animals, disease control and management. It can be said that Brazil has been an extremely privileged country with respect to the infectious diseases that affect its cattle herds. The majority of infectious and parasitic diseases can be controlled by sanitary conditions through well-organized campaigns, like the one developed in the last few years against foot and mouth disease. The benefits of these campaigns in many areas are presenting extremely positive results.

Similar campaigns will be able to be carried out against brucellosis, using a similar scheme adopted for the foot and mouth disease, and utilizing the same people involved in this project. The same could be said in relation to parasites, bovine rabies, and anthrax. For all these diseases there are relatively good vaccines and/or medications capable of substantially reducing the unfavorable effects of these endemic conditions.

Nutritional deficiencies, especially of proteins, energy, minerals and vitamins that are critical during definite times of the year, or even during an entire year, seem to constitute the principal factors responsible for the low livestock yields in Brazil.

During the long periods of drought when the quantity and quality of forage-producing plants diminishes, the cattle producer has not yet developed the practice of preserving feeds for the animals. Also, in order to prevent nutritional deficiencies due to the lack of phosphorus, cobalt, and copper which are recognizable in herds found in large areas of Brazil, the cattlemen are not yet sufficiently accustomed to the utilization of mineral mixtures.

For a bovine population calculated at 90 million head the annual consumption of mineral mixtures is not greater than 25,000 tons. This represents only 278 grams of mineral supplements available per head per year excluding common salt. Considering a minimum consumption of 6 kg of mineral supplements per year, the present demand would be sufficient for scarcely 5 million head, which is only 5.5% of all cattle in Brazil.

Production data of cattle in a Region of Central Brazil	
1. Calving percentage (%)	55
2. Mortality up to 3-4 years of age (%)	20
3. Weight gain from birth up to the age of slaughter (g/head/day)	280
4. Age at slaughter (years)	4
5. Percent slaughtered $\frac{\text{No. sloughtered}}{\text{No. of existing animals}} \times 100$	-12
6. Live weight per hectare/year (kg)	40

Evidently, one cannot attribute these low production rates to only malnutrition. Parasites, infectious diseases, and toxic plants also contribute to low calving percentage, high mortality rates, and slow growth rates. But the contribution of malnutrition and mineral deficiencies assumes a decisive role upon cattle production indices throughout Brazil. These have unfavorable repercussions on cattle production per land area and consequently on production costs.

Lack of Minerals

It will not be necessary to emphasize the great losses resulting from mineral deficiencies in terms of low production rates in whatever regions of the world where these deficiencies are not duly avoided or controlled.

Areas deficient in essential minerals occur in vast regions of the world in both developing and developed countries. Brazil with its 8.5 million square kilometers, cannot be considered an exception because studies in the majority of Brazilian states have confirmed, with sufficient frequency, areas which are deficient in phosphorus, cobalt, copper, and iodine.

From many reports in Brazil, the administration of phosphorus supplements in many areas has offered extremely significant response in terms of higher calving percentages. These responses at times represent increases in calving rates of from 20 to 30%.

The beef and dairy cattle industries in numerous areas of the country have been economically assisted through the use of phosphorus, copper and cobalt supplements for the correction of pasture deficiencies.

Lack of phosphorus, according to all indications, is the most frequent deficiency in Brazilian pastures. The situation is considered serious during the dry season when protein and energy deficiencies are also associated with phosphorus deficiencies.

From 1,030 analyses conducted on grass forage samples coming from the majority of the Brazilian states, which were collected in different months of the year, and in different stages of development, the Tortuga Zootechnical Agrarian Company accumulated the following data during a period of 4 years:

Results of analysis of phosphorus in the most common grasses used as forage in Brazil (1972 to 1975)

% of P	No of samples	%
0.35 or more	26	2.53
0.30 to 0.34	40	3.88
0.25 to 0.29	51	4.95
0.20 to 0.24	141	13.69
0.15 to 0.19	246	23.88
0.10 to 0.14	320	31.07
0.05 to 0.09	173	16.80
0.00 to 0.04	33	3.20
TOTAL	1030	100.00

Source: Tortuga Zootechnical Agrarian São Paulo.

Of the total forages analyzed, 76% of the total samples showed a level of less than 0.20% phosphorus (782 samples). Of the 1,030 samples, 526 (51.1%) showed levels of phosphorus less than 0.15% and 206 samples (20.0%) revealed levels of phosphorus less than 0.10%.

A majority of the samples were guinea grass *(Panicum maximum)*. In smaller proportions were jaragua grass *(Hyparrhenia rufa)*, molasses grass *(Melinis minutiflora)*, pangola grass *(Digitaria decumbens)* and others.

Areas extremely deficient in phosphorus were identified independently from the forages that were analyzed. In this same region the levels of phosphorus varied considerably in accordance with the seasons of the year (wet and dry) or the phase of development of the grass plants (Veiga, unpublished data).

In the national literature many reports refer to the identification of mineral deficiencies, especially phosphorus, copper, and cobalt in various regions of the country, and much of this bibliography can be found in the excellent review presented by Lee R. McDowell from the Univeristy of Florida, U.S.A. at a conference concerning Mineral Deficiencies and Toxicities and their Effect on Cattle Production in Developing Countries, held at the University of Edinburgh, Scotland in September of 1974.

More recently, a Group of Researchers are making a mineral survey on more than 30 properties located in the Amazon region. This was organized by the Brazilian Amazon Cattlemen's Association with the participation of the Biological Institute of São Paulo and in agreement with SUDAN and the SUDECO. They have discovered in the great majority of areas visited, certain signs of mineral deficiencies in animal and plant tissues, involving principally phosphorus, copper, and cobalt.

Industries Producing Mineral Mixtures

Industries which are capable of manufacturing mineral mixtures in Brazil have been working actively in this field of production and commercialization. For more than two decades they have attempted, where it has been possible, to bring together information for the improvement and perfection of their products which would be most efficient and most adequate for each region.

The desire of the industries to prepare the most appropriate mineral mixture for each area or region frequently is impossible because of an absolute lack of consistent and sufficient mineral research data. With adequate data the industries can formulate mixtures with greater efficiency and probably with less cost to the cattle producer.

Naturally, we are beyond the time when the same simple or complex mixtures were preformulated and commercialized for all regions of the country, indiscriminately combining numerous mineral elements in the most varied and inconsistent proportions. Mixtures of this type, unfortunately, are still merchandized in this country and often contribute to the disillusions and prejudices of the producers.

In reality, extensive work has been performed in this country by companies who are interested in protecting their good name. Much useful information has been provided directly to producers, many of whom had not been reached by official programs up until the present time. The contributions of the commercial companies cannot be underestimated nor should they be impeded by competitors with fewer scruples.

The manufacturers of mineral mixtures struggle against the small amount of inconsistent data related to specific areas where mineral deficiencies constitute problems. But many of them, through observed results, analyses of plant and animal tissues and experimental research that they themselves have conducted, have already begun to prepare more adequate mineral mixtures for determined areas. This research, nevertheless, executed by an extremely small number of firms, obviously should not be so slow and, above all, it is considerably burdensome.

In many situations, the experiments which are set up on private ranches, conducted by researchers of official organizations or by researchers of the commercial industries that produce mineral mixtures, are met with immense difficulties. In many cases the manager, the owner of the cattle or the owner of the land, abandons his part of the agreement.

On the other hand, there does not exist in this country sufficient numbers of specialized laboratories nor enough trained technicians to effectively analyze plant and animal tissue on a large scale. In São Paulo, this work is being conducted by the Biological Institute of the Secretary of Agriculture, with serious limitations of personnel and funds. In a recent agreement between the Biological Institute and Brazilian Amazon Cattlemen's Association, an attempt is being made to assist the Biological Institute with personnel and funds in order to survey the mineral status of more than 40 ranches in the Amazon area.

The preliminary results indicate extensive areas of pasture where, as a general rule, low levels of phosphorus predominate and, regionally, low levels of cobalt and copper exist.

The already well known disease of young animals called "swollen face" ("cara inchada") is of great concern to numerous researchers of EMBRAPA and of the Biological Insitute (through the Brazilian Amazon Cattlemen's Association), that coordinates a project of the SUDAN and SUDECO for the identification of mineral deficiencies.

The Tortuga Zootechnical Agrarian Company has just initiated an experiment in the Rondonopolis area involving about 210 adult and young animals, part of which have clinical signs of the swollen face syndrome and part of them still without apparent clinical signs.

The "swollen face" syndrome is only one of the problems that is probably linked to the deprivation of minerals. Even though this problem is frequently found thoughout a vast area of Mato Grosso which contains more than one million cattle, this disease has been found in other areas where it was verified more than 20 years ago. For example,

in the Paraiba Valley (State of São Paulo) cases of "swollen face" were very frequent and were observed by us on various ranches (Veiga, unpublished data). In the same period, René Correia documented cases of swollen face with excellent photographs (René Correia, personal communication).

However, in addition to "swollen face" there are other problems of mineral deprivation which occur in the majority of Brazilian states, especially insufficient amounts of phosphorus, copper and cobalt. The deficiency of iodine has also been identified. All this information, is sparse and covers only micro-regions in a country of 8.5 million square kilometers.

The procedure of the mineral manufacturers has obviously been that of offering one mixture which contains all the elements considered essential, or at least those that are known to be deficient in a specific area. It is easy to understand that a mixture developed for an entire country will not be able to furnish uniform results and satisfactory answers for every case. These mixtures attempt to offer the minimum level that is considered normal, but this minimum is not always sufficient. The best manufacturers are already trying to diversify their mixtures for specific or regional cases based on their own observations. Meanwhile, mineral manufacturers need conclusive results from well developed regional surveys so that they can provide the most effective mineral mixtures.

The problem of mineral deficiencies is a problem which has severely limited the productive capacity of the national herds and, consequently, the economy of Brazilian cattle producers. This subject merits the highest priority of the official authorities from the identification of deficient areas to the inspection of the products that are offered in the market.

Information the Mineral Manufacturers Would Like from Researchers

Without using the name of any particular industry, but personally involved in this problem as an animal scientist and particularly concerned with the great national problems related to the production of food for our population, I believe that the mineral manufacturers would like more complete information with regard to the prevention of mineral deficiency diseases.

Among the desired information, I will cite only those which I consider most important:

1) A general survey of the problem areas where there are large concentrations of beef and dairy cattle in order to identify the principal mineral deficiencies which are related to poor animal performance and to observe herds with typical deficiency disease symptoms.

2) Research on specific diseases which affect animals in certain regions of the country. There are still many doubts regarding their etiology because sometimes the cause is attributed to one or more mineral deficiencies, or to toxic plants or to deficiencies of other origins or even to infectious and parasitic diseases.

3) Means and methods of administering minerals that guarantee minimum consumption which is sufficient for the prevention of the deficiencies predominating in the researched area.

4) An indication of the most recommended mineral compounds for the development of mineral mixtures and proportions which should be maintained between the different elements for each situation and region.

5) Relationships between types of soils, vegetation, and mineral deficiencies.

6) Periods of the year or seasons of the year in which the mineral deficiency becomes more critical.

7) Regions or areas where the excess of mineral elements (molybdenum, selenium, etc.) may be responsible for the states of deprivation or intoxication.

It should be unrealistic to expect researchers from the national organizations to map the pasture areas of Brazil in a short or medium time span, in order for the mineral manufacturers to be able to operate with more certainty and effectiveness. We believe that more rapid and compensating results will be achieved in areas or regions where the problems are more acute.

Commercial industries without a doubt, want to collaborate in the solution of the great problems facing national cattle production, as they have been doing by the introduction of new drugs, new medicines and vaccines which are more efficient in controlling the infectious and parasitic diseases. In this area the industries have found as much support in research conducted outside as research conducted within the country by scientists of official institutions and by their own scientists. But in the specific case of mineral deficiency diseases, the research has not yet been considered with sufficient magnitude through planning and the application of research methods. The research in this area is extensive and exhausting. The researchers need essential support, coordination, and planning. There are few of us in Brazil specialized in this subject, therefore, it is not advisable for us to divide or dilute our efforts and to act in isolation which would be sporadic and futile. Consequently, if the mineral manufacturers have something to request from the researchers, they have much more to request from the national authorities.

The identification of regions lacking in essential elements and where the herds do not have the conditions to provide satisfactory economic profits, is a serious matter which requires absolute priority, or at least, the equivalent of the priorities which have already been given to other known problems which affect the national bovine herd.

If I could speak in behalf of the mineral manufacturers, I would add that they could acclaim all the measures than can be taken by the official authorities in the realm of:

1) Formation of researchers and technicians specialized in the identification and prevention of deficiency diseases.

2) Installation of laboratories equipped for the analysis of animal and plant tissues for more rapid identification of the deficiency diseases in various regions of the country.

3) Development of a national plan or at least regional projects for a more rapid survey of the situation.

4) Full disclosure of results and the recommended measures for solution to the problems.

5) Appropriate regulations for mineral mixtures placed on the market as a guarantee of efficacy for each region.

6) Fiscal incentives or whatever type of designated subsidy to stimulate the industries to undertake research related to deficiency disease.

7) Full campaign at the national level to inform cattle producers about the facts with respect to deficiency diseases and the methods to correct these detrimental deficiencies.

EVALUATION OF MINERAL SUPPLEMENTS FOR RUMINANTS

by
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It is a rare occasion when ruminant nutritionists visit ranches in Latin America without being shown an ingredient label from a commercial mineral mix and asked "Will this supplement meet the mineral needs of my animals?" The answer is seldom simple. An evaluation of the ability of any supplement to meet the mineral requirements of a class of animals presupposes that those requirements are known. Although the authors fully recognize the complications of any such assumption, a discussion of the many factors that affect the mineral requirements of ruminants is beyond the scope of this paper. Underwood (1971) has discussed this problem in depth.

A further complication is often the ingredient tag itself. Sources of mineral elements are frequently not listed, or several sources of the same element are cited (i.e., copper sulfate, copper oxide, etc.) leaving it to the buyer's imagination what percent of the total composition of the mineral element is supplied by which compound. Ingredient tags would be much simpler if presented in a manner similar to that of Cunha *et al.* (1964):

Ingredient	%
Dicalcium Phosphate	59.38
Trace Mineralized Salt 1/	30.00
Copper Sulfate	.60
Cobalt Sulfate	.12
Cane Molasses	6.00
Cottonseed Meal	4.00

1/ **Trace Mineralized Salt Contains (%):**
NaCl 99, Zinc Sulfate .53, Ferrous Sulfate .25, Manganese Carbonate .1, Copper Sulfate .10, Cobalt Choride .006, and Potassium Iodide .002.

For such a tag, it might be easier to make a more accurate judgment concerning the quality and quantity of ingredients in a mineral mix. Even labeling such as the above would not allow a completely accurate evaluation, however. Although it would be natural for the user to assume that the names defluorinated phosphate, cobaltous carbonate, etc. identify specific compounds, this is not found to be true in actual practice. Compounds used by the mineral mix industry may vary markedly in their content of the desired element. Table 1 presents a listing of various mineral sources that are used by the industry today. A reference to this Table will quickly point out that "Feed Grade" mineral sources usually vary somewhat from the amount of specific elements that would be calculated in pure compounds. It may also be noted that the "Feed Grade" compounds themselves vary greatly from one to another in the amount of mineral elements that they furnish. For a striking example of this, refer to cobaltous carbonate in Table 1.

Making a judgment from such a tag also assumes, of course, that the quality control of the supplement manufacturer is such that the mixture actually contains the amount that is stated on the tag. Unfortunately this has not proven to be the case in many instances. Analyses of mineral mixes throughout Latin America have often shown little relationship between the amount of elements listed on the tag and those actually found in the supplement. In the final analysis the user must rely on the reputation of the manufacturer for mineral mix content. When evaluating mineral mixes under field conditions the researcher is usually obliged to accept that the mineral content is as listed on the label.

Table 1.

PERCENT OF MINERAL ELEMENT IN COMPOUNDS COMMONLY USED IN MINERAL SUPPLEMENTS

Element	Source Compound	% Element in Pure Compound or Source	% Element in Feed Grade Compound*
Calcium:	Steamed Bonemeal	29.0 (23-37)	24.0
	Defluorinated Rock Phosphate	29.2 (20-36)	—
	Soft Phosphate	18.0	—
	Calcium Carbonate	40.0	—
	Ground Limestone	38.5	38.0
	Dolomitic Limestone	22.3	—
	Monocalcium Phosphate	15.9	—
	Tricalcium Phosphate	38.6	31.5
	Dicalcium Phosphate	23.3	22.0
	Calcium Sulfate	29.4	20.0
Cobalt:	Cobaltous Carbonate	49.5	20, 55, 46
	Cobaltous Chloride	24.7	—
	Cobaltous Sulfate	24.8	21.0
	Cobaltic (ous) Oxide	73.4	—
Copper:	Cupric Carbonate	53.0	—
	Cupric Chloride	37.2	—
	Cupric Oxide	80.0	75.0
	Cupric Sulfate	25.5	25.0
Iodine:	Calcium Iodate	65.1	62.0
	Potassium Iodide	76.4	69.0
Iron:	Red Iron Oxide	69.9	46, 60, 56
	Ferrous Sulfate	20.1	—
	Ferrous NH_4 Sulfate	14.2	—
	Ferrous Carbonate	41.7	35, 41.7
Magnesium	Magnesium Carbonate	28.8	—
	Magnesium Chloride	12.0	—
	Magnesium Oxide	60.3	50, 54, 58.5
	Magnesium Sulfate	19.9	19.0
Manganese:	Manganous Carbonate	47.8	—
	Manganous Chloride	27.8	—
	Manganous Sulfate	32.5	27.0
	Manganous Oxide	77.4	56, 60, 62
Phosphorus:	Steamed Bonemeal	13.6 (8-18	12.0, 13.0
	Defluorinated Rock Phosphate	13.3 (9-21	18.0
	Calcium Phosphate	24.6	21.0
	Dicalcium Phosphate	18.0	—
	Tricalcium Phosphate	20.0	19.0
	Phosphoric Acid	31.6	23.7
	Diammonium Phosphate	23.5	20.0
	Monoammonium Phosphate	27.0	24.0
	Disodium Phosphate	21.3	—
	Monosodium Phosphate	22.4	—
	Sodium Tripolyphosphate	25.3	25.0
	Potassium Phosphate	22.8	—
	Tripotassium Phosphate	14.6	—
	Soft Phosphate	9.0	—
Potassium:	Potassium Chloride	52.4	50.0
	Potassium Sulfate	44.9	41.0
Selenium:	Sodium Selenite	45.6	—
Sulfur:	Sulfur, Flours of	96.0	—
	Potassium Sulfate	18.4	17.0
	Magnesium Sulfate	13.0	11.6
	Sodium Sulfate	22.6	—
	Ammonium Sulfate	24.3	24.0
	Calcium Sulfate	29.4	18.0
Zinc:	Zinc Carbonate	52.1	—
	Zinc Chloride	48.0	—
	Zinc Sulfate	22.7	34.5
	Zinc Oxide	80.3	73, 70

*Contents of actual feed grade compounds experienced by International Minerals Corp. and Allied Mills, Inc. Where — is indicated, feed grade compounds were found to be essentially the same as the pure compounds.

In order to evaluate a mineral supplement, one must at least have an approximation of:

1. The requirements of the class of animals involved for the essential elements.
2. The relative biological availability of the elements in the compounds through which they will be supplied.
3. The approximate daily intake per head per day of both mineral mixture and total dry matter that can be expected by the class of animals under consideration.
4. The concentration of the essential elements in the mineral mixture.

Dietary Requirements For Essential Mineral Elements

Although precise figures for mineral requirements of different classes of animals under varying conditions are still not known, enough research data is available from which some general conclusions may be drawn as to dietary levels under which cattle will usually thrive (NRC, 1976). A dietary allowance can be defined as the requirement plus an additional amount which can be used as a safety factor. These dietary allowances for various classes of cattle have been summarized by Ammerman (1975) and are presented in Table 2. It is recognized that most of the requirements were not established with Zebu cattle nor with cattle living under tropical conditions, but researchers agree that this is the best information that we have and that these requirements should be used until research data becomes available concerning tropical cattle.

Table 2

MINERAL REQUIREMENTS AND ALLOWANCES FOR BEEF CATTLE

	Requirements[1]			Allowances[5]
	Growing & Finishing Steers & Heifers	Pregnant Cow	Lactating Cow	Lactating Cows
Calcium, %	.18 - 1.04	.18	.18 - .44	.30
Phosphorus, %	.18 - .70	.18	.18 - .39	.25
Potassium, %	.6 - .8	—	—	.80
Sodium, %	.06	.06	.06	.15
Chlorine[2]	—	—	—	—
Sulfur, %	.1	—	—	.15
Magnesium, ppm	400 - 1000	—	1800	2000
Iron, ppm	10	—	—	80
Copper, ppm	4	—	—	10
Zinc, ppm	20 - 30	—	—	50
Manganese, ppm	1- 10	20	—	25
Iodine, ppm	—	.05 - .1	.05 - .1	.6[3]
Cobalt, ppm	.05 - .10	.05 - .10	.05 - .10	.1
Selenium, ppm[4]	.05 - .10	.05 - .10	.05 - .10	.1

1. NRC, Nutrient Requirements of Beef Cattle, 1976. All values expressed in percentage or ppm of dry ration.
2. No requirement for chlorine shown. Requirement will be met by sufficient NaCl to provide sodium requirement.
3. Based on iodine levels listed for lactating dairy cows. (NRC, Nutrient Requirements of Dairy Cattle, 1971). Higher levels of iodine are frequently added to mineral mixtures because of the instability of many iodine compounds.
4. At present, selenium cannot be added to supplements for ruminants in the U.S.A.
5. Ammerman (1975). Personal communication.

Biological Availability

The biological availability of the macro and microelements has been discussed previously in this symposium. Animal requirements were originally determined using compounds with relatively high availability (i.e., sulfates and chlorides). If compounds that are less available are used in a mineral supplement, a larger amount of these substances must be added in order to meet the animal's requirement for the mineral involved. In addition to availability, the stability of the compound used to supply the mineral element is important. Unstabilized potassium iodide, for example, is less effective under wet tropical conditions, since iodide in this form is readily volatilized or leached. Calcium or potassium iodate, stabilized potassium iodide or pentacalcium orthoperiodate are much more stable forms of iodine (McDowell, 1976).

Average Daily Intake of Mineral Mixtures and of Total Dry Matter

The average daily intake of free choice mineral mixtures by cattle is highly variable. Factors that affect the consumption of mineral mixtures in the United States were cited by Cunha *et al.* (1964):

1. Usually, the higher the level of soil fertility, the lower the consumption of minerals.
2. Some forages cause an increase in mineral consumption, whereas others lower it. Cattle on native range consume more mineral supplement than those on improved pastures. Usually, when forages are growing rapidly there will be less mineral consumption than during the periods of the year when plant growth is slow or stops. Cattle on low quality and overgrazed pastures consume more mineral supplements.

3. The kind and level of supplemental feeding will influence mineral intake.
4. Growth rate, percentage calf crop, and milk production influence mineral needs. The added requirements of gestation and lactation increase mineral needs.
5. The amount of minerals in the drinking water influences mineral intake.
6. The palatability of the mineral mixture affects intake. If the mixture is not palatable enough, the cattle may not consume enough mineral to satisfy their needs. If the mineral mixture is too palatable, they may consume too much and develop mineral imbalance. Cane molasses, cottonseed meal, and other ingredients may be added to mineral mixtures to increase their palatability, but they must be used in moderation or they will cause over consumption of the mineral mixture.
7. Mineral boxes which keep out the rain help increase mineral intake. Minerals should not be allowed to cake in the box, as this decreases consumption. Boxes should be constructed so that the calves can also consume minerals from them. Keeping the mineral supply fresh increases its consumption.
8. Less mineral is consumed if cattle have to travel long distances to the mineral box. Mineral boxes should be located near the water supply or where cattle rest.
9. Moldy mineral mixes will lessen consumption. Use mineral mixtures which will not spoil during damp, wet weather or blow away in windy weather. The use of 20 to 40 percent salt prevents molding and blowing.

As the salt content of water increases, cattle consume much less of a high salt mineral mixture. If salt content of the water is high, the level of salt in the mineral mixtures should be decreased. Otherwise, cattle will not consume enough of the mixture to satisfy their phosphorus and micro-mineral needs.

Table 3 presents mineral consumption data obtained at the University of Florida Range Cattle Station under three different pasture programs (Cunha *et al.*, 1964).

Chachamovitz (1974) has indicated that cattle grazing in Brazil often consume between 40 and 50 g of mineral mix per head per day. Holder (1972) has indicated a consumption of 50 to 100 g/head/day by cattle grazing in Guyana. Between 40 and 50 g/head/day is commonly used as an estimate for intake of mineral supplements (50% salt: 50% phosphorus and microelements). Cattle do not always consume mineral mixtures well under tropical conditions. Rios (1974) has presented data showing a wide monthly variation in the consumption of mineral mixtures by Venezuelan cattle. Rosa (1975), working on ranches in Mato Grosso, Brazil, has also encountered very low voluntary intake of mineral mixtures. Table 4 summarizes some of the results of Rios and Rosa. It is noteworthy that in both experiments, cattle consumed very little mineral mixture during the dry season. This finding is supported by work from other Latin American countries and Africa, but it conflicts with findings in temperate regions, where cattle tend to eat more mineral when grass is poorer. This difference may be explained by the observation that "poor" pasture in temperate regions has a different meaning than in tropical regions. Cattle may consume more mineral as grass quality declines, but at some point, the quality may be so bad or dry matter so scarce that the animal does not continue to consume mineral supplement. Further research is needed to determine the pattern of mineral consumption on tropical pastures.

When evaluating mineral supplements where consumption is not known, researchers commonly start with an intake figure of 50 g per day and adjust this figure according to local conditions.

Table 3

AVERAGE MINERAL CONSUMPTION OF BEEF COWS FROM 1956 to 1962 AT THE RANGE CATTLE STATION, ONA, FLORIDA[1]

Herd No.	Pasture[2]	No. Cows	Average Mineral Intake per Cow	
			Yearly (kg)[3]	Daily (g)
1	Native	60	17.0	50.0
2	Combination native and improved	60	15.4	40.9
3	Pangola digitgrass overplanted with 1/3 clover	60	4.4	22.7

[1] Data supplied from Range Cattle Station. (Cunha *et al.*, 1964).

[2] Herd 1 on 333 ha. native range, one-half burned alternate years, and fed hay and cottonseed meal in winter. Herd 2 grazed 131 ha. native range and 31 ha. fertilized pasture consisting of 7.5 ha. Pensacola bahiagrass overplanted with hairy indigo, 9 ha. each of pangolagrass and Pensacola bahiagrass and 17 acres of mixed grass, only fed cottonseed meal in 1957-58 winter. Herd 3 kept on fertilized pasture consisting of 29 ha. pangolagrass and 9 ha. of the same grass overplanted with Whiteclover, and fed hay each winter.

[3] Range in average yearly mineral intake per cow: Herd 1, 8.2 kg in 1956 to 21.4 kg in 1959; Herd 2, 11.4 kg in 1951 to 21.8 kg in 1957; Herd 3, 6.8 kg in 1956 and 1959 to 14.0 kg in 1962.

Table 4

MONTHLY CONSUMPTION OF MINERAL MIXTURES BY CATTLE UNDER TROPICAL CONDITIONS (g/h/d)[1,2]

Month	Venezuela[3]		Brazil[4]	
	Females	Males	Iodized Salt	Complete Mix
January	12	27		
February	12	20		
March	10	8	26	26
April	10	12	24	28
May	15	18	26	32
June	32	35	19	21
July	52	42	15	14
August	25	35	12	11
September	30	37	10	11
October	26	35	18	25
November	32	40		
December	28	17		

[1,2] Rosa (1975), Rios (1974).
[3] Complete Mineral Mixture.
[4] Two year-old steers.

Total Dry Matter Intake

It is virtually impossible to know the total daily dry matter consumption of cattle on pasture. The quality of a pasture will to a great degree, determine intake. Although 2% body weight is considered a rough estimate of forage dry matter intake by cattle, they may eat much less if the forage is of poor quality, or (as could be the case during the dry season) quantity is limiting. This factor also, often becomes a matter of judgment on the part of the researcher. In most cases, only an approximate estimate is available to gauge daily dry matter intake.

Concentration of Elements in the Mineral Mixture

As can be seen in Table 2, mineral requirements are usually expressed in some concentration unit (percent, parts per million, gram per kilograms, etc.). It is useful to remember that parts per million (ppm), milligrams per kilogram (Mg./Kg.), and microgram per gram ($\mu g/g$) are identical. One sees all of these nomenclatures on various mineral supplement labels. Since the NRC tables (NRC, 1976) use percentage units for elements that are required in relatively large amounts and ppm for those required in much smaller amounts, this nomenclature will be used hereafter.

After an evaluation has been made as to the biological availability of the elements to be supplied by the mineral mix and a judgment has been made as to the approximate daily intake of mineral mixture and of total dry matter, the concentration of each element in the mineral mixture can be used to calculate the amount of each element that will be furnished per animal, expressed as a percentage or ppm of the total dry matter intake (the manner in which requirements are usually expressed). The concentration in the total diet of each element furnished by the mineral mixture can be compared to the total requirements for that element in order to determine if a significant amount is being furnished by the supplement.

The calculation is made as follows:

(1) $\dfrac{\text{(\% Element In Mineral Mixture)}}{\text{(Total Daily DM Intake (g))}}$ (Daily Intake Of) = % Element In
(Mineral Mix (g) Total Diet

If for example:

Copper In Mineral Mixture (%) = .12
Daily Intake Of Mineral Mix (g) = 50
Total Daily Intake Of DM (kg) = 10

Then: $\dfrac{.12 \times 50}{10{,}000}$ = .0006% Or 6 ppm

The reader will note that it is a simple matter to convert percent to ppm, by moving the decimal 4 places to the right and vice versa.

It is difficult to say what constitutes a "significant portion" of the requirement for each mineral that should be supplied by the mineral mixture, but it is generally believed that this figure should be at least 25 to 50%. In the above example, 6 ppm copper would be furnished by the mineral mixture. From Table 2, we can see that approximately 10 ppm is considered the allowance for copper. About 60% of the requirement for copper would be supplied by the mineral mixture.

Table 5 presents an example of mineral allowances and proportions supplied by a mineral mixture (similar to certain commercial preparations) offered free choice on range or pasture (Ammerman, 1975). As can be seen, this particular mixture supplied only 5% of the zinc requirement but that a relatively high portion of the other elements is furnished. The reader should note the assumptions listed at the end of the table. Table 6 presents examples of some mineral mixes sold in Latin America and the approximate amount that they would supply in the diet. A careful evaluation of these mixtures indicates that improvements could be made. Assuming a consumption of .5% of total dry matter, for example, mixtures No. 1 and 4 supply relatively insignificant amounts of iron and copper and mixture No. 4 supplied very little zinc and manganese. If these elements are considered to be necessary in a particular mineral mixture, they should be added at a higher level. If not, they should be omitted.

Attention should be called to mixture No. 4 which is sold widely throughout Latin America. This mixture contains selenium, which is a toxic mineral and should only be used where a deficiency is suspected. If this mixture is used in areas where selenium content of the forage is high, it will only aggravate the problem.

Finally, a word should be said about the magnesium content of mixture No. 1. Forage usually contains sufficient magnesium. There are certain seasons of the year, however, when magnesium deficiency becomes a problem. During this time, large amounts (a mineral mixture containing 25% MgO has been effective in the Southeastern U.S.A.) are necessary to overcome the problem of "grass tetany." Small amounts of Mg given routinely in a mineral mix are really of no value (Underwood, 1971).

Table 5.

MINERAL ALLOWANCES AND PROPORTIONS SUPPLIED BY A MINERAL MIXTURE OFFERED FREE-CHOICE ON RANGE OR PASTURE

Mineral	Dietary Allowance	Mineral Mixture[1]	Amount from Mineral Mix[2]	% of Allowance from Mineral Mix
	%	%	%	
Calcium	.30	18.0	.09	30
Phosphorus	.25	8.0	.04	16
	ppm	%	ppm	
Magnesium [3]	2000	—	—	—
NaCl [4]	—	—	—	—
Copper	10	.10	5.0	50
Iron	80	1.00	50.0	63
Manganese	25	.20	10.0	40
Zinc	50	.05	2.5	5
Cobalt	.1	.01	.50	5 x
Iodine	.6	.01	.50	83

[1] Composition similar to certain mineral mixtures available on the market.
[2] It is assumed that mineral consumption will average approximately .5% of the total dietary intake. This is based on an estimated intake of 50 g of mineral mixture and 10 kg of total dry feed per head daily.
[3] Magnesium is generally not added except for special mixtures for lush winter or spring grazing etc.
[4] It is generally assumed that sodium and chlorine requirements are more than adequately met by mineral mixtures containing 25 to 30% salt and consumed at a rate of .5% of the total ration.

After all the calculations have been made concerning the adequacy of mineral mixtures, it is important to keep in mind that if the rancher does not supply the mixture in the manner recommended by the manufacturer, all calculations are invalid. It is common in Latin America to find mineral mixtures which the manufacturer recommends to be mixed 1:1 with salt, being mixed 9 parts salt to 1 part mineral. De la Torre (1975) studied 150 farms in Ecuador and found that 80 fed only salt and that among the rest, mineral mixtures were diluted 20:1 to 100:1 with salt.

Many other factors are involved in a proper evaluation of mineral supplements. Space has not permitted a discussion of the mineral interrelationships, for example, that can play a large part in the availability of individual elements. Cattle grazing pasture high in molybdenum need more copper than normal. High calcium in the mixture can tie up certain microelements and render them insufficient to satisfy the cattle's needs. Usually, under field conditions, the researcher can only calculate whether or not a particular mixture should satisfy the needs of the majority of the cattle and emphasize the importance of good mineral nutrition in the overall management program.

Table 6.

EXAMPLES OF SOME MINERAL MIXES SOLD IN LATIN AMERICA AND THE APPROXIMATE AMOUNT THAT THEY WOULD SUPPLY IN THE DIET[1]

Element	Dietary Allowance	Mixture 1		Mixture 2		Mixture 3		Mixture 4	
		Content	Supplies	Content	Supplies	Content	Supplies	Content	Supplies
Sodium chloride	.50	50	.25	–	–	–	–	–	–
Calcium, %	.30	12	.06	–	–	20	.10	–	–
Phosphorus, %	.25	10	.05	–	–	16	.08	–	–
Magnesium ppm	2000	1400	7	–	–	–	–	–	–
Iron, ppm	80	2500	13	18,000	90	–	–	500	2.5
Zinc, ppm	50	500	2.5	10,000	50	7000	35	1200	6.0
Manganese, ppm	25	0	0	10,000	50	–	–	500	2.5
Copper, ppm	10	250	1.3	5,000	25	2700	13.5	250	1.2
Iodine, ppm	.6	100	.5	500	2.5	–	–	15	.08
Cobalt, ppm	.1	50	.25	500	2.5	700	3.5	16	.08
Selenium, ppm	.1	–	–	–	–	–	–	5	.03

[1]Based on a mineral consumption of .5% of the total ration.

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MINERAL RESEARCH PROJECTS FOR RUMINANTS IN THE AMAZONIAN REGION OF BRAZIL

by
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At this time there are several cattle production projects underway in the Amazon region of Brazil which are designed to study cattle raising and management practices which are adapted to these regions. These regions include extensive beef production areas where the diet is composed exclusively of pasture. These ranches are confronted with problems inhibiting cattle production and the solutions depend on a series of scientific investigations that are now taking place.

Mineral deficiencies are without a doubt part of the reason for the low productivity. Inadequate mineral nutrition debilitates the animal, decreases fertility, slows sexual maturity, impedes adequate growth, and consequently may result in loss of body weight, thus bringing on serious economical loses.

Attempts to resolve a problem of this magnitude have not been successful under existing conditions, therefore a research group was formed for this specific purpose. The research group is composed of individuals with diverse training and experience from both private and public institutions whose goal is to discover solutions to the problems. An agreement was signed by the Secretary of Agriculture of the State of São Paulo (through the Biological Institute) and the Association of Beef Cattle Producers of the Amazon with the objective of improving beef cattle production in the Amazon which already numbers more than 1,000,000 head.

The general objectives of the agreement can be summarized as follows:

a) To promote research and experimentation in the region for at least five years;
b) To define those problems related to mineral deficiencies of cattle in the Amazon region, since only meager information currently exists;
c) To equip public research institutions for conducting the necessary analyses;
d) To furnish cattle ranchers with reliable data so they can begin mineral supplementation programs;
e) To promote the technical development of the mineral industry by the characterization of the demand;
f) To facilitate the distribution network as well as impede the proliferation of "super formulas" of mineral mixtures.

The specific short term objectives are as follows:

a) To collect bibliographical data and technical observations on minerals.
b) To collect data on the mineral requirements of cattle (Zebu) with regard to the specific mineral status of cattle at different seasons of the year.
c) To compile and illustrate the current problems of mineral deficiencies and diseases and how they are linked, for example, to parasites.

The intermediate term objectives are as follows:

a) To investigate different soil classes and determine macro and micro elements from samples collected once a year
b) To survey, collect and analyze forages up to four times per year in accordance with their origin.
c) To confirm the diagnosis of mineral deficiencies through necropsy examination of the organs and intestines.
d) To conduct mineral supplementation experiments when necessary.
e) To collaborate in the quality control of mineral supplements.

This project can conveniently be divided into two phases:

1) Collection and analyses of plant and animal tissues from areas considered to be mineral deficient.
2) Establishment of experiments with appropriate mineral mixtures in areas where mineral deficiencies have bee identified.

This research which includes analyses of animal and plant tissues, has the potential, if well-directed, to increase th production capacity of a large number of herds over a vast region. It is a well-known fact that in Brazil, the level o phosphorus is low. However, the application of phosphate supplements has permitted the recuperation of vast area as was done with copper and cobalt administration in those regions where the disease known as "mal do colete" o "peste de secar" frequently occurred.

It would be impractical to conduct a detailed study of an extensive area like the Amazon, therefore, nine region were chosen which include a large part of the cattle raising projects, including the states of Amazonas, Pará (from nort to south) and Mato Grosso in its northern part, as follows: 1) Northeastern Pará, 2) Southern Pará, 3) Northeastern Mato Grosso (north of the Araguaia River), 4) Southern basin of the Araguaia, 5) Cáceres, Mato Grosso, Barra o Bugres, Nortelândia, 6) Diamantino and Chapada dos Guimaraes, 7) Arinos and Juruena River basins, 8) Northern Goiás and 9) Manacapuru, Silves (Amazonas). Of the numerous cattle ranches situated in the Amazon region, we selected for concentrated research those that offered the necessary infrastructure as well as being located in areas in which the cattle demonstrate mineral deficiencies.

At the same time, a survey will be made of internal parasites, reproductive diseases and toxic plants. To accomplish this, questionnaires will be distributed to each of the cattle researchers.

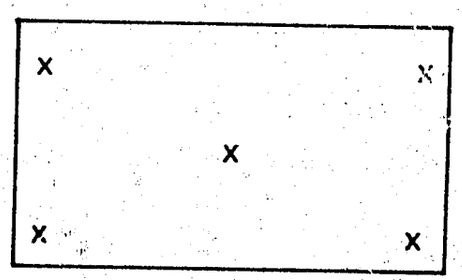
Collection of Material

The collection of soil samples were conducted according to recommendations of technicians responsible for the analyses.

The forages and animal tissues should be collected 2 times per year (wet and dry seasons) using stainless steel knives and clippers to avoid metallic contamination.

FORAGE

1. The forage sample (± 300 g) should be representative of the portion that the cattle consume.
2. Cut the grass at approximately the same height that the cattle are grazing or 20 cm above the ground when the vegetation is tall and 2 to 5 cm from the ground when short. Collect only the aerial part. Shake the plant gently to remove soil residues which would alter the results of the analysis.
3. Forage samples should be collected from various locations in the pasture with consideration being given to dominant forage species, soil type, high and low ground. Samples from four or five locations in a pasture can be kept separate or pooled. Do not collect samples along fences, watering troughs or other areas where larger than normal quantities of manure are found.



4. All samples should be properly identified.
5. Samples should be spread in a dry place in the shade for six hours to avoid fermentation and mold.
6. The samples should be kept well ventilated until dry. Placing the sample in a plastic bag before it is dry will result in fermentation and mold.

LIVER

Approximately 200 g of liver should be collected in large mouth non-metallic containers with plastic or other non-metallic covers. The preservative can be ethyl alcohol or 10% formaldehyde. The liver should be cut with stainless steel scissors or stainless steel knife.

Liver samples can be taken from animals sacrificed for this purpose, animals slaughtered for meat or a liver sample from live animals using the liver biopsy technique. Blood is collected from the jugular vein and allowed to coagulate. The serum is separated from the coagulant, placed in a clean sample jar and refrigerated. Hemolyzed serum is unsatisfactory for analysis.

Samples should be properly identified with name of ranch, location, number of animal, age, breed, sex, date and nutrition state. If the samples cannot be refrigerated, they can be boiled in a pressure cooker and sent immediately to the laboratory.

ANALYSES AND RESULTS

The first collections during the dry season have already been completed. Copper, cobalt, zinc, manganese, phosphorus and calcium were analyzed in forage and animal (liver and blood) tissues. In addition, forages were analyzed for molybdenum, conventional chemical methods and atomic absorption spectrophotometry were used for mineral analyses.

The intensity of mineral deficiencies vary between seasons and at times there are borderline deficiencies. Cobalt deficiencies which occur in the northern part of Brazil persist in both wet and dry seasons when not treated. According to research already conducted, we have found that the copper deficiency in northwest Mato Grosso occurs in the introduced pastures and diminishes during the rainy season in the natural pastures. However, when native pastures are burned we have verified that the ensuing diarrhea can be cured by the administration of copper. These scours may be the result of increased levels of molybdenum and low levels of copper since an analysis of young sprouting grasses indicated high molybdenum levels (>25 ppm) and lower than normal copper levels (4-4.45 ppm).

We expect to find a widespread phosphorus deficiency. However, the levels of manganese and zinc constitute new data and the levels were unexpected in our study. The data as presented in the following tables are inconclusive and some are unexpected.

Table 1.
MINERAL CONCENTRATIONS FROM SAMPLES COLLECTED DURING THE DRY SEASON IN DIFFERENT REGIONS OF THE AMAZON BASIN.

REGION	SAMPLE	ELEMENT	RESULTS $\bar{x}$ ± 95% C.L.			UNITS	NUMBER
AMAZON A	GRASS	Ca	0.17	±	0.02	%	7
		P	0.12	±	0.05	%	7
		Cu	5.64	±	2.38	ppm	7
		Mn	80.35	±	45.62	ppm	7
		Zn	35.04	±	7.48	ppm	7
		Co	0.085	±	0.024	ppm	6
	SERUM	Ca	8.11	±	0.79	mg%	10
		P	6.02	±	1.06	mg%	10
		Cu	0.06	±	0.03	mg%	7
		Total Protein	6.76	±	0.53	%	10
	LIVER	Co	0.07			ppm	1
		Cu	115			ppm	1
		Mn	12			ppm	1
		Zn	91			ppm	1
AMAZON B	GRASS	Ca	0.25	±	0.04	%	10
		P	0.15	±	0.06	%	10
		Cu	6.5	±	0.91	ppm	10
		Mn	149.6	±	50.73	ppm	10
		Zn	41.2	±	9.39	ppm	10
		Co	0.09	±	0.02	ppm	10
	LIVER	Co	0.15			ppm	1
		Cu	31			ppm	1
		Mn	12			ppm	1
		Zn	11.0			ppm	1

Table 1 (continued)

REGION	SAMPLE	ELEMENT	RESULTS $\bar{x}$ + 95% C.L.			UNITS	NUMBER
NORTHEASTERN PARA	SERUM	Ca	1.52	±	0.47	mg%	15
		P	5.89	±	0.63	mg%	15
		Cu	0.07	±	0.01	mg%	15
		Total Protein	5.74	±	0.59	%	14
	GRASS	Ca	0.23			%	1
		P	0.21			%	1
		Cu	6.6			ppm	1
		Mn	173			ppm	1
		Zn	36.5			ppm	1
		Co	0.1			ppm	1
	LIVER	Co	0.15			ppm	1
		Cu	125			ppm	1
		Mn	12			ppm	1
		Zn	107			ppm	1
SOUTHERN PARA A	SERUM	Ca	7.3	±	0.53	mg%	9
		P	6.37	±	0.72	mg%	9
		Cu	0.05	±	0.02	mg%	8
		Total Protein	7.37	±	0.63	%	9
SOUTHERN PARA A	GRASS	Ca	0.44	±	0.10	%	8
		P	0.14	±	0.04	%	8
		Cu	6.85	±	3.31	ppm	8
		Mn	108.57	±	28.97	ppm	7
		Zn	34.00	±	3.40	ppm	8
		Co	0.07	±	0.02	ppm	8
	LIVER	Co	0.06			ppm	1
		Cu	141			ppm	1
		Mn	20			ppm	1
		Zn	9.4			ppm	1
SOUTHERN PARA B	GRASS	Ca	0.43	±	0.09	%	10
		P	0.14	±	0.05	%	10
		Cu	6.4	±	1.25	ppm	10
		Mn	78.6	±	17.48	ppm	10
		Zn	31.7	±	3.89	ppm	10
		Co	0.08	±	0.01	ppm	10
	SERUM	Ca	7.29	±	0.49	mg%	10
		P	5.92	±	0.82	mg%	10
		Cu	0.06	±	0.02	mg/100 ml	9
		Total Protein	7.02	±	0.26	g/100 g	9
	LIVER	Co	0.06			ppm	1
		Cu	175			ppm	1
		Mn	20			ppm	1
		Zn	130			ppm	1
SOUTHERN PARA B	GRASS	Ca	0.39	±	0.12	%	9
		P	0.12	±	0.02	%	9
		Cu	5.22	±	1.09	ppm	9
		Mn	92.67	±	47.34	ppm	9
		Zn	17.37	±	5.12	ppm	9
		Co	0.08	±	0.02	ppm	9

Table 1 (continued)

REGION	SAMPLE	ELEMENT	RESULTS x̄ ± 95% C.L.			UNITS	NUMBER
SOUTHERN PARA C	SERUM	Ca	8.59	±	0.47	mg%	14
		P	6.38	±	0.78	mg%	14
		Cu	0.06	±	0.01	mg%	14
		Total Protein	7.88	±	0.28	g%	13
	LIVER	Co	0.07	±	0.04	ppm	3
		Cu	242	±	179.07	ppm	3
		Mn	16.67	±	14.34	ppm	3
		Zn	131.33	±	11.47	ppm	3

Table 2

SAMPLES FROM NORTHEASTERN MATO GROSSO (A)

	RESULTS							
Grasses (Wet Season)	Ca %	P %	Cu ppm	Mn ppm	Zn ppm	Mo ppm	Fe	Mg
P. notatum	0.35	0.07	4.7	124	24.3	0.06		
" "	0.49	0.06	4.3	140	26.0	0.065		
" "	0.15	0.03	3.1	109	–	0.075		
" "	0.48	0.06	4.8	154	88.0	0.100		
" "	0.39	0.04	6.4	290	128.0	0.100		
H. rufa	0.19	0.03	4.2	127	97.0	0.075		
P. notatum	0.53	0.03	10.4	229	90.0	0.090		
" "	0.33	0.14	3.6	261	131.0	0.075		
Native	0.32	0.03	7.2	141	108.0	0.100		
H. rufa + M. minutiflora	0.32	0.04	2.6	285	110.0	0.065		
Material: Liver (Wet Season)								
Pregnant cows (last trimester)			200	8.7	95	0.100		
Grasses (Dry Season)								
P. notatum	0.26	0.075	6.0	62.0	20.0	0.100		
" "	0.25	0.110	3.5	95.0	10.0	0.100		
" "	0.32	0.080	4.6	118.0	10.0	0.100		
" "	0.32	0.080	3.1	61.0	17.0	0.055		
" "	0.60	0.060	4.2	92.0	17.0	0.085		
" "	0.76	0.040	3.3	57.0	14.5	0.060		
" "	0.85	0.040	3.8	120.0	10.5	0.090		
" "	0.72	0.050	5.2	100.0	13.1	0.110		
" "	0.77	0.040	5.7	40.0	12.6	0.100		
" "	0.62	0.042	6.5	80.0	15.7	0.120		
" "	0.65	0.042	5.4	54.0	6.8	0.100		
" "	0.70	0.060	9.1	94.0	16.8	0.120		
H. rufa	0.73	0.040	9.5	94.0	11.5	0.110		
Native	0.72	0.055	4.2	47.0	14.2	0.075		
H. rufa	0.81	0.040	3.6	97.0	10.5	0.100		
Material: Liver (Wet Season)								
Cow in good condition			169	9.0	94	0.100		

SERUM (DRY SEASON)

Sample	Animal	General status	Observations (age)	Ca (mg%)	P (mg%)	Cu (mg%)	Total Prot. %
Crossbred	Steer	Weak	3 years	14.2	11.0	–	7.2
"	"	Fat	3 years	–	7.8	–	7.2
Nelore	Weaned calf	Weak	1.5 years	12.8	7.3	0.015	6.8
Nelore	Cow	Weak	5 years	10.8	9.5	–	–
"	"	"	5 years	12.0	8.6	–	–
"	"	"	5 years	–	7.0	0.163	7.3
Gir	"	Fat-pregnant	4 years	9.2	8.1	0.120	7.1

SERUM (WET SEASON)

Nelore	Cow	Good	Heifer-6 years	11.0	4.3	0.083	9.0
"	"	"	" " "	10.3	6.0	0.125	8.4
"	"	"	" " "	11.2	5.2	0.187	7.6
"	"	"	" " "	10.5	3.5	0.104	7.4
"	"	"	" " "	11.0	4.5	0.166	8.6
"	"	"	" " "	9.5	4.5	0.145	7.2
"	"	"	" " "	10.6	5.3	0.145	7.8
"	"	"	" " "	11.3	3.5	0.145	7.4
"	"	"	" " "	10.6	5.0	0.145	7.2
"	"	"	" " "	9.0	5.4	0.145	8.0
"	"	"	" " "	10.5	4.5	0.083	8.4
"	"	"	" " "	11.5	6.0	0.125	7.8
"	"	"	" " "	10.0	5.6	0.104	8.0
"	"	"	" " "	–	7.5	–	7.6

Element	RESULT (x ± 95 C.L.)					
Grass	Dry	n	Wet	n	Units
Ca	0.35 ± 0.09	10	0.61 ± 0.12	15	%
P	0.05 ± 0.02	10	0.06 ± 0.01	15	%
Cu	5.13 ± 1.66	10	5.18 ± 1.09	15	ppm
Mn	186 ± 51.43	10	80.73 ± 14.09	15	ppm
Zn	89.14 ± 30.15	9	13.33 ± 1.96	15	ppm
Co	0.08 ± 0.01	10	0.09 ± 0.01	15	ppm
SERUM					
Ca	11.8 ± 2.37	5	10.55 ± 0.43	13	mg%
P	8.19 ± 1.53	7	4.87 ± 0.50	13	mg%
Cu	0.12 ± 0.09	3	0.13 ± 0.02	13	mg%
Total Prot.	7.12 ± 0.24	5	7.91 ± 2.34	13	%

Element	RESULT (x ± 95 C.L.)				
LIVER					
Co	0.1	1	0.10	1	ppm
Cu	200	1	169	1	ppm
Mn	8.7	1	9.0	1	ppm
Zn	95	1	94	1	ppm

Table 3

SAMPLES FROM NORTHEASTERN MATO GROSSO (B)

Element	RESULT ($\bar{x}$ ± 95% C.L.)				
Grasses	Dry		Wet	n	Units
Ca	0.29	1	0.30 ± 0.06	8	%
P	0.04	1	0.07 ± 0.02	8	%
Cu	4.8	1	4.7 ± 1.9	8	ppm
Mn	60	1	124.18 ± 62.59	8	ppm
Zn	28.6	1	10.75 ± 1.55	8	ppm
Co	0.07	1	0.09 ± 0.02	8	ppm

RESULTS

Grasses (Dry Season)	Ca%	P%	Cu ppm	Mn ppm	Zn ppm	Mo ppm	Fe	Mg
Native "Pool of samples"	0.29	0.04	4.8	60.0	28.6	0.085		
Material:								
LIVER (Dry Season)								
Pregnant cow (Last Trimester)			170	8.7	131.0	0.100		
GRASSES (WET SEASON)								
P. notatum	0.30	0.11	7.5	63.0	9.5	0.090		
" "	0.25	0.10	6.0	54.0	10.5	0.100		
Native	0.42	0.05	3.1	137.0	9.0	0.075		
"	0.28	0.04	2.2	115.0	13.0	0.125		
"	0.41	0.11	6.0	160.0	14.0	0.050		
"	0.21	0.04	7.5	285.0	11.0	0.150		
"	0.30	0.05	2.2	95.0	9.0	0.085		
"	0.28	0.05	3.4	84.5	10.0	0.060		
Material: LIVER (Dry Season)								
Pregnant cow (Last Trimester)			185	12.7	193.0	0.150		
" " "			107	11.0	180.0	0.050		
" " "			179	7.2	157	0.100		

SERUM (DRY SEASON) Sample	Animal	General Status	Observations	Ca %	P mg%	Cu mg%	Total Protein%	Fe	Mn
Nelore	Cow	Weak	3 years calves	–	6.2	–	6.5		
"	"	"	" "	12.8	4.7	0.096	6.2		
"	"	"	" "	10.6	5.6	0.065	6.4		
"	Heifer	"	1.5 years calved	13.4	8.6	0.092	–		
Gir	Cow	Weak	5 years	15.3	3.8	–	7.2		
Nelore	Steer	Fat	5 years	13.2	7.1	0.065	6.6		
"	Cow	Weak	5 years calved	12.4	6.2	–	7.4		
"	Heifer	"	2 years	10.9	6.0	0.086	7.0		
"	Cow	"	5 years calved	12.7	4.1	0.105	6.2		
Gir	Cow	Weak	4 years	14.2	5.8	0.063	–		
SERUM (WET SEASON)									
Nelore	Cow	Fair	6 years calved	10.0	3.9	0.104	5.4		
"	"	"	Dry cow-5 years	10.8	4.9	0.083	7.2		
Gir	Cow	Fair	Dry cow-6 years	8.0	5.8	0.120	8.0		
Nelore	Cow	Fair	6 years calved	8.5	4.1	0.104	5.6		
"	"	Poor	4 years-dry cow	–	5.1	0.063	8.4		
"	"	"	5 years-dry cow	10.00	4.8	0.063	8.0		

LIVER					
Element	**RESULTS (x ± 95 C.L.)**				
	Dry	**n**	**Wet**	**n**	**Units**
Co	0.1	1	0.1 ± 0.01	3	ppm
Cu	170	1	157 ± 1.92	3	ppm
Mn	8.7	1	10.30 ± 0.02	3	ppm
Zn	131	1	176.66 ± 0.70	3	ppm
SERUM					
Ca	12.83 ± 1.13	9	9.46 ± 1.44	5	mg%
P	5.81 ± 1.01	10	4.76 ± 0.72	6	mg%
Cu	0.08 ± 0.02	7	0.09 ± 0.02	6	mg%
Total Prot.	6.69 ± 0.38	8	7.1 ± 1.4	6	%

Table 4

SAMPLES FROM NORTHEASTERN REGION OF MATO GROSSO (C)

GRASSES (WET SEASON)					
Element	**RESULTS (x ± 95 C.L.)**			**n**	
Ca	0.29	1	0.55 ± 0.13	6	g%
P	0.07	1	0.06 ± 0.01	6	g%
Cu	8.0	1	7.80 ± 1.09	6	ppm
Mn	200	1	65.53 ± 34.45	6	ppm
Zn	22	1	16.18 ± 3.28	6	ppm
Co	0.07	1	0.09 ± 0.01	6	ppm
SERUM					
Ca	10.47 ± 1.35	4	10.77 ± 1.64	7	mg%
P	9.1 ± 1.67	5	7.54 ± 1.50	9	mg%
Cu	0.07 ± 0.03	4	0.09 ± 0.03	9	mg%
Total Protein	6.46 ± 1.30	5	5.02 ± 2.06	6	%

GRASSES (WET SEASON)	Ca mg%	P %	Cu ppm	Mn ppm	Zn ppm	Co ppm	Fe	Mg
P. notatum	0.52	0.035	7.7	54.0	17.7	0.095		
"	0.32	0.057	8.1	57.2	13.4	0.100		
"	0.34	0.067	7.0	45.0	17.5	0.075		
"	0.31	0.056	6.8	62.0	20.0	0.110		
"	0.41	0.072	7.5	44.0	17.0	0.085		
"	0.039	0.055	9.7	131.0	11.5	0.075		
Material: Grasses (Dry Season)								
P. notatum	0.29	0.07	8	200	22	0.075*		

*Taken from a pool of 5 samples.

SERUM (DRY SEASON)

Sample	Animal	General Status	Observations	Ca mg%	P mg%	Cu mg%	Total Protein	Fe	Mn
Nelore	Cow	Good	6 years-pregnant	9.8	8.0	0.096	7.6		
"	"	Weak	5 years-pregnant	9.7	8.5	0.061	7.0		
"	"	"	3 years-pregnant	11.3	8.0	0.062	11.5		
"	"	"	" "	11.1	10.0	0.062	4.8		
"	"	"	" "	—	11.0	—	6.4		

SERUM (WET SEASON)

Sample	Animal	General Status	Observations	Ca mg%	P mg%	Cu mg%	Total Protein%
Nelore	Steer	Good	3 years	8.7	5.8	0.115	10.4
"	Cow	Fair	6 years	10.5	7.6	0.112	5.0
"	"	"	6 years	—	8.6	0.150	5.8
"	Steer	Poor	2.5 years	10.9	9.0	0.065	2.4
"	"	Fair	2 years	11.3	11.0	0.150	5.0
"	"	"	3 years	13.6	8.4	0.065	4.2
"	Cow	Good	6 years (calving)	11.9	7.2	0.115	7.0
"	Sheep	Poor	1 year	8.5	4.9	0.022	1.0
"	"	Poor	1 year	—	5.4	0.065	4.4

Observations: Material: liver (Wet Season) Cu 276.0 Mn 9.0 Zn 214.0

Material: GRASSES (DRY SEASON)

Sample	Ca %	P %	Cu ppm	Mn ppm	Zn ppm	Mo ppm
*P. notatum**	0.31	0.03	3.7	180	29.2	0.075
" "	0.33	0.05	3.5	130	23.0	0.050
" "	0.36	0.03	2.9	100	10.8	0.090
" "	0.34	0.06	3.0	170	17.0	0.050
*M. minutiflora***	0.32	0.05	5.5	60	22.6	0.075
P. notatum	0.31	0.03	3.1	132	14.7	0.050
" "	0.34	0.025	4.6	140	25.0	0.060
Native + *H. rufa****	0.23	0.03	3.5	120	40.0	0.050
H. rufa	0.27	0.12	2.5	50	40.0	0.100
Material: LIVER (DRY SEASON)						
Cow in good condition			171	12	111	0.075

* Colonião: *Paspalum notatum*
** Gordura: *Melinis minutiflora*
*** Jaragua: *Hyparrhenia rufa*

GRASSES (WET SEASON)

Sample	Ca %	P %	Cu ppm	Mn ppm	Zn ppm	Mo ppm
P. notatum	0.30	0.14	7.0	71.0	18.0	0.075
" "	0.34	0.05	5.6	51.0	12.5	0.100
" "	0.30	0.075	6.2	120.0	13.5	0.090
" "	0.32	0.075	5.2	54.0	16.0	0.050
" "	0.39	0.16	8.0	82.0	15.0	0.085
H. rufa	0.34	0.075	6.5	100.0	14.0	0.150
Material: LIVER (WET SEASON)						
Weaned calf in good condition			165	9.0	89.0	0.085
" " " " "			265	7.2	184.0	0.076

SERUM (DRY SEASON)

Sample	Animal	General Status	Observations	Ca mg%	P mg%	Cu mg%	Total Protein %
Nelore	Cow	Good	6 years-Calved	—	10.0	0.104	—
Nelore	Cow	Good	5 years-Calved	9.1	6.0	0.088	—
Nelore	"	Weak	5 years-Diarrhea	9.6	11.5	0.088	6.0
"	"	"	6 years-Calved	11.7	8.5	0.088	7.4
"	Calf	Good	1 year-Weaned	12.8	10.4	0.087	6.7

SERUM (WET SEASON)							
Nelore	Cow	Good	6 years-Calved	9.5	7.5	0.042	7.2
"	"	"	" " "	9.0	8.0	0.042	7.8
"	"	"	5 years-Calved	10.0	7.4	0.042	7.4
Gir	Heifer	Good	2.5 years	8.8	10.0	0.083	7.6
Nelore	Heifer	Good	1.5 years	8.5	11.0	0.083	7.4
"	"	"	2.0 years	10.0	9.5	0.063	6.6
Gir	Cow	Good	8 years	9.8	8.0	0.120	7.0
Nelore	Heifer	Good	2.0 years	10.5	7.7	0.120	5.4
"	"	"	1.5 years	8.5	8.5	0.110	5.6

GRASS								
Element	RESULTS (x ± 95 C.L.)							
	Dry			n	Wet			n	Units
Ca	0.31	±	0.03	9	0.33	±	0.03	6	%
P	0.05	±	0.02	9	0.09	±	0.04	6	%
Cu	3.59	±	0.72	9	6.42	±	1.05	6	ppm
Mn	122.44	±	31.68	9	79.83	±	28.19	6	ppm
Zn	24.7	±	7.92	9	14.83	±	2.06	6	ppm
Co	0.07	±	0.01	9	0.09	±	0.03	6	ppm
SERUM									
Ca	10.8	±	2.78	4	9.40	±	0.56	9	mg%
P	9.28	±	2.64	5	8.62	±	0.97	9	mg%
Cu	0.09	±	0.01	5	0.08	±	0.02	9	mg%
Total Prot.	6.7	±	1.74	3	6.86	±	0.65	9	%
LIVER									
Co	0.075			1	0.08			1	ppm
Cu	171			1	215			1	ppm
Mn	12			1	8.1			1	ppm
Zn	111			1	136			1	ppm

Table 5

SAMPLES FROM NORTHERN REGION OF GOIAS

GRASS								
	RESULTS (x ± 95 C.L.)							
	Dry				Wet			
Ca	0.31	±	0.11	6	0.38	±	0.04	8	%
P	0.06	±	0.06	6	0.04	±	0.01	8	%
Cu	3.08	±	1.21	6	7.75	±	1.95	8	ppm
Mn	142.3	±	63.69	6	98.50	±	42.51	8	ppm
Zn	126.5	±	64.93	6	11.41	±	4.05	8	ppm
Co	0.07	±	0.02	6	0.09	±	0.01	8	ppm

GRASSES (DRY SEASON)								
Sample	Ca %	P %	Cu ppm	Mn ppm	Zn ppm	Co ppm	Fe	Mg
H. rufa	0.33	0.165	2.6	208	16.6	0.05		
Native+	0.23	0.030	3.2	166	18.6	0.10		
H. rufa	0.31	0.020	4.8	173	34.0	0.075		
Native	0.50	0.06	1.9	146	8.0	0.065		
H. rufa	0.20	0.04	2.0	182	18.2	0.100		
H. rufa+	0.28	0.05	3.1	142	11.1	0.075		
Native								
Material: LIVER (DRY SEASON)								
Cow in good condition			113	12.2	66	0.075		

GRASSES (WET SEASON)

	RESULTS							
	Ca %	P %	Cu ppm	Mn ppm	Zn ppm	Mo ppm	Fe	Mg
H. rufa	0.35	0.04	11.0	49	8.4	0.075		
Native	0.38	0.02	9.5	65	10.0	0.100		
Native	0.35	0.06	10	160	15.0	0.110		
H. rufa	0.40	0.05	7.0	52	10.0	0.065		
Native	0.38	0.04	6.0	54	8.4	0.100		
Native "varjao"	0.50	0.03	7.0	135	22.0	0.100		
Native "cerrado"	0.31	0.03	7.0	171	7.5	0.090		
Native "campo"	0.41	0.03	6.5	102	10.0	0.110		
Material: LIVER FOR WET AREAS								
Cow in good condition			210	10.8	145	0.150		

SERUM (DRY SEASON)

Sample	Animal	General Status	Observations	Ca mg%	P mg%	Cu mg%	Total Protein %
Nelore	Cow	Good	6 years, calved, diarrhea	11.5	5.0	0.041	7.0
Nelore	"	"	8 years, calved, diarrhea	11.1	—	—	6.8
Gir	"	"	6 years, calved, diarrhea	11.9	3.9	0.155	5.2
Nelore	"	"	6 years, calved, diarrhea	10.9	6.5	0.043	7.1
Nelore	"	Fair	5 years, calved, diarrhea	9.1	5.0	0.108	6.4
Nelore	"	"	5 years, calved, diarrhea	10.8	5.4	0.087	6.0
Gir	"	"	6 years, calved, diarrhea	9.4	6.8	0.150	6.6

SERUM (WET SEASON)

Nelore	Cow	Good	4 years	9.6	8.3	0.044	7.1
Nelore	"	Fair	6 years, calved	14.2	6.1	0.086	4.2
Nelore	"	"	5 years, calved	17.6	11.1	0.085	5.5
Nelore	"	Good	5 years	7.2	4.9	0.092	9.2
Gir	Cow	Good	5 years	13.4	8.0	--	6.4
Gir	"	"	5 years	9.8	6.5	0.09	7.4
Nelore	Cow	Good	5 years	9.6	5.7	0.067	6.2
Nelore	"	Fair	8 years, calved	15.8	11.4	0.069	5.1
Nelore	"	Good	6 years, calved	9.4	4.8	0.050	9.3
Nelore	"	"	6 years, calved	10.7	5.9	0.050	6.3
Gir	Heifer	Fair	1.5 years	10.2	6.9	0.100	4.4
Gir	"	"	2 years	16.2	11.6	0.120	5.1
Nelore	Heifer	Fair	1.5 years	9.1	5.2	0.050	4.0

SERUM

ELEMENT	RESULTS ($\bar{x} \pm 95$ C.L.)					
	Dry	n	Wet	n	Units
Ca	10.67 ± 0.97	7	11.75 ± 1.98	13	mg%
P	5.43 ± 1.12	6	7.41 ± 1.50	13	mg%
Cu	0.10 ± 0.05	3	0.07 ± 0.01	13	mg%
Total Prot.	6.59 ± 0.74	7	6.17 ± 0.39	13	%

LIVER

ELEMENT	RESULTS ($\bar{x} \pm 95$ C.L.)				
	Dry	n	Wet	n	Units
Co	0.075	1	0.15	1	ppm
Cu	113	1	210	1	ppm
Mn	12.2	1	10.8	1	ppm
Zn	66	1	145	1	ppm

Table 6

SAMPLES FROM NORTHEASTERN OF MATO GROSSO (D)

SERUM

ELEMENT	RESULTS (x ± 95 C.L.) Dry	n	Wet	n	
Ca	0.40 ± 0.26	5	0.45 ± 0.15	6	%
P	0.11 ± 0.02	5	0.09 ± 0.04	6	%
Cu	4.14 ± 1.90	5	6.71 ± 2.27	6	ppm
Mn	388.00 ± 230.49	5	120.33 ± 39.09	6	ppm
Zn	20.80 ± 5.36	5	17.95 ± 6.57	6	ppm
Co	0.06 ± 0.02	5	0.09 ± 0.04	6	ppm

GRASSES (WET SEASON)

Sample	Ca %	P %	Cu ppm	Mn ppm	Zn ppm	Mo ppm	Fe	Mg
Native	0.41	0.15	9.2	155.0	16.6	0.100		
P. notatum	0.45	0.06	6.7	160.0	19.0	0.060		
" "	0.41	0.07	4.7	129.0	16.6	0.075		
" "	0.31	0.13	9.5	125.0	28.0	0.050		
" "	0.41	0.11	4.7	66.0	19.0	0.130		
Material: GRASSES (DRY SEASON)								
Native	0.49	0.04	4.0	640.0	20.0	0.075		
"	0.43	0.05	6.5	430.0	20.0	0.085		
"	0.71	0.37	4.5	390.0	27.0	0.050		
P. notatum	0.20	0.06	2.5	120.0	15.0	0.030		
" "	0.21	0.03	3.2	360.0	22.0	0.085		

REGION	SAMPLE	ELEMENT	RESULTS (x ± 95 C.L.)	UNITS	n
A CACERES MATO GROSSO BARRA DOS BUGRES NORTELANDIA	Grass	Ca	0.36	%	1
		P	0.05	%	1
		Cu	2.5	ppm	1
		Mn	110	ppm	1
		Zn	58	ppm	1
		Co	0.1	ppm	1
	Serum	Ca	10.77 ± 0.94	mg%	3
		P	4.9 ± 0.66	mg%	3
		Cu	0.09 ± 0.03	mg%	3
		Total Protein	5.9 ± 0.43	%	3
	Liver	Co	0.1	ppm	1
		Cu	291	ppm	1
		Mn	17	ppm	1
		Zn	100	ppm	1
B CACERES MATO GROSSO BARRA DOS BUGRES NORTELANDIA	Grass (Pool)	Ca	0.30	%	1
		P	0.09	%	1
		Cu	3.8	ppm	1
		Mn	125	ppm	1
		Zn	15	ppm	1
		Co	0.095	ppm	1
	Serum	Ca	10.23 ± 0.75	mg%	6
		P	5.72 ± 0.77	mg%	10
		Cu	0.09 ± 0.01	mg%	4
		Total Protein	6.17 ± 0.41	%	10
	Liver	Co	0.12	ppm	1
		Cu	188	ppm	1
		Mn	5.71	ppm	1
		Zn	100	ppm	1

REGION	SAMPLE	ELEMENT	RESULTS (x ± 95 C.L.)	UNITS	n
C CACERES MATO GROSSO BARRA DOS BUGRES NORTELANDIA	Grass (Pool)	Ca	0.36	%	1
		P	0.07	%	1
		Cu	3.9	ppm	1
		Mn	164	ppm	1
		Zn	41.5	ppm	1
		Co	0.1	ppm	1
	Serum	Ca	11.82 ± 1.03	mg%	5
		P	10.9 ± 1.97	mg%	5
		Cu	0.10 ± 0.03	mg%	5
		Total Protein	6.16 ± 0.20	%	5
	Liver	Co	0.13	ppm	1
		Cu	166	ppm	1
		Mn	99	ppm	1
		Zn	9	ppm	1
SOUTHERN BASIN OF THE ARAGUAIA RIVER	Grass (Pool) 1 + 1 samples*	Ca	0.29	%	1
		P	0.12	%	1
		Cu	6.6	ppm	1
		Mn	140	ppm	1
		Zn	28	ppm	1
		Co	0.1	ppm	1
	Serum (Pool)	Ca	11.6	mg%	1
		P	7.5	mg%	1
		Cu	0.1	mg%	1
		Total Protein	6.6	%	1
	Liver	Co	0.1	ppm	1
		Cu	156	ppm	1
		Mn	12	ppm	1
		Zn	114	ppm	1
A DIAMANTINO AND CHAPADA GUIMARAES	Grass	Ca	0.36 ± 0.12	%	10
		P	0.08 ± 0.06	%	10
		Cu	4.2 ± 0.56	ppm	10
		Zn	23.54 ± 15.48	ppm	10
		Mn	159.6 ± 65.97	ppm	10
		Co	0.06 ± 0.01	ppm	10
	Serum	Ca	11.13 ± 0.57	mg%	12
		P	7.83 ± 0.56	mg%	13
		Cu	0.08 ± 0.02	mg%	11
		Total Protein	6.46 ± 0.38	%	14
	Liver	Co	0.2	ppm	1
		Cu	210	ppm	1
		Mn	11.4	ppm	1
		Zn	80	ppm	1
B DIAMANTINO AND CHAPADA GUIMARAES	Grass	Ca	0.39 ± 0.11	%	10
		P	0.06 ± 0.03	%	10
		Cu	5.56 ± 0.88	ppm	10
		Mn	183.6 ± 37.04	ppm	10
		Zn	22.21 ± 6.89	ppm	10
		Co	0.06 ± 0.01	ppm	10
	Serum	Ca	11.44 ± 0.48	mg%	7
		P	8.11 ± 1.08	mg%	8
		Cu	0.11 ± 0.04	mg%	6
		Total Protein	6.76 ± 0.52	%	8
	Liver	Co	0.15	ppm	1
		Cu	105	ppm	1
		Mn	8.5	ppm	1
		Zn	135	ppm	1

*Insufficient samples and analyses for a pool.

Table 1 (continued)

REGION	SAMPLE	ELEMENT	RESULTS $\bar{x} \pm 95\%$ C.L.	UNITS	NUMBER
C DIAMANTINO AND CHAPADA GUIMARAES	Grass	Ca	0.38 ± 0.08	%	10
		P	0.10 ± 0.07	%	10
		Cu	3.97 ± 0.97	ppm	10
		Mn	160 ± 29.36	ppm	10
		Zn	18.9 ± 3.82	ppm	10
		Co	0.06 ± 0.01	ppm	10
	Serum	Ca	10.9 ± 0.55	mg%	8
		P	7.25 ± 1.42	mg%	8
		Cu	0.1 ± 0.01	mg%	7
		Total Protein	5.95 ± 2.49	%	6
	Liver	Co	0.12	ppm	1
		Cu	137	ppm	1
		Mn	8.5	ppm	1
		Zn	160	ppm	1
ARINOS AND JURUENA RIVER BASINS	Grass	Ca	0.41 ± 0.06	%	10
		P	0.07 ± 0.03	%	10
		Cu	4.35 ± 1.08	ppm	10
		Mn	152.8 ± 38.07	ppm	10
		Zn	31.8 ± 6.09	ppm	10
		Co	0.07 ± 0.01	ppm	10
	Serum	Ca	11.85 ± 0.59	mg%	13
		P	7.34 ± 0.65	mg%	13
		Cu	0.11 ± 0.02	mg%	11
		Total Protein	6.22 ± 0.47	%	13
	Liver	Co	0.09	ppm	1
		Cu	121	ppm	1
		Mn	8.5	ppm	1
		Zn	100	ppm	1

Table 7

RESULTS OF THE ANALYSES OF GRASS LEAVES FROM DIFFERENT REGIONS OF S.U.D.A.M., DURING WET SEASONS

MAGNESIUM AND MOLYBDENUM

RESULTS

	Samples	Mg(%)	Mo (ppm)
I NORTH OF GOIAS	1. *H. rufa*	0.27	0.11
	2. Native	0.14	0.02
	3. Native (pincaba)	0.23	0.16
	4. *H. rufa*	0.06	0.02
	5. Native (field)	0.06	0.03
	6. Native	0.05	0.03
	7. Native	0.06	0.02
II SUL DO PARA	11. *P. notatum*	0.10	0.41
	12. " "	0.10	0.13
	13. " "	0.14	0.39
	14. " "	0.16	0.29
	15. " "	0.11	0.79
	16. " "	0.12	0.75
	17. " "	0.09	0.15
	18. " "	0.15	0.45

Table 1 (continued)

REGION	SAMPLE	ELEMENT	RESULTS $\bar{x} \pm 95\%$ C.L.	UNITS	NUMBER
	19.	*P. notatum*	0.14		1.38
	20.	" "	0.17		1.71
	21.	" "	0.16		2.22
III	22.	" "	0.15		1.66
BARRA DOS BUGRES	23.	" "	0.25		3.15
	24.	" "	0.10		1.35
	25.	" "	0.16		2.14
	26.	" "	0.15		1.77
	27.	*P. notatum*	0.09		0.05
	28.	" "	0.21		0.03
IV	29.	" "	0.12		0.02
NE OF MATO GROSSO	30.	" "	0.16		0.07
	31.	" "	0.12		0.02
	32.	" "	0.10		0.11
	33.	*B. mutica*	0.13		0.06
V	34.	Native	0.08		0.03
NORTH, SOUTH and	35.	Brachiaria sp	0.26		0.03
EAST OF MATO GROSSO	36.	Native	0.04		0.01
	37.	Native	0.05		0.04
	38.	Native	0.01		0.02

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LIMITING NUTRIENTS: THEIR IDENTIFICATION AND SUPPLEMENTATION IN GRAZING RUMINANTS

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Livestock production in much of Southern Africa is largely dependent upon the vast tracts of unimproved open grassland and savannah which cover much of the continent from the equator southwards. The performance of unsupplemented animals kept under these conditions is, however, severely restricted by the extreme variation in nutritive value of the grazing. Both the quantity and the quality of available herbage closely follows the rainfall pattern which is strictly seasonal, the summers being wet and the winters dry and often cold. The environmental conditions of this region are described in greater detail by Topps (1971).

The body weights of animals grazing such pastures show a characteristic pattern of rapid summer gains followed by loss of weight during winter. Under the more extreme conditions of the "sour" highlands animals may lose as much as 30% of their maximum summer weight. Because of this, cattle will take 6 years or even longer to reach their maximum mature weight. From an economic point of view the result of fluctuating body weight is disastrous as beef cows are unable to maintain their weight in winter and are not able to recover these losses during the immediate post-calving period in spring. The net result is that cows tend to conceive in alternate years, only after they have had a chance to recover their lost body reserves. Limited growth rate and low calving percentages combine to give the poor herd turnover rates so characteristic of extensive beef production in Africa.

In an attempt to identify the nutrients and other factors responsible for the poor performance of grazing ruminants, extensive research work has been conducted in Southern Africa since the turn of the century. It is the purpose of this paper to describe some of this work which might be of significance in areas of South America where similar environmental conditions are encountered.

Significance of Phosphorus as a Limiting Nutrient

Research work on supplementary feeding and the use of phosphorus supplements in particular, has its origin in Theiler's (1912, 1920) investigations into the cause of bovine botulism *(lamsiekte)* and aphosphorosis *(stywesiekte)*. During the course of their investigations Theiler and his associates (1927) found a marked deficiency of phosphorus in both soils and pastures of areas affected by *lamsiekte* and *stywesiekte*. Cattle grazing such pastures showed sub-normal growth and reproduction and exhibited a depraved appetite or "pica" manifesting itself in the eating of wood, stones, rotten bones, dead tortoises, skins and other carrion. In the process animals ingested the botulism toxin, causing paralysis and death of the affected animals.

By feeding bone meal at a rate sufficient to supply 9 g phosphorus to growing and dry cattle or approximately 15 g to breeding cattle pica, the ingestion of toxic materials could be stopped. In experiments reported by Theiler *et al.* (1924) it was demonstrated that weaned calves, fed phosphorus, could gain 61 kg more weight over a 12 month period than unsupplemented controls. Similarly, young oxen gained 68 kg per year more than their controls while supplemented cows showed a weight advantage of 48 kg over an 11-month feeding period. Bisschop and Du Toit (1929) later showed that by continuous phosphorus supplementation, 2.5 year old oxen had a 30% weight advantage over their controls while bone meal supplemented cows weighed 20% more and produced 30% more calves. Death losses amongst 139 bone meal-fed cows over a 40-month period amounted to only 10% while 94% of the unsupplemented control cows died during the experimental period.

The success of these early experiments led to wide ranging surveys of the nutrient content of pastures in Southern Africa (Du Toit *et al.*, 1935; Du Toit *et al.*, 1940; Van Wyk *et al.*, 1955) and the mapping of protein and phosphorus deficiency areas (Du Toit *et al.*, 1940). The beneficial effects of phosphorus supplementation were subsequently confirmed by means of feeding trials in other regions of Southern Africa (Kotze, 1948; Hurrell and Dugdale, 1958; Shur, 1968; Ward, 1968; Grant, 1975).

Seasonal Response to Phosphorus Supplementation

Analytical surveys show that the phosphorus level of grazing is at its lowest during the dry season and at its highest during spring after the first rains (Table 1).

Table 1

PERCENTAGE PHOSPHORUS IN PASTURE FROM DIFFERENT REGIONS AND DURING DIFFERENT MONTHS OF THE YEAR (Du Toit *et al.*, 1940)

Region	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	0.13	0.11	0.11	0.11	0.10	0.09	0.09	0.07	0.09	0.11	0.13	0.15
2	0.15	0.14	0.11	0.11	0.08	0.08	0.07	0.07	0.08	0.11	0.14	0.18
3	0.13	0.11	0.10	0.10	0.07	0.07	0.07	0.06	0.06	0.07	0.09	0.13
4	0.13	0.13	0.11	0.11	0.07	0.07	0.07	0.06	0.04	0.10	0.12	0.13
5	0.16	0.16	0.15	0.13	0.13	0.12	0.11	0.11	0.08	0.09	0.19	0.18
6	0.16	0.13	0.12	0.10	0.09	0.08	0.07	0.07	0.06	0.08	0.13	0.18
7	0.13	0.15	0.12	0.12	0.09	0.07	0.06	0.05	0.06	0.09	0.09	0.12
8	0.20	0.17	0.17	0.18	0.16	0.15	0.15	0.15	0.14	0.15	0.16	0.19
9	0.11	0.12	0.12	0.12	0.14	0.13	0.14	0.16	0.15	0.14	0.13	0.12

It is therefore often assumed that phosphorus supplements exert their greatest influence during the dry season. This is, however, not supported by the results of feeding experiments. This fact is borne out by all experimental work in which responses to phosphate supplementation are recorded. Published results in both South Africa and Rhodesia show quite clearly that phosphorus supplements, if given alone, have no effect on reducing winter weight loss. This is illustrated by the results of Van Schalkwyk and Lombard (1969) summarized in Table 2. In fact some studies show that phosphorus, if given as the sole supplement, can actually accentuate winter weight loss (Shur, 1968; Ward, 1968). This phenomenon has also been observed in the sheep feeding trials reported by Kotze (1924) as summarized in Table 3 and by Australian results of Winks and Laing (1972) recorded in Table 4. It is therefore obvious that phosphorus is not the first

Table 2

AVERAGE WEIGHT CHANGE (kg) OF CATTLE WITH INORGANIC PHOSPHORUS LEVELS OF BLOOD PLASMA (mg %) GIVE IN BRACKETS

Date	Season	Control Group	Winter Group	Summer Group	Year Group
1 January – 31 March	"Summer"	+35.2 (3.74)	+41.6 (4.13)	+61.6 (6.90)	+57.1 (7.04)
1 April – 30 June	"Winter"	+5.3 (5.41)	+18.1 (8.27)	+14.0 (4.78)	+6.8 (7.28)
1 July – 30 September	"Winter"	-29.8 (4.00)	-30.3 (8.03)	-36.3 (4.15)	-30.6 (7.77)
1 October – 31 December	"Summer"	+45.7 (3.99)	+61.6 (5.41)	+77.5 (7.54)	+88.1 (7.97)

Table 3

EFFECT OF BONE MEAL SUPPLEMENTS ON SEASONAL WEIGHT CHANGE (kg) OF SHEEP OVER A 3-YEAR EXPERIMENTAL PERIOD

Treatment	First Summer	First Winter	Second Summer	Second Winter	Third Summer	Third Winter
Control	-0.1	-1.9	+1.8	-6.6	+4.0	+1.0
Bone meal	+2.7	-4.2	+9.7	-10.7	+7.0	-2.0

Table 4

SEASONAL EFFECT OF UREA, MOLASSES AND PHOSPHORUS ON LIVEWEIGHT CHANGE (kg) IN GRAZING CATTLE, QUEENSLAND, AUSTRALIA

	Control Group	Molasses Group	Molasses + Phosphorus	Molasses + Urea	Molasses + Urea + Phosphorus
1 January – 1 May	+74.8	+80.5	+80.5	+73.6	+78.2
1 May – 9 June	+ 5.2	+ 6.8	+ 5.2	+14.0	+ 7.2
9 June – 16 October	-29.4	-32.0	-42.2	- 1.3	-10.2
Total weight change	+50.6	+55.3	+43.5	+86.3	+75.2

(Urea intake = 56 g/day; Molasses intake = 230 g/day; P intake = 5 g/day)

limiting nutrient in dry winter grazing and that there are other factors which are more critical to the grazing animal under these conditions. No attempt appears to have been made to explain these apparently negative responses to dry season phosphorus supplementation. Animals in a state of negative nitrogen and/or energy balance must, however, have an extremely low phosphorus requirement so that the feeding of phosphorus under these conditions could create nutritional imbalances.

Although phosphorus supplements have not been shown to have any advantage while animals are in the process of losing weight, Van Schalkwyk and Lombard (1969) were able to demonstrate a significant phosphorus carry over effect (Table 2). These workers compared 4 groups of cattle receiving phosphorus supplements either in winter or in summer or throughout the year while a fourth group acted as control. During the period of weight loss the "winter"-fed group showed the same rate of weight loss as the control group but during the subsequent 3-month period, when they received no supplement, they gained 35% more weight than the control group. During the winter feeding period and subsequent 3-month period this group also maintained significantly higher blood plasma inorganic phosphate levels than the control group. These results show that animals fed phosphorus during the dry season are apparently able to build up phosphorus reserves which benefit the animal during subsequent periods of rapid growth. Thus although phosphorus supplements appear to have little advantage during periods of weight loss, they could conceivably be important in the case of reproducing females.

Nutrient Deficiencies Causing Dry Season Losses

Because phosphorus is not effective in reducing dry-season weight loss, research workers during the past 40 years have increasingly directed their attention towards overcoming this problem. Analytical surveys and digestion trials showed that other factors, notably protein and energy, to be as deficient as phosphorus in dry grazing. The earlier belief that lack of energy might be the primary cause of winter weight loss (Smuts and Marais, 1940; Louw and Van Der Wath, 1943) has subsequently been disproved by the results of many investigators, both in Southern Africa and Australia (Rhodes, 1956; Von La Chevallerie, 1965; Van Niekerk *et al.*, 1968; Nel and Van Niekerk, 1970; Winks *et al.*, 1970; Winks and Laing, 1972). In fact some of these experiments show that energy-rich but protein-deficient supplements such as molasses or maize meal can actually accelerate weight loss if fed on protein deficient pastures (Table 4, Table 5). The depressing effect of molasses as sole supplement under these conditions can be attributed to the fact that

Table 5

EFFECT OF MOLASSES AND UREA SUPPLEMENTATION ON LIVEWEIGHT GAIN AND GRASS INTAKE OF GRAZING CATTLE OVER A 141-DAY EXPERIMENTAL PERIOD

	Control Group	Molasses Group	1 Urea: 20 Molasses	1 Urea: 10 Molasses
Molasses intake, g/day	–	910	865	820
Urea intake, g/day	–	–	45	90
Total weight change, kg	-37.0	-41.7	-22.2	-0.2
Grass intake, kg/day	3.62	1.84	2.64	4.29

molasses (and starch) stimulate the growth of rapid growing amylolytic and other lactic acid-producing organisms at the expense of the slower growing cellulolytic bacteria. The net result is a lowering of rumen pH, poorer digestion of cellulose, slower rate of passage and depressed pasture intake (Gilchrist and Swartz, 1972). These results clearly show that energy is not the primary limiting nutrient in dry winter grazing.

During subsequent years the importance of protein (or ammonia) as the major and first limiting nutrient in dry grazing has been conclusively demonstrated. This work shows that the feeding of protein on protein deficient pasture improves the animal's ability to digest roughages and considerably enhances the animal's voluntary food intake. Protein supplementation therefore not only enables the animal to make better use of the feed it ingests, but the improved feed intake also enables the animal to satisfy its energy requirements. By supplementing protein, the secondary energy deficiency can be simultaneously eliminated. The voluminous research work dealing with the use of protein, urea and energy supplements in Southern Africa has been reviewed by Pieterse (1966, 1967) and by Topps (1971). It has furthermore been demonstrated how the use of protein or protein plus energy supplements can reduce weight loss in beef cows and markedly improve productive and reproductive performance in the process (Bembridge, 1963; Elliott, 1964; Shur, 1968; Ward, 1968; Lesch *et al.*, 1969; Maree and Harwin, 1971; Steenkamp *et al.*, 1975).

Role of Phosphorus in Protein-Energy Supplements

It is generally assumed that phosphorus should be fed in conjunction with protein or protein-energy supplements during the dry season. For this reason phosphorus is widely used in practice as an ingredient in winter supplements. Experimental evidence in support of this practice is, however, presently still lacking. Ward (1968), working with reproducing cows in Rhodesia, was able to demonstrate an increase in cow productivity (in terms of weight of calves weaned) by feeding both bone meal and peanutcake meal. In combination, these supplements had an additive effect. As bone meal was fed throughout the year and the protein supplement only in winter, it is not known whether bone meal exercised its effect only during summer. This experiment therefore does not produce conclusive evidence in favor of the inclusion of phosphorus in winter supplements. Winks and Laing (1972), using phosphorus in conjunction with urea-molasses supplements, found phosphorus to have a negative effect when fed with urea and molasses during the dry season. The phosphorus status of the soils and pastures of Australia is, however, far less critical than in Africa. This experiment nevertheless illustrates the need to resolve the uncertainty surrounding the role of phosphorus in winter protein supplements.

Phosphorus as a Summer Supplement

The very marked response to summer phosphorus supplements, during a period when the phosphorus levels of pastures are at their highest (Table 1) and when animals are rapidly gaining weight, indicates that phosphorus must be the most important limiting factor in summer grazing. That this is in fact the case is illustrated by the inability of either energy (Lyle, 1970) or protein supplements (Kreft, 1963, 1966; Van Niekerk and Muir, 1970; Lyle, 1970) to have any significant effect on improving early summer weight gains.

Identification of Mineral Deficiencies

The identification of mineral deficiencies is a relatively straightforward procedure in areas where such deficiencies are sufficiently acute to result in recognizable clinical deficiency symptoms. The general procedure in such cases has been to do chemical analysis of pasture and/or animal tissue samples from problem areas followed by feeding or dosing trials to prove the existence of the suspect mineral deficiency. This procedure led to the discovery, not only of the phosphorus deficiencies referred to above, but also to the discovery of areas of acute copper (Perold, 1952), cobalt

(Perold *et al.*, 1957; Van Der Merwe, 1959) and iodine (Blom, 1934) deficiency. In general, these trace element deficiency areas are relatively well delineated, often being associated with specific soil and climatic conditions.

The important question of identifying borderline deficiency areas, which may not produce clinical deficiency symptoms, but which may nevertheless be of considerable economic importance, is of utmost practical importance. The idea of using soil analysis as an indication of possible trace element deficiencies has been rejected since alkaline soils may be rich in trace minerals which are not available to plants growing in such soils (Perold 1952, 1956). In an attempt to resolve this problem, extensive surveys of the mineral composition of plants themselves were carried out. Although these surveys proved to be useful in identifying areas of potential protein and phosphorus deficiencies, they have been of little use in exposing trace element deficiency regions. Van Der Merwe (1967) has pointed out the almost impossible task of identifying trace element deficiencies by this means. His own work and that of other investigators at Stellenbosch University, spanning a period of almost 40 years, has revealed the complex nature of this problem. The interpretation of analytical results is complicated, not only by trace mineral interactions, but by factors such as depth and distribution of the roots of plants being analyzed. Deep rooted shrubs and edible trees, for example, often grow in conjunction with shallow rooted grasses. The significance of this point is illustrated by Fryer's (1967) work where he failed to measure a response to copper supplementation in an area with very low copper status in grass pastures. The only explanation he could find was that a shrub growing in the same area had up to 15 times the level of copper in its leaves. Under these conditions, the selective grazing habits of animals make it impossible to predict the concentration of ingested nutrients. Van Der Merwe (1967) considers pasture and tissue analysis as only the first step in identifying nutrient deficiencies and stresses the importance of using diagnostic experiments as proof of deficiencies.

The use of tissue analysis also has limitations. Although an acute phosphorus deficiency is associated with low plasma inorganic phosphorus levels, this measurement is not reliable in diagnosing less marked, but nevertheless economically important, deficiencies. This is illustrated by Ward's (1968) experiment where normal blood plasma phosphate levels failed to indicate a sub-clinical phosphorus deficiency revealed by a 21% increase in cow productivity following year-long phosphorus supplementation. In an ambitious program to identify trace elements deficiency areas, Boyazoglu (1973 and personal communication, 1975) has analyzed over 10,000 liver samples for a whole range of trace elements. Based on deviations from normal values, Boyazoglu has identified mineral "deficiencies" in 10 regions of South Africa and its adjoining territories. Unfortunately, no evidence is produced proving that grazing animals would respond to supplements of the "deficiencies" indicated by his survey. The question of identifying sub-clinical trace element deficiencies thus remains an unresolved problem which will undoubtedly receive further attention from research workers.

Formulation and Feeding of Range Supplements

Based on the principle of supplementing only those nutrients which are known to limit animal production during different seasons of the year, three basic supplementary feeding programs have evolved in Southern Africa.

Summer Supplements

During the period when animals are gaining weight, only phosphorus is supplemented. This is usually fed in the form of a free-choice salt-phosphate "lick". Salt is used not only to attract animals, but it also serves to limit intake. A mixture of 50% salt and 50% calcium phosphate is often used. Molasses may be added to this mixture at a rate of 5-10%, acting as a binding agent and also as a palatability factor in those areas where lick intakes are poor.

Dry Season Maintenance Supplements

When protein is the major limiting nutrient during the dry season, a wide variety of supplements can be used. One of the simplest and most widely fed supplements consists of a mixture of 10-25% urea, 25-40% maize meal, 25% calcium phosphate and 25% salt. This mixture can be dangerous and its use must be carefully controlled. Other protein sources are extensively used if available. Salt-fish meal licks are expensive, but extremely effective. Oilcake meals are also highly prized as dry season supplements. In recent years broiler litter and dried poultry layer manure have become popular as sources of protein, energy and minerals. Liquid feed supplements, made from urea, molasses, phosphoric acid and trace minerals, are also effective as dry season supplements. Commercially, a wide variety of meals and blocks are manufactured for the large winter maintenance market.

Production Supplements

In certain areas the natural grazing is so poor that protein supplements alone are not enough to ensure an adequate energy intake from the pasture. This is particularly true in the case of lactating cows. In such cases protein-energy supplements are preferred. Maize meal and molasses are cheap energy sources and are fed in conjunction with protein supplements in such cases. Protein supplements can also be effectively combined with farm-produced feeds such as hay and silage for this purpose.

Feeding of Trace Minerals

If trace elements are required, these are mixed in with the other ingredients of the lick. In areas of known deficiencies, only the deficient elements can be added, or alternatively, a whole range of elements (shotgun mixture) can be fed. Supplementing trace elements in areas with brack (saline) waters, where stock refuse to consume salt supplements, is a problem. In such cases it is not possible to feed trace elements in a lick. It is also not possible to feed the trace minerals through the drinking water, as the trace minerals are precipitated in alkaline water. This problem was solved by Perold (1956) through the development of trace element complexes which remain in solution when added to brack water.

Summary

The primary objective of supplementary feeding of grazing animals should be to obtain maximum returns from the pasture with a minimum investment in supplementary feeds. To achieve this, it is necessary to determine in what respects the grazing is deficient and how these deficiencies can best be supplemented. In Southern Africa, research workers have succeeded in identifying the most important limiting nutrients in various regions and in different seasons of the year. Their work emphasizes the importance of supplying these nutrients and the futility and economic wastefulness of feeding nutrients which have not been shown to limit animal performance.

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