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MINERAL INTERRELATIONSHIP BETWEEN SOIL-PLANT-ANIMAL IN THE NORTHERN AND SOUTHERN REGIONS OF VERACRUZ, MEXICO

by

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ABSTRACT

MINERAL INTERRELATIONSHIP BETWEEN
SOIL-PLANT-ANIMAL IN THE
NORTHERN AND SOUTHERN REGIONS
OF VERACRUZ, MEXICO

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The mineral soil-plant-animal interrelationships were studied in the North and South regions of the state of Veracruz, Mexico.

Low soil phosphorus, magnesium, copper and selenium concentrations were found in both regions, where 89%, 18%, 72%, and 21% of the samples were deficient, respectively.

In Region I (South) 75% and 56% of Pangola and Llano grass samples were deficient in calcium, 88% and 94% in phosphorus, 31% and 24% in magnesium, 43% and 49% in copper, and 43% and 53% in selenium, respectively. In Region II (North) 11% and 0% of Star and Guinea grasses were deficient in calcium, 27% and 8% in phosphorus, 77% and 77% in magnesium, 25% and 15% in copper and 66% and 61% in selenium, respectively.

Mineral deficiencies in grasses were reflected in the cattle grazing on it. Deficiencies of calcium, phosphorus, magnesium, copper and selenium were detected with different degrees of incidence in cows, heifers and calves.

TO MY MOTHER

ANA MARIA AYON

AND

TO THE MEMORY OF MY FATHER

VICTOR MONROY

whose sacrifices, encouragement, support and understanding throughout the years made possible the accomplishment of this goal.

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LIST OF ABBREVIATIONS

CA	Calves
CO	Cows
DM	Dry Matter
GRA	Grass
HB	Hemoglobin
HE	Heifers
HT	Hematocrit
Reg	Region
SO	Soil

Compound Abbreviations should be read as follows:

CASe	Calves Selenium
COK	Cows Potassium
GRAP	Grass Phosphorus

INTRODUCTION

Ruminants long have had a special role in human economy, providing meat, milk, leather, and wool. They are also a major source of power, and transportation in many parts of the world. Because of the presence of rumen microorganisms, ruminants are able to utilize cellulose to produce high quality human food.

Ruminants, like all other animals, must receive all of the essential dietary nutrients in optimal amounts to maintain health, and to grow and reproduce with maximal efficiency. If nutrients are imbalanced, normal development will cease. Proper nutrition of the rumen microorganisms is essential for digestion of feed in the rumen.

In countries other than those of western Europe and North America, a large proportion of animals obtain food entirely from pasture and receive no supplements for the whole or the greater part of the year. In pastoral systems wide variations in quality and quantity of forages exist. These variations depend on many environmental factors as well as management practices.

In Latin America, livestock production is based exclusively on grasslands with minimal or no supplementation. Native grasses provide the nutrients required to support reasonable animal performance. However, climatic and seasonal factors modify the amount and quality of the nutrients available in the forage. The primary limitation in animal production is lack of forage during the dry

season. Adverse effects on cattle depend on the severity and duration. Weight losses are large among all classes of cattle. Deaths are substantial, particularly for older cows and for calves born during the dry season.

Animal reproduction rates are low. Thirty to 50% of the cows calve per year (17). Steers require 4 to 6 years to obtain the desired market weight, with annual gains in weight between 50 and 100 kg.

Malnutrition is commonly believed to be the most important limitation to ruminant livestock production in tropical countries. Wasting diseases, loss of hair, depigmented hair, noninfectious abortion, diarrhea, anemia, loss of appetite, tetany, low fertility and pica are clinical signs suggestive of nutrient deficiencies.

Much of the work on nutritional deficiencies has been related to minerals. Becoming more generally recognized among animal producers are the facts that concentrations of soil minerals and their availability to plants are strongly related to the health of animals fed on plants grown on deficient soils. Studies of mineral deficiencies are important for making available information to livestock producers.

Mexico has a National Soil Mapping program to determine mineral adequacies in regions important for livestock production. This thesis is a study of the mineral status of soils, plants, and cattle in two different regions in the state of Veracruz, Mexico.

The objectives of this experiment are: 1) To determine the mineral status of grazing animals in two different regions in the state of Veracruz, Mexico. 2) To find appropriate methodology for

sampling soils, plants and animals.

LITERATURE REVIEW

During recent years, knowledge of nutritional physiology of minerals has developed rapidly. This review will be confined to aspects of mineral nutrition that involve minerals in soils, plants and animals.

Minerals are very important in the metabolism of organisms. They are required for biosynthesis of essential nutrients for bones and teeth, as constituents of proteins and lipids and as cofactors for enzyme systems of the body. They are also related to osmotic pressure and acidbase equilibria, and have effects on the irritability of muscles and nerves.

Evolution has selectively established certain elements as essential for the functioning of living organisms. At the present time 22 of the 90 naturally occurring elements are known to be essential for animal life (129). They can be divided into two groups based on the amounts needed to satisfy the requirements of each elements. I) Macroelements are expressed in milligrams or grams required in daily ration. They are: calcium (Ca), phosphorus (P), magnesium (Mg), sodium (Na), sulfur (S), potassium (K), and chloride (Cl). II) Microelements, or trace elements, are expressed in parts per million (ppm). They are: iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), nickel (Ni), cobalt (Co), molybdenum (Mo), selenium (Se), chromium (Cr), iodine (I), fluoride (F), tin (Sn), silicon (Si), vanadium (V), and arsenic (As).

Different criteria of essentiality have been used to establish the classification of elements (14, 79, 80, 105, 116). Schutte relates the criteria of essentiality as follows:

An element cannot be considered essential, unless:

- A deficiency of it makes it impossible for plant and animal to complete the vegetative or reproductive stage of its life cycle.
- Such deficiency is specific to the element in question, and can be corrected or prevented only by supplying this element.
- The element is directly involved in the nutrition of the plant or animal, quite apart from its possible effects in correcting some microbial or chemical condition of the external medium.

An element is considered by Mertz (79) to be essential if its deficiency consistently results in impairment of a function from optimal to suboptimal.

Further classification for trace elements is done and it is justified for a few elements such as lead, cadmium, and mercury because their biological significance is confined to toxic properties (129). Verchikov (132) describes three zones of action: a) Biological, which expresses the optimal supplementation and normal function. b) Pharmacological, where increasing doses of the element produce a phase of irritation and stimulation of some functions. c) Toxicological, where higher doses produce signs of toxicity.

Domestic animals can be exposed to potentially toxic mineral

elements from several sources. High concentration in the diet can result in acute toxicities. Also lower levels of certain minerals may be consumed over extended periods of time and result in tissue accumulation of the element leading to chronic toxicity.

Ammerman (2) suggested that a complete evaluation of mineral toxicity requires information on concentration, form and distribution of the element in water, soils, and air. An element is known as toxic if it impairs growth or metabolism of an organ when it is supplied above certain concentrations.

All elements are toxic at high concentrations and some are notorious poisons even at low concentrations. A good example is copper. An optimal range of concentration (sometimes narrow) exists for the supply of each element to each organism. Smith 1962 (cited by Bowen) showed the ideal curve relating growth and concentration of a nutrient, in which the difference in concentration of a certain element between minimal dietary requirement and maximal safe level or maximal tolerance level varies considerably under different conditions.

To discuss the complexity of biological toxicity of one element requires the new concomitant discussion of the effects of a deficiency of another interacting element or elements (19).

Mineral Availability

It is generally recognized that the concentration of a mineral element in a particular feed or ration has little significance unless it is qualified by a factor indicating the biological

avilability of the element to animals.

Physiological availability, or potency, is influenced by two principal factors. One is the chemical form in which the element is ingested. The second factor is the ratio or proportion that the dietary concentration of that element bears to other elements or compounds with which it reacts metabolically (130).

A number of terms have been developed to describe certain specific measurements. These include percent utilization, percent apparent digestibility, percent of absorption and others. The term biological availability is used as a measure of the ability of the element or ion under consideration to support some physiological process. Biological availability data are reported in numerical terms relative to a previously selected reference standard (103). For example, ferrous sulfate is usually used as a standard for determining the bioavailability of iron, dicalcium or monosodium phosphate as a standard for phosphorus and sodium selenite as standard for selenium.

The bioavailability of a mineral element may be measured by total body retention, specific tissue incorporation or specific compound synthesis. The bioavailability of calcium and phosphorus may be measured by element balance or by incorporation into bone; iron might be measured best by generation or erythocytes or hemoglobin synthesis and selenium by activity of glutathione peroxidase (81). The bioavailability of calcium, magnesium, iron and zinc in commercial mineral complexes were determined by Ranhotra et al (110). For Fe determination, hemoglobin depletion-repletion

technique was used and for the other elements, the retention of minerals in bone (femur) was used as a test criterion.

Large amounts of literature on mineral availability deals with factors that influence the utilization of the elements in various ways. Some important factors for animals are type of ration, chemical form of the element, age and sex of the animal, fat, protein and energy levels of the ration, plane of nutrition, environment, hormone concentrations, diseases and parasites, and interaction with other minerals or nutrients and cheleting agents.

Livestock obtain minerals primarily from two sources, feed ingredients and mineral supplements. Water may or may not provide minerals, and air rarely contributes significant amounts. Because the majority of minerals are obtained through consumption of forages, grains and by-products, it is well to consider soil factors that influence the mineral content of plants. Of the total mineral concentration in soils only a fraction is taken up by plants. The availability of minerals in soils depends upon their effective concentration in soil solutions. Lindsay (76) presented a dynamic situation. As the plants remove minerals from the soil solution, equilibrium may be restored by the release of minerals from the exchange complex.

Korte et al (73) studied the relative mobilities of trace elements in soils. They pointed out that it should be possible to predict qualitatively the migration of an element through the soil on the basis of physical and chemical properties of the soil. Among them, soil texture, surface area, the content of hydrous oxide

and free lime provide the most useful information for predicting retention of soil elements.

Soil properties and conditions markedly affect the uptake and utilization of minerals by plants. The supply of ions to plant roots is controlled by processes of convection, diffusion and interception. The root also produces exudates of organic complex anions to dissolve fixed metals for absorption (52, 100, 139).

Beeson (9) summarized studies on properties of soil and other factors that influence plant growth and mineral availability. He pointed out that soil consists of three phrases, a gaseous phase, a liquid phase and a solid phase. Minerals are found in the solid phase; to be available to the plants they must be released from the solid phase by hydrolysis. Examples are calcium, magnesium and potassium. The uptake of elements by plants is directly related to the concentration in the liquid phase. Most of the released elements will be attached to the surfaces of the colloidal particles of soils, mainly by base exchange reaction with hydrogen ions.

Microelements such as copper, cobalt and zinc undergo the same reactions as macroelements. However, the microelements are greatly influenced by soil organic matter. Although there appears to be a general relationship between content of organic matter in soils and micronutrient content, most organic soils are very low in copper (15). There is continuous interchange of the nutrient cations in the liquid phase with the cations absorbed on the colloidal surfaces. The pH has profound influence on the solubility of mineral elements and their availability to plants. Very acid

or alkaline soils (4.5 and 8.5 respectively) may result in excessive or limited solubility of an element.

In general, calcium content is adequate for most field crops and pasture. Even acid soils contain sufficient calcium for reasonable plant growth which on acid soils is usually caused by excess of manganese, iron and aluminium rather than deficient calcium.

The most important factors that determine the mineral uptake by crops and pastures were listed by Fleming (1973). These include soil acidity, moisture or drainage conditions, soil temperature and seasonal effects, plant genus, species and variety. On the other hand, the concentration of the mineral elements in plant tissue can vary over a wide range, depending upon availability of the element in soil, cutural practices, proportion of plant parts and climatic factors (9).

Climatic factors, principally rainfall and temperature, play important roles in the absorption and uptake of the mineral nutrients from the soil. Climate is important but it indirectly influences the nature of the vegetation in a special region which has a marked effect on soil type. Low soil temperatures limit the uptake of minerals by plants (9).

In the humid tropics, forage growth is continuous and very rapid, but seasonal. Very high annual yields may be obtained (17). It is logical that forage grown under abundant rainfall and high humidity should contain more water. The relationship between rainfall and nutritional value of tropical forage shows that grasses are more

nutritious in the wet than in the dry season. Positive correlations exist between rainfall and crude protein, silica free ash, and nitrogen-free-extract in forages. A negative correlation exists between crude fiber content and rainfall (53). Marked decline in whole plant mineral concentration with advancing maturity has been found. Underwood (129) reported a concentration increase with advancing maturity of the plant of Si, Al, Cr, and a decrease in Cu, Zn, Co, Ni, Mo, Fe, and Mn.

Vegetational factors that determine the mineral content of plants include species and state of growth. With most plant species the differences in mineral content are smaller among the seeds than those which occur in the vegetative plants.

Even when the mineral content of feeds is known it is not an indicator of the availability of minerals to body tissue. Minerals in plants are largely in organic form whereas most of those in supplements are in inorganic form. It has been established that minerals from most supplements are used more efficiently than minerals from natural feedstuffs. Over 50% of manganese, cobalt and zinc in dried grass may be soluble in water; their solubility in the rumen is also very high.

The forms in which minerals are present in plants may determine the efficiency of utilization within the digestive tracts of animals (2, 14, 128). Also, the availability of minerals may be affected by the presence of interfering compounds, both organic and inorganic, by the maturity of the plant and the type of plant and fertilization.

As with the uptake of elements by plants, only a fraction of the total minerals present in the diet are utilized for maintenance and production in the animal body, while the remainder is generally recycled as excreta directly or indirectly to the pasture (112). Mills (87) pointed out that the availability of ten of the most important essential elements could be modified by concentrations of at least 15 other dietary compounds and 21 interactions influencing availability of trace elements.

The essential processes to be considered when discussing availability and absorption of trace metals are, 1) chemical form of the element in food, 2) stability and solubility during digestion, 3) formation of new species with metal binding components of gastrointestinal secretion, and 4) active or passive absorption of the final product from the intestinal lumen and the release of its metal component of specific mucosal carriers involved in transport. The absorption of each element depends primarily on the element itself, but also on factors such as dietary concentration of other nutrients. Once absorbed an element is deposited throughout the body or in a target organ (43).

Factors that have a great influence on the availability of mineral elements for absorption from digesta are water content, pH and location in the tract (32). Flow rates of digesta are also important in mineral absorption. Sites of intestinal absorption for a given substance become more distal when the concentration of that substance increases in the diet (13).

Calcium and Phosphorus

Availability of phosphorus to crops is low in practically all soils after they have been cropped for many years. Phosphorus deficiencies are common in gray, brown and black soils, and in older soils with low organic matter (140).

Information on phosphorus availability is presented separately for each of the major animal species (81, 103, 104). The value of phosphorus of plant origin has been questioned for years. Phytate phosphorus, as it occurs on plants, generally is regarded as being substantially less biologically available than most forms of inorganic phosphorus.

Phytate combines with many elements (Ca, Mg, Zn, Mn, as well as P) making them to some degree unavailable to the animal. The biological availability of the phosphorus in phytin varies depending on the species and age of the animal. For cattle only 60% of the phosphorus in this form is available (4). Also it is known that older animals have greater ability to utilize the phytate form of phosphorus, because more of the enzyme phytase is present in the gut. Another factor influencing phytate phosphorus availability is calcium level. Generally, as calcium increases in the diet, phytate phosphorus becomes less available. Vitamin D may affect phytate phosphorus by its effect on calcium.

Forages are characteristically low in phosphorus. Soils in areas of high rainfall are normally low in phosphorus and other minerals (37). Soils in the humid tropics are characteristically acidic, with high amounts of exchangeable aluminum, which forms

complexes with phosphorus, making it unavailable to plants (140).

The value of a feedstuff as a source of calcium depends not only on its calcium content but also on the amount that the animal can extract and retain for its own use. Many factors influence the absorption and retention of calcium, such as age of animal, level of vitamin D, concentrations of blood hormones, amount and form of calcium fed, and calcium status of the animal.

In ruminants wide differences in biological availability of calcium sources have been reported (4). Calcium from inorganic sources have appeared to be utilized more efficiently than alfalfa and orchard grass hays. Peeler (103) working with 15 different organic and inorganic sources of calcium, pointed out that true digestibility of calcium was greater in young cattle than in mature steers. The bioavailability of calcium in some forages has also been determined (81, 104).

Brazilian workers found that the calcium content of grasses was enough to supply the calcium required by grazing ruminants. On the other hand, phosphorus concentration in most forages was insufficient to prevent chronic deficiency in cattle. The low phosphorus level became a serious problem during the summer (47).

Blue and Tergas (12) reported that nitrogen fertilization produced a more rapid decline in phosphorus content and that the rate of decline is proportional to nitrogen added. They also reported that calcium and magnesium concentrations declined during the dry season. For calcium that result could be expected because much of it is incorporated into the cell wall tissue. The Ca:P

ratio increases from less than 5:1 to more than 10:1 during the dry season, which by far exceed the recommended values, especially with low phosphorus levels.

For grazing cattle, the most prevalent mineral deficiency around the world is lack of phosphorus. Twenty one Latin American and Caribbean countries reported deficiencies (90).

Magnesium

Several criteria have been used to measure magnesium availability such as apparent absorption and blood plasma levels, percent urinary excretion of magnesium intake and more recent studies involving complete balance trials.

The availability of herbage magnesium increases as the herbage matured. A negative correlation was found between crude protein content and magnesium. Moreover, heavy application of nitrogen and potassium on pasture have a negative influence on the availability of magnesium (67). Magnesium availability in concentrate feed is ranging up to 40% and from 10% to 40% in grains and forages (104).

Only a relatively small proportion of the total magnesium present in agricultural soils is available to the plants. The level of exchangeable Mg is frequently placed at about 10% of cation exchange capacity. Metson (cited by Reid) pointed out that plant responses are at <5-6% Mg saturation and unlikely at >10% saturation. The exchangeable magnesium in part determines availability of magnesium in plants. Legumes are generally higher in magnesium than grasses (95).

Fender (43) summarized the factors that have been isolated as influencing the availability of dietary magnesium for the animals. 1) Low pH allows soluble magnesium to be in an absorbable form, 2) Diets producing low levels of ammonia in the rumen and low dietary phosphorus intake promote magnesium absorption. Also ammonia formed from the digestion of excessive dietary protein or high NPN diets will combine with the available magnesium to form ammonium magnesium phosphate. At elevated pH this compound is formed reducing the availability of all three elements. 3) Moderate intake of monovalent cations as sodium and potassium which have higher solubility than magnesium compete for absorption mechanisms from the rumen.

Iron

Iron may be absorbed by the roots of plants in ionic form. Availability to plants is greatest in acid soils, depending on the oxidation state (14). Factors such as high pH and excess phosphate, bicarbonate and Ca salts can interfere with Fe uptake. The iron content in plants is a reflection of the species and soils upon which the plants grow. The availability of iron in certain grass and legume species was studied by several authors (1, 81). The iron content of cultivated grasses and legumes ranges from 100 to 700 ppm.

Iron deficiency in grazing cattle is rarely observed under natural conditions. Blood loss, parasites or disease can cause iron deficiency (89, 129).

Miller (81) has reported the bioavailability of iron from various sources for poultry, swine and ruminants using $FeSo_4 \cdot 7H_2O$

as a standard. Many factors including iron status of the animal, dietary reducing, compounds, particule size, etc. can influence the availability of iron (81). Iron is poorly absorbed for most diets. Uptake by the animal is affected by other nutrients present in the diet. High zinc intakes reduce iron absorption (30), and high levels of phosphate, cobalt, cadmium, copper and manganese interfere with iron absorption through competition for absorption binding sites (129).

Webster (138) studied the effect of cadmium during pregnancy, and reported severe fetal growth retardation. This retardation was not prevented by dietary supplement of zinc, copper or selenium. It was partially reduced by oral iron supplementation. He concluded that cadmium exerted its effect by blocking intestinal iron absorption.

Selenium

It is accepted that selenium is an essential element for the nutrition of ruminants. In grazing cattle, several clinical manifestations have been corrected by selenium supplements to the diets.

Selenium-responsive diseases occur frequently. White muscle disease (WMD) is related to the geologic nature of soils parent materials. There is also evidence that regional patterns of occurrence of WMD are related to regional differences in the Se concentration of feed crops (74).

The total selenium content of soils shows little relationship to the concentrations of selenium in the plants grown on it (10). This may be due to the fact that selenium is present in the soil

in different chemical forms that have widely varied availability to plants. The chemistry of selenium in soils and factors affecting availability of soil selenium to plants have been summarized (3). Many factors are interrelated with the selenium levels in soils. The principal ones are the selenium content of host rocks, the redox potential, pH and nature of the drainage waters. [Couper et al (cited by Barradas)].

In well aerated alkaline soils selenium tends to form selenates which are quite available to plants. In acid soils ferric ion-selenite is formed. Selenium in this form is slightly available to plants. Acid soils do not normally produce plants containing toxic concentrations.

Relationships among the concentrations of selenium in rocks, soils and plants are summarized as follows (3).

1) Where rocks with high content of selenium decompose to form well-drained soils in subhumid areas, the selenides are converted to selenates and organic selenium compounds.
2) Where rocks with a high content of selenium weather to form soils in humid areas, soluble complexes of ferric oxide or hydroxide and selenite ions will be formed. These soils will be slightly to strongly acid.
3) Where rocks with high content of selenium weather to form poorly drained soils and are alkaline, plants containing toxic levels of selenium are likely to be produced. The more acid the soils in an area the less the likelihood of vegetation containing toxic

levels of selenium.

4) Where rocks with a low content of selenium decompose to form soils under either humid or dry conditions, the plant growing is likely to contain insufficient selenium to protect animals from selenium deficiency. The more humid the area the more acid the soil, the greater the likelihood of low selenium concentration in the plant.

For most soils selenium values are between 0.1 and 2.0 ppm. If the total selenium is above 2.0 ppm soils are considered seleniferous. Values up to 20.0 ppm have been reported from certain areas of Mexico (123).

In addition to effects of soil characteristics and pH, plant concentrations of selenium may be affected by plant species and state of maturity. The effect of species is apparent with the variously called accumulator, or indicator plants that occur in seleniferous areas. Se concentrations up to 1400 ppm have been reported for Astragalus racemosus (129). Accumulator species with more than 50 ppm of selenium have been found in most of the Latin American countries (90).

The differences in Se concentration between accumulator and non-accumulator plants are great. For non-accumulator plants the Se concentrations in legume and grass hays were reported by Miltmore et al (cited by Reid) to be 0.22 and 0.21 ppm respectively. Underwood (129) pointed out that pastures and forages free from selenium-responsive diseases in animals generally contain 0.1 ppm Se or

more while in areas with a variable incidence of such diseases the levels are below 0.05 ppm.

Biological availability of selenium in feedstuffs for chicks was studied (24). It was pointed out that selenium from plant origin was highly available, ranging from 60 to 90%, but less than 25% available in animal products. Also, high availability values were observed for sodium selenite and selenocystein. Ammerman (1) mentioned that sulfur may interfere with the utilization of selenium. This is a result of the similar chemical structures of these elements and the fact that they form structural analog, such as selenoamino acids (selenium is substituted for sulfur).

Few selenium sources have been tested for selenium bioavailability for swine and ruminants. Based upon prevention of exudative diathesis, the biological availability of selenium was 100% in wheat, 50% in poultry by-product meal and 40% in tuna meal.

Byers and Moxon (23) studied the feedlot response to supplemental selenium of growing and finishing beef cattle fed various protein levels. Their data indicate that the needs for selenium are greatest when protein requirements are greatest. The response to supplemental selenium was greatest for cattle fed diets that provided less than the optimum levels of protein.

Zinc

Several factors influence zinc uptake by plants. Soil pH reduces availability (101). Soil deficiencies are due to reduced solubility of zinc compounds in the presence of calcium carbonate

and an alkaline pH. Zinc content in soil ranges from 10 to 300 ppm with a mean of 50 ppm (14).

Phosphorus has been reported to affect the availability of zinc when it is utilized in large applications. This has been noticed when superphosphate is used.

In general, high protein feed ingredients are good sources of zinc. Values for pasture ranged between 17 to 60 ppm (129). Penn State Forage Service reported average values for different types of feeds. For example, corn as silage 31 ppm, legume forage 28 ppm and grass forage 42 ppm (86).

Kalinowski (112) reported high levels of zinc in forages collected from different areas in Peru. Values up to 363 ppm for native forages were found, although these levels are below the zinc concentrations producing signs of toxicity. Miller (84) has suggested the probability of problems arising even when the zinc intake is below 400 to 500 ppm.

McDowell (91) reported that 24.1% of the total Latin American Forages analyzed for zinc were borderline or deficient. Underwood (129) pointed out that zinc concentration in plants falls with advancing maturity and that legumes carry higher zinc levels than grasses. Gomide (49) notes that zinc is almost immovable in plant tissue and therefore it tends to increase in old organs and in the stem.

In animals the single most important factor which affects absorption is the zinc content of the diet. As dietary zinc decreases the percentage absorbed increases. Zinc absorption is highly

variable in ruminants going from less than 10% to more than 30% of that consumed (86). The effect of other dietary factors in zinc absorption has been studied. High levels of cadmium reduce zinc absorption. The estimated zinc requirement for dairy cattle is 40 ppm in the diet. The toxicity threshold is estimated to range from 500 to 1500 ppm (94).

Potassium

Potassium makes up 2.6% of the earth's crust. Potassium is more likely to be found on weathered sandy soils than on fine textured soils, it is absorbed by plants in greater amounts than any other mineral with the exception of nitrogen, as K^+ ion from the soil solution. Since the total amount of potassium in soils is no criterion of the amount of potassium available to plants, three arbitrarily designated categories were used by Tisdale and Nelson (126) to classify the degree of availability of poassium in soils unavailable (90-98% of total), slowly available (1-10% of total) and readily available (0.1-2.0% of total). The same authors mention that potassium content in tropical soils may be low due to leaching of soils over the years. A value of 120 ppm of available potassium is considered as adequate in soils.

Potassium is a mobile element in plants. It is present in ionic form and is not associated with any particular compound. It is involved in photosynthesis and translocation of carbohydrates and as the plant matures it is found in areas of new growth.

Feedstuffs derived from plants are an important source of

potassium in most animal diets. For grazing cattle, plant material represents the major source of potassium. In general grain and concentrates are poor sources of potassium (29, 77).

Potassium levels in forages rarely go below 1.0% of dry matter. For legume forage average values are 2.55% but this range is 0.21 to 4.93%. Grass forages are considerably lower than legumes but the ranges are of similar magnitude. Some of this variation is due to time of the year and state of maturity as well as soil fertility.

Barradas (8) found potassium average values of 1.49% dry matter for Pangola grass and 2.15% of dry matter for Guinea grass from Veracruz, Mexico. Only 15% of the entries reported by McDowell (91) in the Latin American forages were from 0 to 0.8% dry basis.

The suggested requirement level by the National Research Council (94) based on the studied conducted, is 0.8% potassium for lactating cows, but it is possible that at peak of lactation a high producing cow the requirement could be 1.0% of the ration dry matter (77).

It is usually considered that soils influence animal nutrition by the quantity and quality of the herbage they produce, following the usual pattern soil-plant-animal. Another important factor is eating dirt. Grazing animals ingest soil along with herbage and this ingested soil can be a major source of minerals.

Some minerals are obtained by grazing livestock through the consumption of large amounts of soil annually, up to 600 kg for cattle (55). Soil consumption depends on the weak structure of the soil, poor drainage, high stocking rates and shortage of pasture

during winter or dry seasons.

Ingested soil appears to be taken in accidentally along with herbage and does not appear to be the result of depraved appetites. Herbage from grazed areas can contain up to 25% soil (Dry Matter basis). Brazilian workers reported that feces from cattle eating mud contain 95% of dry matter, 83% ash and 64% sand.

Researchers in New Zealand and the United Kingdom suggest that soil may be an important source of trace elements in the diet and perhaps the main source of cobalt.

Little is known about the forms of the element and their availability and absorption in the alimentary tract.

In summary, it is suggested that there is a direct soil-animal effect in animal nutrition.

Mineral Interactions

The biologically active forms of trace elements are probably metal chelates (9). Considering this, it was assumed that many of the biological antagonisms between and among trace elements might well be the result of similarity in chemical properties. The coordination chemistry brought d orbitals into consideration since the bulk of the essential cationic elements are found in the transition-element groups of the periodic table. Matrone (78) explained the properties of coordination compounds taking into consideration, valency bound, molecular orbital, and ligand field theories. Nine essential elements fall among those classified as transition elements, which have several unique properties as paramagnetism, variable valency and

ability to form colored ions (20).

The special properties of the transition elements have been attributed to the approximate relative energy levels of the atomic orbitals. The addition of successive electrons into the atomic orbitals is carried out in a regular manner in the order 1s, 2s, 2p, 3s, and 3p. However, at this point the 4s orbital is filled before the 3d orbitals. The reason is that 3d lies at a higher energy level than 4s orbital (20). This situation is repeated three times in the periodic table.

The number of metal-ligand bounds in a metal chelate is known as the coordination number (CN). Matrone (78) uses the effective number as an approach to the interaction prediction. In this system a metal ion in the first transition group attains an electronic configuration similar to the next higher inert gas. The CN is determined by the number of unfilled orbitals of the metal ion.

The Zn^{2+} ion with 28 electrons has four more empty orbitals than krypton. Zn^{2+} has a sp^3 configuration or tetrahedral shape. Cupprous copper (Cu^{+}) also has a CN of 4 and tetrahedral shape. This similarity in chemical properties may predict biological antagonisms beteen Zn^{2+} and Cu^{+}. Other examples are Fe^{3+} and Mn^{2+} in which both are d5 ions with the same CN and configuration. Cu^{2+} and Ag^{2+} both have d9 orbital, dsp^2 configuration and CN 4.

At this point the coordination number and configuration of the cations of the transition elements are highly correlated with the number of d electrons. Several other parameters are also connected in the biology of the transition elements, such as valency,

iso-electronicity of the valency shell and radius of the metal ion.

All the minerals found to be essential do not complete their biological function in a straight way without interacting among themselves and with other nutrients. The complexity of mineral interactions is well known but not completely understood, and interrelationships of minerals with vitamins, proteins and energy further complicate the problem.

Among minerals, the interactions are primarily manifested as a type of antagonism. Every element in a nutrient solution influences the others, and a balance must be maintained between all nutrients. Reid (112) summarized data from different authors illustrating the effect of pH on mineral absorption by plants, and the synergistic and antagonistic effects of ion interactions at the root surface.

Interactions between metal ions in living systems can be classified in at least two categories (78).

- Direct interaction. i.e., Substitution of a native metal ion in a biologically active coordination compound by another metal ion.
- Indirect interaction. Interaction of one metal ion with either a precursor in the chelate formation pathway of another metal ion or interaction of one metal ion with a precursor in one or more steps involved in metabolic processes of another such as absorption, transport or physiological function.

Suttle (122) grouped mineral interactions into six categories

according to the type of mechanism involved. Although the biological consequences of either type of interaction could be very similar, the mechanisms of antagonism would be different.

Until now over 70 mineral interrelationships in which an additional dietary quantity of one mineral element will influence absorption or utilization of another element are known. The interrelationship of Ca, P, Mg and K is of fundamental importance. Very high percentages of Ca, P, and Mg are located in the bone and most of these elements can be mobilized for use in metabolic events of body tissue. Many of the dietary interrelationships among these minerals occur at the absorption site (61). High dietary K impaired intestinal absorption of sodium whereas low K increased urinary sodium excretion. High dietary K concentration enhances Mg deficiency (97). Mg absorption was reduced by increasing dietary Ca from .34% to .68% or P from .39% to .79%. Also, increasing dietary Ca decreased P absorption, but magnesium excess seemed to have the greatest bearing on reducing calcium and phosphorus absorption (99). The depressing effect of magnesium upon calcium absorption may be moderated by exceeding phosphorus requirements in the diet. Phosphorus absorption also can be depressed by excessive levels of zinc, copper and molibdenum (18). Although calcium may interfere with phosphorus absorption, the ruminants can tolerate excessively wide calcium/phosphorus ratios (4, 61, 71). This indicates that calcium does not have a severe effect on phosphorus absorption.

High magnesium intake increased Ca loss from the body. High phosphorus prevented Ca loss and vitamin D affects Mg absorption

quite markedly.

In summary, phsiologically calcium and magnesium are strong antagonists, but from a nutritional standpoint this antagonism is less marked.

Copper-Molybdenum-Sulphate

Dich (1956) showed that copper-molybdenum interaction was dependent on sulfate. He suggested a three way interaction. Subsequent studies showed that the sulfate could either increase or decrease copper status of ruminants and more recent studies have shown that molybdenum could do the same with copper. Since the effect of any one of these elements is dependent on both previous and present dietary levels of the other two elements, it is difficult to predict the effect of dietary changes.

The essential role of molybdenum in plant nutrition has been studied. Molybdenum is known to function in nitrogen fixation by soil microorganisms. Molybdenum deficient soils were subsequently recognized and significant improvements were made by appropriate molybdenum application. The principal function of molybdenum in plants is the reduction of nitrates by the molybdenum containing enzyme reductase.

The absorption of molybdenum by plants is favored by low pH. However this is apparently counteracted in soils by the fact that in alkaline soils it is more available to the plant than it is in acid soils (9, 70, 86). The level of molybdenum in pastures and forages varies greatly depending on the soil conditions. Values

from 0.10 ppm to 100 ppm have been reported (129). Most dietary forms of molybdenum, except molybdenite, are absorbed from the gastrointestinal tract, but the rates of absorption and roles of excretion may differ with species.

The major biochemical role of molybdenum in animals is in the formation and activity of xantine oxidase, a molybdenum-containing metallo protein, indispensable in the anabolic metabolism of purines to uric acid (95, 129).

An explanation of the complex interrelationship of copper-molybdenum and sulphate in the rumen has been proposed (60). The first interaction observed is between copper and molybdenum. High dietary Mo produces copper deficiency. The higher the copper content of the diet the higher the level of molybdenum required to observe copper deficiency. This antagonims is due to the formation of copper-molybdenum complex at a pH range near neutrality. They proposed that copper may become unavailable through the formation of cupric molybdate that is absorbed, transported and excreted as a unit. Copper sulfide and cupric molybdate are almost insoluble and unabsorbable.

The interaction between copper and sulfate is due to the reduction in copper absorption as a result of the precipitation of copper sulfide in the rumen. The mechanism of interaction between these two elements is proposed to result from the formation of hydrogen sulfide in the rumen either from inorganic sulfate or the desulfhydration of sulfur amino acids.

Two systems are proposed to describe molybdate and sulfur

interactions. One is the sulfate reduction system present in the rumen and the second is in the membrane transport system. It has been shown, both in vivo and in vitro that sulfate is reduced to sulfide by rumen microorganisms.

The amount of molybdenum is the most important variable affecting copper needs in ruminants. The effect of molybdenum on copper requirements and tolerance is complex. Although the exact mechanisms are not understood, it is well recognized that the antagonism between copper and molybdenum is interrelated with the sulfate, sulfide and/or sulfur content of the diet (83, 86, 121, 129, 134). Ammerman (1968) found that Mo and sulfate will reduce the Cu level in tissue of the cattle and sheep by reducing the Cu uptake and increasing the rate of absorption.

There is a considerable difference among animals to the tolerance of high doses of molybdenum. Cattle have the least tolerance and sheep are next. The tolerance to high levels of molybdenum varies with the age of animal, quantity and form of ingested molybdenum, the inorganic sulfate content of the ration, the copper status and intake of amino acids that can be oxidized to sulfate in the body.

Copper is associated with many enzyme systems of plants and animals, especially with oxidative pathways and respiratory pigments. In sheep, Cu is one of the few essential elements on which both deficiency and toxic excess can occur under normal grazing conditions. Harker (54) found that giving 7.7 ppm of Mo to lambs receiving high copper diets produced liver copper levels 40% lower than controls.

He concluded that the addition of ammonium molybdate to the concentrate diet is useful in reducing nutritional copper poisoning.

Cymbaluk (34) studied the effects of molybdenum on copper metabolism using three Mo levels. He pointed out that the addition of Mo to the diet decreased copper absorption and retention as a consequence of excretion of dietary copper in feces, and increased excretion of absorbed copper in bile. Molybdenum was absorbed but urinary excretion was effective in eliminating most of the Mo from the body.

Spears (119) reported that increased molybdenum in the fermentation medium increased the sulfur requirement for maximum in vitro ruminal cellulose digestion. Miller (83) pointed out that molybdenum has a stimulatory effect in the cellulose-degrading microorganisms.

Fisher and Prentice (45) proposed that high dietary Mo may lead to the formation of a Co-Mo complex in which copper is more rapidly absorbed from the gastrointestinal tract and more slowly excreted in the urine than copper in normal diets. They also pointed out that if Cu-Mo complex is formed in the rumen or tissues of the animals it was not excreted in the urine.

Industrial pollution is a potential source of molybdenum in the environment. Ruminants are particularly sensitive to Mo toxicity (129). Molybdenosis, characterized by symptoms of copper deficiency, may occur in cattle with 4 ppm dietary Mo intake and low copper intake (60).

Kincaid (70) established the minimum toxic concentration of molybdenum in drinking water of calves. He found that the

concentration of copper in liver was reduced with 50 ppm of Mo added to water, but not with 1 or 10 ppm. However, Cu in plasma was elevated with 50 ppm of Mo. Apparently uptake of plasma copper by tissue was reduced by molybdenum decreasing the bioavailability of copper. He pointed out the difficulty of detecting molybdenum induced hypocuprosis from plasma copper and ceruloplasmin without data on tissue copper. Ward classified Mo toxicity in four groups:

- High Mo (more than 20 ppm)
- Low Cu:Mo ratio (2:1 or below)
- Copper deficient (less than 5 ppm)
- Normal Cu (5-10 ppm) and Mo, both high soluble protein (20 to 30%)

This last statement probably results from high levels of sulfide produced from sulfur amino acids during rumen fermentation.

Huber et al (59) working with lactating dairy cows found symptoms of Mo toxicity with 173 to 200 ppm in the diet. Liver, blood and milk levels of molybdenum were increased 5 to 10 fold. Kidney and spleen concentrated Mo several times higher than any other tissues. Also the addition of .26% sulfate to rations containing 200 to 300 ppm of Mo greatly increases the severity of Mo toxicity. The same results were reported by Vanderueen (131).

Cattle are apparently more susceptible than sheep to excess molybdenum and deficient copper in their diet. When the ratio of Cu to Mo in feed drops below 2:1, Mo poisoning can be expected (19). Copper is a member of the transition element with one electron in the outer shell. In addition to the metallic form, copper can exist

in the $^{+}1$, $^{+}2$, $^{+}3$ valence state. The most commonly found form in solid is as the cupric ion (Cu^{+2}) which is absorbed by clay soils. Below a pH of 7.3 Cu^{2+} is most abundant and above this pH $CuOH^{+}$ predominates (76).

Copper plays a very important role in plant and animal metabolism. In plants it is a constituent of ascorbic acid oxidase, the enzyme laccase and of other important proteins. In animal metabolism it is important in hemoglobin formation, elastin and collagen formation and melanin production.

A simple copper deficiency in grazing animals as a result of subnormal concentrations of copper in forages has rarely been reported. Normal copper concentrations in plants range from 8 to 20 ppm. Six ppm is considered deficient and higher than 20 ppm toxic (63). Copper deficiency is manifested by the same syndrome as chronic molybdenum poisoning is identical to molybdenum deficiency. Copper poisoning is brought about by the sudden release into the blood stream of copper which has been stored in the liver.

Australian work showed that gramineous species take up less copper than many herbage plants, even on soils with high concentrations of available copper.

The amounts of copper needed to counteract excess molybdenum is variable due to the interrelationship between copper, molybdenum, sulfate and other factors. Copper deficiencies usually occur when forage molybdenum exceeds 3 ppm and the copper level is below 5 ppm (33).

Sulfur-Selenium Interactions

Sulfur and selenium interact because sulfur compounds influence the uptake of selenite by rumen microbes. Selenium may replace the sulfur in methionine and cystein.

In proteins, the covalently bound selenium is linked to either carbon or sulfur. The selenium atom is either incorporated in place of sulfur in sulfur amino acids, or is attached to the sulfur atoms of cysteine residues (46).

In ruminants it is probable the sulfur and selenium nutrition is influenced by rumen microbial metabolism (50). There are some implications that change in Se. Metabolism due to sulfate supplementation which may be due solely to changes in microbial and tissue metabolism associated with a change from a deficient to an adequate dietary sulfur supply. Also there is evidence that seleno methiomine is one, if not the main source of selenium ingested by ruminants and that its metabolism by the rumen bacteria differs from that of inorganic forms of selenium (108).

In view of the high affinity of heavy metals for sulfur and selenium, there are some specific biological interactions between selenium and other metals (46). There is considerable evidence that selenium protects animals from the toxic effects of certain heavy metals such as cadmium, mercury and thallium.

Sulfur and selenium compete for the same active sites of enzymes because of their similar chemical structures. These elements have similar electron configuraton, valence shell, atom size, bond energy, electron affinities and electronegativity (95). Despite

these similarities the biological properties of sulfur and selenium are different.

Levander (50) pointed out that the metabolic differences could be explained by their oxidation states and the degree of dissociation of the S-H and Se-H groups. Se compounds are reduced during metabolism while sulfur undergoes oxidation.

Pope (107) describes the selenium-vitamin E-sulfur-nitrogen interrelationship. This interaction has become more important in recent years due to extensive use of fertilizers in pastures. He pointed out that the metabolism of sulfur (S) and nitrogen (N) are very closely interrelated in ruminants. Sulfur fertilization has increased the incidence of selenium deficiency in animals (129).

Zinc-Copper-Manganese Interactions

Underwood (129) notes the discrepancies with levels of copper may be due to the differences in zinc and iron levels in the base diet. It is known that copper competes with iron for absorption binding sites and zinc for metal-binding protein.

In ruminants soluble complexes of Zn and Mn occur in the rumen and lower region of the small intestine. The soluble zinc and manganese in the abomasum, duodenum and upper jejunum appeared to exist in ionic form (16). It appeared that much of the insoluble metal, particularly copper might be associated with microbial matter. The suggestion that over 85% of the zinc in the plant could be in the soluble form in the stomach, as a combined result of the acid environment and proteolitic digestion.

There is significant variation in the forms in which Zn, Mn, and Cu are present along the alimentary tract of sheep maintained on a dried grass ration. The solubilities of the three metals in the rumen were found to be extremely low. Although over 50% of the Zn, Mn, and Cu in the dried grass ration was found to be water soluble and over 90% of the Zn and Mn was liberated on celluloytic digestion of ryegrass in the rumen only 5-10% of the Zn and Mn and less than 20% of the Cu were in soluble form. The large increases in the solubility of Zn and Mn on passage of the digesta into the abomasum must arise from the dissociation at low pH of the insoluble complexes present in the rumen.

The effects of Zn in young lambs was studied by Davies et al (36) and their results suggest that the suckling lamb is considerably more susceptible to zinc toxicity than more mature animals. This must be due to greater absorbtion of dietary zinc since absorption has been shown to be higher in the young of many species. Miller in 1970 summarized the relation between copper and zinc. Although many details remain to be established, he pointed out the important biochemical relationship existing between Zn and Cu in ruminants. For example, in liver copper and zinc bind to some of the same or similar proteins.

Increasing dietary zinc can decrease liver copper in cattle. Dietary copper supplementation also can affect metabolism and tissue concentration of other elements. Supplementation with dietary cadmium depresses copper and supplementation with dietary iron markedly decreased liver and blood copper, ceruloplasmin and amine

oxidase.

The effect of dietary protein and phosphorus levels on the utilization of zinc, copper and manganese on adult males has been studied. Greger (51) found interactions between phosphorus excretion and protein level. Urinary zinc excretion was significantly greater when subjects consumed the high protein diets rather than the low protein diets. Also, the dietary treatments did not affect urinary excretion of copper, serum copper levels or the apparent absorption and retention of manganese by the subjects. Biological interactions between Se and a number of other elements have been shown. These elements are arsenic, mercury, cadmium and copper (3, 42, 56). The presence of Se reduces the toxicity of mercury and cadmium (25, 56, 95).

The effect of copper on iron has been studied by Matrone (93). He showed that increased levels of copper promote higher levels of hemoglobin with the same level of iron. Several investigators concluded that copper does not affect assimilation of iron but does function in the conversion of inorganic iron into hemoglobin. Evidence of and iron-copper interaction is apparent only in hemoglobin. Iron plays a role in the synthesis of both heme and globin of hemoglobin. The primary role of copper is hemopoiesis which appears to be in the formation and development of reticulocytes rather than in the synthesis of protoporphyrin and hemoglobin (93).

Cadmium and Zinc

Almost nothing is known of interactions between cadmium and other nonessential toxic elements. But supplemental zinc appears to have a definite tendency toward reducing the toxic levels of cadmium in bovine (108). Also that the level of Cd tolerated in the diet is much higher for cattle than for monograstric animals.

Hsu (58) investigated the influence of high dietary calcium on the biochemical and morphological manifestation of lead and zinc toxicity in pigs. The results indicate that high dietary calcium (1.1%) has a protective effect against the adverse effects of Pb and Zn. Zinc aggravates Pb toxicity in growing pigs. Chertock et al (26) summarized the influence of cadmium on the intestinal uptake and absorption of calcium in rats. He pointed out that cadmium inhibits calcium binding to calcium-binding protein. The active form of cholecalciferol is 1-25 dihydroxy cholecalciferol which regulates intestinal calcium absorbtion. Lorentzon and Larsson (cited by Chertock) reported that 25-hydroxy cholecalciferol-1-hydroxylase activity decreases in rats receiving cadium orally. It appears that cadmium can interfere with calcium transport by reducing the activity of this enzyme.

MATERIALS AND METHODS

Veracruz is located along the coast of the Gulf of Mexico in the eastern part of the country between 17°08' and 22°18' north latitude. The area of the state of Veracruz is 72,815 Km^2 which represents 3.7% of the national territory.

It is a long narrow state with the Gulf of Mexico to its east and the eastern Sierra Madre to its west. Its maximum length is 800 Km and its width is from 42 Km in the northern part to 156 Km in the central part.

The topography is very irregular. It has the highest peak in the country, 5,747 m high, where the snow never melts, and extends to sea levels where the average annual temperature is 30° C. This topographical characteristic causes the great diversity of climates, soil types, and vegetation. Three main types of climate exist. The tropical rainfall climate which covers the major part of the state is present in altitutde no higher than 900 m with an annual temperature of 26.5° C and an annual rainfall of 1100 mm. The temperate rainy climate is located at altitudes over 1000 m with an annual rainfall over 1500 mm and average annual temperature of 18° C. In the highest and middle mountain region the temperature in the hottest months of the year is over 18° C, falling sharply in the winter when the annual rainfall is over 2000 mm.

Veracruz ranks first in beef cattle production in the country. There are 4.5 million beef cattle. Seventy-five percent of the total

animal population are cross breeds between native cattle and Zebu, Holstein or Brown Swiss. Five percent are pure breeds and the rest are native animals (Criollo).

Approximately 39.4% of the total area is used as grassland from which 18.2% are native pastures and the remaining are introduced forages.

Location of the Sudy Area

Two regions were selected. Region I is in the southern part of the state (Isla) and Region II is in the northern Temporal part. Each region was represented by six farms. There was no mineral supplementation except common salt given to the animals and there was no soil fertilization program for any of the farms.

Region I or the southern part is located 17°50' north latitude and 95°45' west longitude and at altitudes between 300 and 600 m. The average rainfall is about 1600 mm from June to November. Region II (northern) is located 21°10' north latitude and 98°35' west longitude. The mean temperature is 25.5° C with an average rainfall about 1100 mm. Although the rainy and dry seasons are generally well defined, during the sample collection period the rains were delayed by one and a half months. This resulted in a severe drought.

Collection and Preparation of Samples

Sample collections were made toward the end of the dry season and the beginning of the rainy season (July 15 to August 20, 1980). Region I was sampled first. Region II was sampled after the first two rains.

In each farm 100 ha were sampled for soils and forages and 30 blood samples were taken from cattle. Soil and forage collections were made on each farm only in the pasture where the experimental animals were grazing.

Soil. Areas of five hectares were sampled. A composite sample made up of seven sub-samples was prepared. There were twenty composite samples per farm.

Soil samples were taken with a stainless steel soil sampling tube at a depth of 20 cm. Each sample was placed in a marked plastic bag. Later, samples were air-dried, ground, passed through a 2 mm sieve, mixed and stored in plastic bags. One hundred grams of each composite sample were transported to Michigan State University for analysis.

Forages. In Region I, Pangola grass (Digitaria decumbens) and Zacate de Llano (Paspalum spp) were the dominant species, and in Region II Star grass (Cynodon plectostachyum) and Guinea grass (Panicum maximum) were sampled. The exceptions were farm 5 in Region I and farm 9 in Region II where Star grass and Pangola grass were also found.

The sampling density was the same as that for soils. Forage samples were taken with stainless steel scissors from the same areas as soil samples. Pangola grass samples were cut at a height of one inch, while Zacate de Llano and Guinea were taken at heights of 2 to 3 inches.

Grass composite samples (2 kg) were prepared in the field and taken to the experiment station. They were then rinsed in acidified water (0.1% HCl). After draining, the samples were cut with scissors into pieces 1 to 2 inches long. The drying process was accomplished

in two steps; at the station, they were partially dried in forced-air ovens at 60° C for 7 hours to reduce moisture to a level necessary to avoid spoiling. Samples were then transported to Mexico City and dried for another 24 hours under similar conditions and the dry weight was recorded. A Wiley mill with a 2 mm stainless steel sieve was used to grind the samples. The samples were then stored in plastic bags (Whirl-pack) and shipped to Michigan State University for analysis.

Livestock. All the farms sampled were commercial beef farms. The cattle were crossbreeds of native cattle with Zebu or Brown Swiss. Thirty animals were divided as follows: 10 lactating cows in their second to fifth lactation, 10, one to three year old heifers and 10, one to ten month calves. All the animals were randomly selected at each farm and duplicate blood samples were taken by jugular venipuncture. One of the samples, 5 ml, was collected in heparinized tubes, kept under refrigeration, and used for hemoglobin and hematocrit determinations. The second one, 20 ml sample, was collected in silicon-coated tubes with no anticoagulant. Twenty-four hours after collection the serum was transfered to plastic vials and kept frozen until analysis.

Soil Analysis

A solution of 1N ammonium acetate, pH 7, was used for calcium, magnesium and potassium extraction on a 1:8 soil solution ratio (8). Two and a half grams of soil were placed into a 50 ml Erlenmeyer flask and twenty ml of extracting solution added. The samples were shaken for five minutes at 180 excursions per minute, and filtered through #42 Whatman filter paper. Then, the soil extract was diluted by a factor of 15 with a 1500 ppm lanthanum solution (lanthanum was

used to avoid interferences for Ca due to Si, Al, PO_4, or SO_4). For iron, zinc and cobalt extraction, 0.1 N HCl solution was used. The soil solution ratio was 1:10. For this extraction the samples were shaken for 10 minutes. Copper extraction was made with 1 N HCl solution following the same procedure as for iron but they were shaken for one hour. Phosphorus was extracted from soils with Bray P1 extracting solution (0.03 N NH_4F - 0.025 N HCl) in a 1:8 soil solution ratio for five minutes. For selenium determinations double acid digestion was used. Two milliliters of concentrated HNO_3 and 3.0 ml concentrated $HClO_4$ were added to 0.5 g of air dried soil and heated. A 1:1 soil water mixture was used for pH determination. Ten grams of soil plus 10 ml of double distilled water were placed in a 50 ml beaker, stirred for 10 minutes and read in an Orion research digital ionizer pH meter.

Determination of extractable phosphorus was accomplished by the Ammonium molybdate-ascorbic acid method (Watanabe and Olseh, 1965). A Gilford Stasar II spectrophotometer at 720 nm was utilized to determine phosphorus concentration. Calcium, K, Mg, Cu, Fe, Zn, and Co determinations were made by flame atomic absorption spectrophotometry with a Perken Elmer 5000 spectrophotometer. Calibration for procedures given by manufacturers were followed (Perkin Elmer 1976). For selenium, a variation of the fluorimetric method by Olson (102) was used.

Forage Analysis

Double acid digestion was used for grass samples 0.5 g of grass samples were weighted into 50 ml Erlenmeyer flasks and 3 ml of concentrated perchloric acid and 5 ml of nitric acid were added. The flasks were heated until the samples were dried down to 0.5 ml, cooled and diluted with 25 ml of dionized water. Copper and zinc were determined directly from this dilution. A ten fold dilution was made for iron and calcium and a one hundred fold dilution for magnesium and potassium using a 3000 ppm lanthanum solution. Final concentrations for these elements were determined by flame atomic Absorption spectophotometry. A further one hundred fold dilution from the original dilution was also made for phosphorous determination. For selenium determination, one gram of sample was digested with nitric and perchloric acid. The mineral concentrations were measured by colorimetric and fluorimetric methods respectively.

Blood and Serum Analysis

For hematocrit determination, blood samples in capillares were centrifuged in a Solbat centrifuge at 9500 g for 10 minutes. A card reader was used to measure the samples. Hemoglobin was determined by the cyanmethemoglobin method. Readings were obtained in a Zeizz PM2A spectrophotometer at 540 nm (35). Drabkin's diluent solution was utilized as a reagent.

Serum samples were centrifuged at 1650 g for 10 minutes. Then 1.5 ml of serum were deproteinized with a solution of 15% trichloracetic acid (TCA) in a dilution of 1:4, and centrifuged at 1650 g

for 15 minutes. Copper and zinc concentrations were measured directly from this dilution. Phosphorus was determined by diluting 0.5 ml of supernatant with 9.5 ml of working solution of ammonium molybdate-ascorbic acid solution. For calcium analysis, separated 1.0 ml. of serum supernatant sample were diluted with 9.0 ml of lanthanum solution (3000 ppm). A other dilution (with a total dilution factor of 150) was made for determination of magnesium and potassium. For iron analysis a dilution of 1:2 serum - TCA 20% solution ratio was mixed and heated at 90° C for 15 minutes and centrifuged at 1650 g for 20 minutes (102). Direct readings were taken from the supernatant. Selenium concentrations were determined by fluorimetry according to Olson et al (1975).

Calcium, magnesium, potassium, iron, copper and zinc were determined by flame atomic absorption spectrophotometry with a Perkin Elmer 5000 spectrophotometer.

Statistical Analysis

Soil data were analyzed according to farm and region. Forage data were analyzed according to farm and grass type for each region since grass type was different in each region. The animal data were analyzed according to farm, region, and livestock type.

For soils a nested model was used. For the forage data, a two way model was used for each region. The experimental design for the animal data was split-plot because variations among farms constituted experimental error for differences between regions, but variations among animals of the same type and farm constituted

experimental error for differences among livestock types. Bonferoni t Test was used to make specific comparisons among means.

All possible correlations were established between minerals in soils, soil minerals and soil pH, minerals in grasses, and between grass minerals and grass dry matter. Correlations between homogenous pairs were obtained between minerals in soils and minerals in grasses, and between minerals in soils or grasses and minerals in serum. Serum to serum correlations were also obtained for individual elements between the livestock types.

For any correlation in which animal data were included only ten pairs were used. This was because of the difference in numbers of samples for forages, soils and animals (20, 20 and 10 respectively).

The SPSS system was used for computer processing of the data.

RESULTS AND DISCUSSION

The mineral concentrations in all samples are summarized and presented in Table 1 to 10. Individual farm data are presented in Table A1 to A10 (Appendix). Correlation coefficients and confidence limits are presented in Table A11 to A16 (Appendix).

Soil-Plant-Animal Calcium Relationship

Extractable soil calcium ranged from 157 ppm in Farm 2 up to 8059 ppm for Farm 12 with an overall figure of 3777 ppm. Values found for soils were higher than those reported by De Sousa (39) for Brasilian soils using double acid extraction solution. However, the values were within the range reported by Blue et al (11) from soils of Eastern Panama and by Barradas (8) for soils of Veracruz, Mexico.

Grass calcium concentrations ranged from 0.18% on a dry basis for Farm 1 to 0.71% for Farm 7 with an overall average of 0.41%. The calcium concentrations obtained for grasses were within the values reported for the same grasses from other tropical countries (8, 39, 62, 68, 69, 91).

Calcium concentrations in serum ranged from 5.3 mg/dl for heifers at Farm 7 to 11.6 mg/dl for calves at Farm 11 (Table A1). The lowest values were found in heifers followed by cows in Region II, but most of the values were within the normal range reported in the literature (4, 8, 27, 38, 93, 95, 120). De Oliveira (38)

reported serum calcium values obtained in the rainy and dry season of 10.63 and 9.30 mg/dl of blood serum, respectively of Criollo cattle from Brazil. The calcium content of soils, grasses and livestock type are shown in Table 1. Calcium values of soils from Region I were significantly lower ($P<.0001$) than those from Region II. Calcium content in grasses from Region I shows a significant difference ($P<.0001$) being lower for Pangola grass than for Llano grass. No significant differences were found between Star grass and Guinea grass in Region II. Serum calcium levels of cattle grazing in the two regions was not different. There was a significant difference between livestock types ($p<.00001$).

Soil calcium correlations with other soil variables are shown in Table A11. Correlation coefficients between calcium and potassium ranged from .28 to .74, with a mean figure of .53. High interactions were found between calcium and magnesium, copper, iron, and pH. The correlation coefficients were .76, .67, -.69, and .90, respectively. De Sousa (39) and Barradas (8) reported high positive correlation between pH and soil calcium. There was high negative correlation between soil calcium and soil iron. This agrees with Bowen (14) and explains the interaction between iron availability in acid soils.

Grass to grass calcium correlations are presented in Table A12. High correlation coefficients were found in the overall figures for grass calcium with grass phosphorus (.70), and grass calcium to grass zinc (.66). Some consistency was also found between grass calcium and grass iron. The coefficients ranged from -.18 to .66 with an overall correlation of .48, being higher for a particular grass than

TABLE 1. MEAN CALCIUM CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	Soil Ca	Grass Ca	Serum Ca		
			Cows	Heifers	Calves
	ppm	% of DM	mg/dl		
Overall	3777.20 (235.50)	0.416 (0.015)	8.20 (0.220)	7.96 (0.213)	9.23 (0.215)
Region I	238.60 (12.08)	0.223 (0.006)	8.00 (0.260)	7.70 (0.240)	9.30 (0.230)
Region II	7315.70 (110.70)	0.608 (0.015)	8.30 (0.350)	8.10 (0.340)	9.10 (0.360)
Grass I* (Pangola)	713.89 (219.30)	0.218 (0.010)	8.43 (0.279)	8.16 (0.241)	9.61 (0.247)
Grass II (Llano)	252.89 (17.44)	0.244 (0.010)	6.22 (0.718)	7.03 (0.662)	9.22 (0.276)
Grass III** (Star)	6718.00 (290.10)	0.561 (0.240)	9.26 (0.421)	9.32 (0.524)	10.21 (0.528)
Grass IV (Guinea)	7384.60 (159.50)	0.640 (0.017)	7.30 (0.493)	6.56 (0.372)	7.63 (0.418)
Region I Grass I	227.08 (17.25)	0.200 (0.006)	8.20 (0.283)	8.10 (0.257)	9.36 (0.236)
Region I Grass II	252.89 (17.44)	0.244 (0.010)	6.22 (0.718)	7.03 (0.662)	9.22 (0.276)
Region II Grass III	7309.20 (150.93)	0.588 (0.023)	9.23 (0.476)	10.01 (0.471)	10.29 (0.519)
Region II Grass IV	7384.60 (159.50)	0.640 (0.017)	7.30 (0.493)	6.56 (0.372)	7.63 (0.418)

[a]Numbers in parenthesis are standard errors.
*Five samples from Region II are included.
**Five samples from Region I are included.

for regions. The relationship with dry matter was low, but consistent.

Soil to grass calcium correlations are given in Table A13. Correlation coefficients were high for soil calcium to grass calcium (.82), soil calcium to grass phosphorus (.75), soil calcium to grass zinc (.78), and soil calcium to grass iron (.65).

Soil to serum correlations are presented in Table A14. Soil calcium to serum copper correlations were consistently negative for the three types of livestock. The correlations were -.29, -.20, and -.18 for cows, heifers, and calves respectively. Soil calcium to serum zinc correlation also were low, but consistent. The values are .35 for cows, .35 for heifers and .26 for calves.

Grass to serum correlations are shown in Table A15. Consistency was found in grass calcium to serum magnesium with values of -.26 for cows, -.08 for heifers, and -.27 for calves. Grass calcium to serum copper correlations were -.30 for cows, -.24 for heifers and -.24 for calves. Grass calcium to serum zinc correlation coefficients were .29, .33, and .28 for cows, heifers and calves respectively.

Serum to serum correlations are shown in Table A16. The cow to heifer calcium correlations were .32, and the cow to calf correlations were .26, the heifer to calves values were .36. A comparison between means (Bonferroni t Test) shows a significant difference ($P<.005$) between cow calcium and calf calcium, heifer calcium and calf calcium.

Soil-Plant-Animal Phosphorus Relationship

Table 2 shows phosphorus concentrations of soils, grasses and blood sera. Phosphorus levels in soils do not differ significantly among regions. Differences were found in phosphorus between Pangola grass and Llano grass ($P<.02$) in Region I and between Star grass and Guinea grass ($P<.01$) in Region II. Phosphorous in Llano grass was .19% of D.M. (Dry Matter) and in Star grass .36%.

Serum phosphorus concentrations were 4.5, 5.0, and 5.9 mg/dl for cows, heifers and calves respectively. These values were in the normal range (>4.5 mg) indicated by Underwood (128). Highly significant differences were found among livestock types ($P<.00001$). Cows vs. heifers, cows vs calves and heifers vs calves were the contrasts tested using Bonferroni t test ($P<.005$). However, the differences were only in Rgion I (Table 2). There was a highly significant difference between regions for livestock type ($P<.00001$).

Mean phosphorus concentrations in soils varied from .62 ppm for Farm 1 up to 4.74 ppm for Farm 7, (Table A2). All were below adequate levels (39). Blue et al (11) reported very low values (0.2 to 2.5 ppm) for soil in Panama. Grass phosphorus levels ranged from .15% to .42% D.M. (Table A2). The values were .21% for Pangola, .19% for Llano, .36% for Star, and .41% for Guinea as overall figures, ranged from deficient to adequate when compared to the 0.30% considered adequate. Jardin et al (62) reported values of .09% to .27% for forages from three different areas of Brazil. Low concentrations have been reported by Kalinowsky (64) for Peruvian grasses

sampled during summer and winter, with phosphorus being lower during winter. According to Christiansen (28) phosphorus is usually either deficient or not present in the forages of Latin America.

Serum phosphorus concentrations ranged from 2.05 mg/dl for cows in Farm 6 up to 8.14 mg/dl for cows in Farm 11 (Table A2). Normal values are 4.5 to 6.0 mg/dl of serum in adult cattle (27, 93, 95, 120, 128). De Oliveira (38) reported serum phosphorus concentrations of 6.40 mg/dl in the rainy season and 5.19 mg/dl in the dry season. These values were significantly different (P .01). Also from Brazilian cattle Sutmoller (120) reported low values (2.4 to 4.0 mg/dl) of serum inorganic phosphorus from cattle in the Amazon Valley. Values ranging from 1.80 to 5.70 mg/dl were reported by McDowell et al (92) for cattle in Costa Rica.

Soil phosphorus correlations with other soil variables are given in Table A11. There was a consistent relationship between soil phosphorus and soil magnesium. The correlation coefficient ranged from .06 to .59 with an average figure of .31. Phosphorus was also positively correlated with zinc in soils. The correlations varied from .12 to .57 with an average of .32. These results agree with those given by Barradas (8) but differ from the values reported by De Sousa (39).

Grass to grass phosphorus correlation coefficients are presented in Table A12. Positive correlations were found between phosphorus and potassium with coefficients ranging from .31 to .45 and an average of .41. These values are similar to those reported by Barradas (8) and De Sousa (39). Consistent positive correlations

TABLE 2. MEAN PHOSPHORUS CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	Soil P	Grass P	Serum P		
			Cows	Heifers	Calves
	ppm	% of DM	- - - - - - mg/dl - - - - - -		
Overall	2.60 (0.110)	0.297 (0.008)	4.50 (0.220)	5.00 (0.200)	5.90 (0.230)
Region I	2.47 (0.180)	0.202 (0.006)	3.30 (0.180)	4.50 (0.220)	6.10 (0.280)
Region II	2.85 (0.140)	0.392 (0.008)	5.60 (0.340)	5.60 (0.320)	5.80 (0.370)
Grass I* (Pangola)	2.52 (0.249)	0.218 (0.009)	3.67 (0.241)	4.97 (0.283)	5.96 (0.321)
Grass II (Llano)	2.18 (0.224)	0.191 (0.009)	3.51 (0.384)	4.26 (0.332)	8.37 (0.645)
Grass III** (Star)	2.91 (0.240)	0.362 (0.012)	6.62 (0.436)	6.68 (0.327)	7.24 (0.360)
Grass IV (Guinea)	3.00 (0.196)	0.416 (0.011)	4.22 (0.486)	3.97 (0.421)	4.08 (0.438)
Region I Grass I	2.47 (0.268)	0.212 (0.010)	3.43 (0.220)	4.70 (0.270)	5.84 (0.310)
Region I Grass II	2.18 (0.224)	0.191 (0.009)	3.51 (0.384)	4.26 (0.332)	8.37 (0.645)
Region II Grass III	2.65 (0.224)	0.375 (0.012)	7.34 (0.031)	7.24 (0.215)	7.60 (0.362)
Region II Grass IV	3.00 (0.196)	0.416 (0.011)	4.22 (0.486)	3.97 (0.421)	4.00 (0.438)

[a]Numbers in parenthesis are standard errors.
*Five samples from Region II are included.
**Five samples from Region I are included.

were also found for grass phosphorus and grass copper with an average value of .48. For grass phosphorous and zinc the correlation was .63. A negative correlation was found between grass phosphorus and grass magnesium (-.42).

Soil to grass phosphorus correlations are presented in Table A13. A positive correlation coefficient was found between soil and grass phosphorus. The values ranged from .02 to .42 with average value of .20, higher values (.57) were found by Peruvian workers (69). Soil calcium to grass phosphorus was consistent going from .10 to .75. These results are supported by those reported by Brazilian workers (39). They stated that little or no relation seems to exist between the concentraion in the plant and the available phosphorus in the soil. On the other hand, Knox et al [cited by De Oliveira (38)] reported a correlation of .61±.06 between forage phosphorus and blood phosphorus of cattle, and concluded that inorganic phosphorus in blood plasma appears to be closely related to the phosphorus intake.

Table A14 presents soil to serum phosphorus correlations. The correlations are consistently low and negative (-.14, -.14, and -.19 for cows, heifers and calves respectively). Positive correlations were reported by Barradas (8) for the same comparison in a similar experiment.

Grass to serum correlations are shown in Table A15. Grass to serum phosphorus correlations were .35 for cows, .21 for heifers and -.04 for calves. The same pattern was found in grass calcium to serum phosphorus correlation (.37 for cows, .14 for heifers, and

-.07 for claves). The same trend was found by Barradas (8).

Serum to serum correlation coefficients among livestock types are presented in Table A16. The correlations were .70 for cows to heifers, .49 for cows to calves and .64 for heifers to calves.

Soil-Plant-Animal Magnesium Relationship

Mean magnesium concentrations and standard errors of soils, grases and blood sera are given in Table 3. Significant differences were found between regions ($P<.0003$). Soil magnesium was higher in Region II. There were no significant differences among grasses within Region I and Region II. No significant differences were found in serum magnesium concentrations of cattle grazing in the two regions. Livestock type by region interaction was significant ($P<.02$). Higher serum magnesium concentrations were found in cows and calves in the two regions.

Extractable magnesium in soils ranged from 32.9 ppm at Farm 2 to 510.7 ppm for Farm 7. These values are considered high according to the values reported in the literature. For Florida soils, Breland reported values going from 0 to >21.2 ppm using double acid extraction. From Michigan soil, Warncke (135) mentioned 40 ppm as adequate. Barradas (8) reported values which ranged from 116 ppm to 464 ppm, from tropical soils. Magnesium concentration in grasses varied from .12% of the dry matter at Farm 10 to .31%. The level in grasses was .23%, .26%, .16% and .16% for Pangola, Llano, Star, and Guinea grass respectively.

Similar values have been reported for Pangola grass in Haiti

(68), Mexico (8), and Eastern Panama (11). For Guinea grass higher values have been reported by the same authors. Very low magnesium concentrations were found in 40 forage samples from Costa Rica [Kidder and Davis, (cited by Lang 75)]. McDowell (91) reported that 47 percent of the forages sampled in Latin America were deficient in magnesium.

Serum magnesium levels ranged from 1.17 mg/dl for heifers in Farm 5 up to 3.16 mg/dl (27, 95). Barradas (8) reported magnesium values (from 2.1 to 3.4 mg/dl) for the same livestock types under tropical conditions. Similar figures were reported by De Oliveira (38) for cattle from Matogrosso, Brazil.

Soil magnesium correlations with other soil variables are shown in Table A11. High correlation coefficients were found between soil magnesium and soil calcium (.76) soil pH (.63), soil copper (.57), and iron (-.55). Magnesium was correlated with potassium (.40), phosphorus (.31), selenium (.44) and zinc (.33). Similar figures have been reported by De Sousa (39) and Barradas (8).

Grass to grass magnesium correlations are shown in Table A12. Magnesium was negatively correlated with all the other variables in the overall figures. Some exceptions were found for the Region II values. Negative correlations have been reported between magnesium and copper, iron, zinc and crude protein for Pangola and Guinea grass (8).

Soil to grass comparisons are given in Table A13. Soil magnesium and grass magnesium showed a negative correlation (-.38). Grass magnesium was negatively correlated with soil calcium (-.53)

TABLE 3. MEAN MAGNESIUM CONCENTRATION OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	Soil Mg	Grass Mg	Serum Mg		
			Cows	Heifers	Calves
	ppm	% of DM	- - - - - - mg/dl - - - - - -		
Overall	183.20 (9.65)	0.207 (0.004)	2.21 (0.052)	2.13 (0.064)	2.22 (0.051)
Region I	65.20 (4.26)	0.249 (0.007)	2.30 (0.007)	2.10 (0.009)	2.30 (0.007)
Region II	301.30 (11.00)	0.164 (0.003)	2.00 (0.006)	2.10 (0.008)	2.00 (0.006)
Grass I* (Pangola)	75.53 (9.00)	0.233 (0.009)	2.38 (0.075)	2.19 (0.097)	2.34 (0.074)
Grass II (Llano)	71.14 (5.53)	0.261 (0.011)	2.15 (0.249)	2.55 (0.197)	2.85 (0.173)
Grass III** (Star)	298.30 (18.93)	0.169 (0.005)	2.36 (0.816)	1.98 (0.087)	2.33 (0.068)
Grass IV (Guinea)	287.78 (14.55)	0.167 (0.005)	1.78 (0.091)	2.04 (0.159)	1.74 (0.082)
Region I Grass I	60.51 (6.64)	0.242 (0.008)	2.40 (0.082)	2.16 (0.106)	2.31 (0.080)
Region I Grass II	71.14 (5.53)	0.261 (0.011)	2.15 (0.249)	2.55 (0.197)	2.85 (0.173)
Region II Grass III	322.20 (17.83)	0.165 (0.005)	2.36 (0.081)	2.14 (0.046)	2.36 (0.054)
Region II Grass IV	287.70 (14.55)	0.167 (0.005)	1.78 (0.091)	2.04 (0.159)	1.75 (0.082)

[a] Numbers in parenthesis are standard errors.
*Five samples from Region II are included.
**Five samples from Region I are included.

and soil potassium (-.31). However, soil magnesium was positively correlated with grass potassium (.11). Correlations for soil magnesium and grass potassium were reported by Barradas (8) and De Sousa (39).

Soil to serum correlations for magnesium were also negative among livestock types. The values were -.38, -.13, and -.36 for cows, heifers and calves respectively. Soil calcium to serum magnesium correlations were variable. The coefficients were -.22 for cows, .02 for heifers and -.25 for calves. Soil potassium to serum magnesium correlations follow the same pattern (Table A14).

Grass to serum correlations are shown in Table A15. The values were .04 for cows, .04 for heifers, and .14 for calves. Negative but consistent correlations were found for grass calcium and serum magnesium (-.26, -.03, and -.27 for the three livestock types). There were highly variable correlations for grass potassium and serum magnesium.

Serum to serum magnesium correlations were low but consistent among livestock types. The correlations were .23 for cows and heifers, .35 for cows and calves, and .34 for heifers and calves.

Soil-Plant-Animal Potassium Relationship

Means and standard errors of extractable soil potassium for individual farms are presented in Table A4. The concentrations ranged from 9.97 ppm in soil from Farm 5 up to 63.56 ppm at Farm 12. Potassium content in soils differed among regions ($P<.01$) and farms within regions ($P<.00001$). The values were similar to those reported

by others (5, 8, 11, 39). Values up to 2700 ppm are reported for limestones (14). A normal value of 120 ppm of available potassium is considered adequate in soils (126). Mean grass potassium levels were 2.0% of D.M. for Pangola grass, 2.1% for Llano grass, 2.4% for Star grass, and 2.49% for Guinea grass (Table 4). No differences were found among grasses in both regions, however significant differences were found among farms ($P<.00001$). The grass potassium values found in the present study were higher than that reported by Gomide (49) for six tropical grasses.

Potassium levels in serum ranged from 15.7 mg/100 ml to 29.0 mg/100 ml. This is considered adequate and is supported by several authors (27, 29, 44, 95). Overall means differed significantly between livestock types ($P<.00001$). Means differed between cows and heifers ($P<.005$) and between heifers and calves ($P<.005$). The same significant contrasts ($P<.01$) were reported by Barradas (8).

Soil potassium correlations with other soil variables are given in Table A11. Soil potassium and soil calcium correlation coefficients ranged from .28 to .74 with an average of .53. For soil potassium and soil copper correlation values were 0 to .49 with an average of .36. The potassium to iron correlation coefficients ranged from -.04 to -.64; the average was -.45. Soil potassium and soil pH correlation also were consistent. The correlations coefficients ranged from .19 up to .68 with a mean of .57. For soil potassium and selenium the correlations ranged from .02 to .39 with

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TABLE 4. MEAN POTASSIUM CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	Soil K	Grass K	Serum K		
			Cows	Heifers	Calves
	ppm	% of DM	mg/dl		
Overall	44.60 (1.54)	2.26 (0.043)	21.30 (0.370)	22.00 (0.420)	23.90 (0.460)
Region I	32.40 (2.40)	2.11 (0.054)	22.70 (0.450)	23.00 (0.610)	25.90 (0.490)
Region II	56.80 (1.07)	2.40 (0.065)	19.90 (0.530)	20.9 (0.550)	30.10 (1.100)
Grass I * (Pangola)	31.24 (2.90)	2.03 (0.076)	23.00 (0.438)	22.70 (0.585)	25.20 (0.477)
Grass II (Llano)	37.98 (4.07)	2.10 (0.067)	22.02 (1.640)	26.78 (0.936)	29.20 (0.537)
Grass III ** (Star)	56.10 (2.25)	2.40 (0.097)	18.10 (0.614)	17.55 (0.569)	19.90 (0.998)
Grass IV (Guinea)	54.00 (1.43)	2.498 (0.091)	21.32 (0.797)	23.71 (0.710)	24.10 (0.984)
Region I Grass I	29.60 (2.96)	2.10 (0.076)	23.22 (0.470)	22.89 (0.630)	25.10 (0.465)
Region I Grass II	37.90 (4.07)	2.10 (0.067)	22.02 (0.640)	26.78 (0.936)	29.20 (0.537)
Region II Grass III	60.01 (1.63)	2.41 (0.091)	18.05 (0.699)	17.55 (0.453)	18.66 (0.678)
Region II Grass IV	54.00 (1.43)	2.498 (0.091)	21.32 (0.797)	23.71 (0.710)	24.15 (0.984)

[a] Numbers in parenthesis are standard errors.

*Five samples from Region II are included.

**Five samples from Region I are included.

a mean of .33. No definite patterns were found for soil potassium and soil zinc, soil potassium and soil phosphorus, or soil potassium and soil cobalt. The depressing effect of potassium on magnesium levels in soils was only found in Region II. This confirms the major exchangeable capacity of magnesium in alkaline soils (14, 67).

Grass to grass correlations are presented in Table A12. The correlation of grass potassium to grass magnesium shows a negative correlation as expected in the overall figure (95). Positive correlations were found between grass potassium and grass phosphorus. The values ranged from .21 to .45 with a mean of .41.

Soil to grass potassium correlations are shown in Table A13. These correlations were consistent (.20) with the exception of Grass I. There was also a negative correlation, -.31, for soil potassium and grass magnesium.

Soil to serum correlation coefficients are presented in Table A14. Low but consistent correlations were found for the potassium variable, for the three livestock types. The correlation of soil potassium with serum magnesium did not show consistency. The values were .02 for cows, .15 for heifers and -.07 for calves. The same tendency was reported by Barradas (8).

Negative values were found for the grass to serum potassium correlations. These were -.35 for cows, -.24 for heifers and -.24 for calves. Grass potassium was not correlated with serum magnesium significantly (Table A15).

Serum to serum correlation coefficients between livestock

types are shown in Table A16. The correlation of cow potassium to heifer potassium was .32, cows to calves .28 and heifers to calves .44.

Soil-Plant-Animal Copper Relationship

Extractable soil copper ranged from 2.1 ppm in Farm 1 up to 6.61 ppm in Farm 12. The mean value of soil copper was 4.40 ppm. Values from 2 to 100 ppm are reported by Bowen (14) for copper in soils. De Sousa (39) reported mean values of 2.1 ppm for Brazilian soils during the dry season and 1.5 ppm during the wet season, showing a significnt difference among means ($P<.007$). Barradas (8) reported 2.43 ppm for Mexican tropical soils.

Grass copper values on a dry matter basis varied from 5.49 ppm to 11.53 ppm among farms values. The overall mean was 7.80 ppm. Normal copper concentrations in plant tissues range from 8 to 20 ppm and values below 6 ppm are considered deficient (8, 63, 133). Values of 2.0 ppm were reported from copper deficient areas in Peru (64). The copper concentrations found for individual grasses were within the values reported for the same grasses in different tropical areas (62, 68, 69, 90).

Copper concentrations in serum ranged from .415 ug/ml in heifers to .752 ug/ml in cows. Underwood (129) reported the normal range of blood copper concentration from .5 to 1.5 ug/ml.

Copper content of soils, grasses, and serum are shown in Table 5. Mean soil copper content was lower in Region I (3.0 ppm), ($P<.01$). Significant differences were also found in farms within regions

($P<.00001$). Copper content in grasses was not different between grasses from each region. Although significant differences were detected in farms for Region II ($P<.00001$), no differences were found for serum copper of cattle grazing in the two regions for the overall values. However, cows in Region I had the lower value .25 ug/ml.

Soil to soil correlations are shown in Table A11. Soil copper was positively correlated with soil calcium (.67), soil potassium (.36), magnesium (.57), selenium (.27), and pH (.66). Soil copper was negatively correlated with soil iron (-.52), and cobalt (-.14). Lower soil copper correlation values were reported for Mexican soils (8) for calcium, potassium and pH interactions.

Grass copper correlations with other grass variables are shown in Table A12. No well defined relationships of grass copper with other minerals were detected with the exception of iron (.54), potassium (.49), zinc (.71) and dry matter (.32). Barradas (8) reported positive correlations with calcium (r=.39 to .49), selenium (r=0 to .33) and De Sousa (39) with phosphorus (r=.39 to .49), magnesium (r=.22) and potassium (r=.79).

Soil to grass mineral correlations are shown in Table A13. The soil copper to grass copper correlation was .34. Soil calcium to grass copper correlation was .50 and soil copper to grass zinc correlation was .58. Inverse relationships were found between soil iron and grass copper (-.33), and soil zinc and grass copper (-.10). Brazilian workers (39) reported negative correlations between soil calcium and grass copper, soil copper and grass zinc,

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TABLE 5. MEAN COPPER CONCENTRATIONS OF SOILS, GRASSES AND BLOOD SERA OF GRAZING CATTLE FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	Soil Cu	Grass Cu	Serum Cu		
			Cows	Heifers	Calves
	ppm	DM ppm	- - - - - ug/ml serum - - - - -		
Overall	4.40 (0.12)	7.80 (0.190)	0.51 (0.012)	0.54 (0.015)	0.53 (0.014)
Region I	3.00 (0.14)	6.40 (0.150)	0.25 (0.020)	0.57 (0.025)	0.56 (0.018)
Region II	5.70 (0.10)	9.20 (0.300)	0.47 (0.012)	0.50 (0.018)	0.50 (0.022)
Grass I* (Pangola)	3.45 (0.23)	6.37 (0.222)	0.57 (0.020)	0.57 (0.024)	0.57 (0.019)
Grass II (Llano)	3.00 (0.20)	6.40 (0.209)	0.48 (0.063)	0.63 (0.066)	0.65 (0.270)
Grass III** (Star)	5.31 (0.19)	8.74 (0.435)	0.48 (0.020)	0.56 (0.034)	0.47 (0.026)
Grass IV (Guinea)	5.89 (0.14)	9.79 (0.398)	0.44 (0.010)	0.42 (0.017)	0.48 (0.035)
Region I Grass I	3.19 (0.22)	6.52 (0.220)	0.57 (0.022)	0.57 (0.026)	0.55 (0.018)
Region I Grass II	3.00 (0.20)	6.40 (0.209)	0.48 (0.062)	0.63 (0.066)	0.65 (0.027)
Region II Grass III	5.59 (0.16)	9.02 (0.453)	0.49 (0.018)	0.58 (0.030)	0.47 (0.230)
Region II Grass IV	5.89 (0.14)	9.79 (0.398)	0.44 (0.017)	0.42 (0.017)	0.48 (0.035)

[a] Numbers in parenthesis are standard errors.

*Five samples from Region II are included.

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Soil to serum mineral correlations were negative for soil copper and serum copper. Correlations were -.24 for cows, -.06 for heifers, and -.18 for calves. Soil calcium to serum copper correlations were -.29, -.20 and -.18 for cows, heifers, and calves respectively. Soil copper to blood hemoglobin correlations were -.36, -.23, and -.31 in the same order. Positive correlations were found in soil iron-serum copper, soil copper-serum iron, soil copper-serum selenium and soil copper-blood hematocrit (Table A14).

Grass to serum correlations are shown in Table A15. Negatively correlated grass copper and serum copper had coefficients of -.15 for cows, -.13 for heifers and -.19 for calves. Grass calcium to serum copper followed the same pattern as soil calcium to serum copper. The values were -.30 for cows, -.24 for heifers and -.24 for calves, the same tendency was found by Barradas (8). Grass zinc to serum copper correlation coefficients were also negative. The values were -.25, -.18 and -.19 for cows, heifers and calves respectively.

Serum to serum correlation coefficients between livestock types are shown in Table A16. Cow copper to heifer's copper correlation was .15, cows to calves .20 and heifers to calves .10.

Soil-Plant-Animal Iron Relationship

Means and standard errors for iron concentrations in soils, plant and animal sera are shown in Table 6. Extractable soil iron ranged from 1.95 ppm in Farm 11 to 13.86 ppm in Farm 1. Levels of

20 ppm in the soil solution is considered adequate for crop production. De Sousa (39) reported values for Brazilian soils of 23±23 ppm.

Grass iron concentrations varied from 113.7 at Farm 5 up to 1331.9 in Farm 8. The mean was 545.1 ppm. For individual grasses the mean values were 312.8 ppm for Pangola grass, 223.4 for Llano grass, 793.0 for Star grass, and 853 for Guinea grass. The iron concentrations found in this experiment were within the range of values as those found in the same grasses in other tropical areas (8, 12, 48, 104). The National Research Council pointed out that the iron content in cultivated grasses ranged from 100 to 700 ppm (95).

Levels in serum ranged from 1.03 ug/ml for cows in Farm 1 to 2.52 ug/ml for heifers in Farm 9. Normal values reported in the literature range from 1 to 2 ug/ml (27, 106). Mc Dowell (90) reported that under natural conditions iron deficiency is rarely found.

The iron content of soils, grasses and livestock type are presented in Table 6. Iron values of soils from Region I were significantly higher ($P<.00001$) than Region II. This confirms the relationship between low pH and high iron concentration (14). Iron content in grasses within Region I and Region II were different. However, there were differences between farms in the iron content of grasses ($P<.00001$). Marked differences were found for serum iron concentrations among livestock grazing in the two regions ($P<.00001$). For the overall means the contrasts that were tested using Bonferroni t test were: cows vs heifers, cows vs calves and heifers vs calves.

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TABLE 6. MEAN IRON CONCENTRATIONS OF SOILS, GRASSES AND BLOOD SERA OF GRAZING CATTLE FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	Soil Fe	Grass Fe	Serum Fe		
			Cows	Heifers	Calves
	ppm	DM ppm	- - - - - ug/ml serum - - - - -		
Overall	7.85 (0.46)	545.10 (30.58)	1.60 (0.051)	1.80 (0.058)	1.70 (0.060)
Region I	13.10 (0.60)	232.00 (13.83)	1.30 (0.067)	1.40 (0.077)	1.50 (0.082)
Region II	2.61 (0.21)	860.80 (43.70)	1.90 (0.057)	2.19 (0.060)	2.00 (0.079)
Grass I* (Pangola)	12.80 (0.79)	312.80 (35.60)	1.37 (0.074)	1.56 (0.81)	1.60 (0.094)
Grass II (Llano)	12.70 (1.00)	223.41 (14.30)	1.15 (0.145)	1.13 (0.196)	1.62 (0.203)
Grass III** (Star)	3.13 (0.41)	793.00 (65.60)	1.93 (0.093)	2.31 (0.101)	2.19 (0.106)
Grass IV (Guinea)	2.87 (0.38)	853.08 (62.42)	1.82 (0.800)	2.08 (0.059)	1.75 (0.099)
Region I Grass I	13.50 (0.77)	250.80 (23.70)	1.32 (0.078)	1.48 (0.078)	1.60 (0.090)
Region I Grass II	12.72 (1.00)	223.41 (14.39)	1.15 (0.145)	1.13 (0.196)	1.62 (0.203)
Region II Grass III	2.31 (0.17)	856.80 (65.22)	2.01 (0.094)	2.30 (0.116)	2.19 (0.115)
Region II Grass IV	2.87 (0.38)	853.00 (62.42)	1.82 (0.080)	2.08 (0.059)	1.75 (0.099)

[a] Numbers in parenthesis are standard errors.

*Five samples from Region II are included.
**Five samples from Region I are included.

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The difference was found for cows vs heifers for the overall values ($P<.005$).

Correlations between soil minerals are shown in Table A16. Soil iron was negatively correlated with soil calcium -.69, potassium -.45, magnesium -.55, copper -.52, selenium -.35, and soil pH -.70. However, positive correlations were found in Region II for soil iron with soil calcium, magnesium, copper and selenium. The antagonistic effect of iron with these elements could be explained by the inverse relationship between pH and iron availability. Similar figures were reported by Barradas (8).

Grass to grass correlation coefficients are given in Table A12. Grass iron was positively correlated with grass calcium (.48), phosphorus (.36), copper (.54), grass zinc (.76) and dry matter (.38). Negative correlations were found in grass magnesium -.23. These data did not follow Bowen's (14) statement, since factors such as high pH, phosphates and carbonate salts interfere with iron uptake. Similar observations were reported for Mexican grass (8) and Brazilian forages (39).

Soil correlations with other grass variables are shown in Table A13. Since the content in plants is a reflection of the species, age, and soils upon which the plants grow, the correlations found in this experiment were different from what was expected. Soil iron to grass iron correlations were -.47, soil calcium to grass iron was .65, soil copper to grass iron was .41 and soil pH to grass iron was .65. The only explainable correlation was found between soil iron and grass copper (-.33). These two elements are antagonistic.

A negative correlation was expected.

Correlations between soil iron and serum iron were negative for the three livestock types. The values were -.45 for cows, -.43 for heifers and -.25 for calves. Soil iron to serum copper were .35 for cows, .28 for heifers and .13 for calves. Soil copper to serum iron was .40 for cows, .43 for heifers and .27 for calves. Positive responses were found for soil iron and blood hemoglobin. These were .41, .30 and .34 for cows, heifers and calves, respectively (Table A14).

Grass to serum iron correlation coefficients were .39 for cows, .30 for heifers and .23 for calves. Negative relationships were found for grass iron and serum copper and grass iron and blood hemoglobin. The values were -.14, -.35 for cows, -.06, -.34 for heifers, and -.07, -.35 for calves (Table A15).

Serum to serum iron correlation coefficients among livestock types are shown in Table A16. For all the combinations, the correlations were positive, .56, .33 and .42.

Soil-Plant-Animal Selenium Relationship

Mean soil selenium concentrations for individual farms are shown in Table A7. Values ranged from .071 ppm to .223 ppm. Normal values are between 0.1 and 0.2 ppm of total selenium (27). For Region I Farms 4, 5 and 6 were found deficient in soil selenium. Selenium in acid soils tended to be less available. Several reports show that Mexican soils range from deficient (8, 123) to toxic (22) levels of selenium.

Selenium concentrations in forages ranged from .054 ppm (D.M.) in Farm 4 up to .172 ppm in Farm 10. The wide variation of selenium concentrations depended on the plant species. Levels of .1 ppm have been recommended as the minimum desirable concentration in feedstuffs (3, 8, 46). Deficient to border line deficient values were found for Star grass and Guinea grass in Region II.

Selenium levels in serum ranged from .012 ug/ml for calves in Farm 3 up to .172 ug/ml for cows in Farm 7. Blood selenium levels between .05 ug/ml to .20 ug/ml are considered normal. Values below this level are considered deficient (27, 31).

Selenium content of soil, grasses and livestock type are shown in Table 7. Significant differences in soil selenium were found among regions ($P<.01$), and farms within regions ($P<.00001$). No differences were found in the selenium content in grasses for individual regions, but large differences were found among farms within regions ($P<.00001$). Livestock types differed significantly in their serum selenium concentrations ($P<.00001$). Cows were different from calves (Bonferoni t Test $P<.005$).

Soil selenium correlations with other soil variables are presented in Table A11. Positive correlations were found for soil selenium with soil calcium (.46) potassium (.33), magnesium (.44), copper (.27), cobalt (.19), and soil pH (.50), negative correlations were found with iron (-.35). Again soil pH helps to explain these relationships (3). Similar observations were reported by Barradas (8).

Correlations between grass minerals are presented in Table A12.

TABLE 7.

Overall	
Region	
Region	
Grass I (Pangol	
Grass I (Llano)	
Grass I (Star)	
Grass (Guine	
Region Grass	
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TABLE 7. MEAN SELENIUM CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	Soil Se	Grass Se	Serum Se		
			Cows	Heifers	Calves
	ppm	DM ppm	ug/ml serum		
Overall	0.133 (0.003)	0.102 (0.003)	0.078 (0.004)	0.065 (0.003)	0.058 (0.003)
Region I	0.105 (0.003)	0.102 (0.004)	0.054 (0.003)	0.050 (0.002)	0.041 (0.002)
Region II	0.161 (0.005)	0.102 (0.004)	0.102 (0.006)	0.080 (0.005)	0.074 (0.004)
Grass I* (Pangola)	0.113 (0.004)	0.108 (0.005)	0.057 (0.004)	0.053 (0.003)	0.043 (0.003)
Grass II (Llano)	0.106 (0.003)	0.098 (0.005)	0.074 (0.006)	0.051 (0.005)	0.054 (0.003)
Grass III** (Star)	0.158 (0.010)	0.097 (0.006)	0.060 (0.007)	0.048 (0.006)	0.048 (0.006)
Grass IV (Guinea)	0.154 (0.005)	0.104 (0.007)	0.134 (0.006)	0.107 (0.002)	0.094 (0.002)
Region I Grass I	0.105 (0.003)	0.105 (0.006)	0.050 (0.003)	0.049 (0.003)	0.038 (0.003)
Region I Grass II	0.106 (0.003)	0.098 (0.005)	0.074 (0.006)	0.051 (0.005)	0.054 (0.003)
Region II Grass III	0.164 (0.011)	0.096 (0.007)	0.059 (0.008)	0.047 (0.007)	0.048 (0.007)
Region II Grass IV	0.154 (0.005)	0.104 (0.007)	0.134 (0.006)	0.107 (0.002)	0.094 (0.002)

[a] Numbers in parenthesis are standard errors.

*Five samples from Region II are included.
**Five samples from Region I are included.

Selenium was correlated with calcium (.48). For the rest of the elements correlations were very low positives, zero or low negative values.

Soil to grass selenium correlation coefficients ranged from .04 to .24 with an overall figure of .10. No correlations were found between soil calcium and grass selenium or grass copper (Table A13). This confirms that the total selenium content of soils shows little relationship to the concentration of selenium in the plants grown on it (10).

Soil to serum selenium correlations were consistent among the three livestock types (Table A14), being .43 for cows, .47 for heifers and .49 for calves. The same pattern was found for soil copper and serum selenium relationship. The values were .21, .23, and .23 for cows, heifers, and calves respectively.

Table A15 shows grass-serum correlation coefficients. The values for selenium were .08 for cows, .27 for heifers, and .23 for calves. For grass copper to serum selenium the correlation values were -.02 for cows, .10 for heifers and .03 for calves. There was a slight antagonistic effect between copper and selenium only for the cow correlations.

Serum to serum correlation coefficients are presented in Table A16. High positive correlations were found among livestock types. These were .75 for cow selenium to heifer selenium, .80 for cow selenium to calf, and .83 for heifer to calf selenium.

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Soil-Plant-Animal Zinc Relationship

Mean and standard errors for zinc from individual farms are presented in Table A8. Extractable soil zinc ranged from .22 ppm up to 3.25 ppm for Farms 10 and 7 respectively. Literature reports mention 0.55 ppm of extractable soil zinc as adequate. From Brazilian soils mean values of 2.4 ppm and 1.9 ppm were reported for wet and dry seasons, respectively.

Zinc grass concentrations ranged from 27.1 ppm (D.M.) in Farm 2 up to 92.5 ppm in Farm 12. Jones (63) reported values from 20 to 150 ppm. Similar values for Pangola grass were reported from Brazil (48), Mexico (8) and Haiti (68).

Zinc levels in serum ranged from 0.54 ug/ml for cows in Farm 5 to 1.42 ug/ml for calves in Farm 7 (Table A8). Zinc plasma concentrations from 0.60 to 1.40 ug/ml are considered normal in cows and values lower than 0.40 ug/ml would be indicative of deficiency. All the values found in this study were within the normal range.

Mean zinc concentration and standard errors of soils, grasses and blood sera are given in Table 8. No significant differences were found among regions in their soil zinc content. Significant differences were found in soil for farms within regions ($P<.00001$). No differences were found among grasses within individual regions. In Region I significant differences were found among farms ($P<.002$). Highly significant differences among farms were observed in Region II ($P<.00001$). Differences among livestock types were significant for animal sera ($P<.0003$). Bonferoni t test showed that the difference was between cows and calves ($P<.005$).

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TABLE 8. MEAN ZINC CONCENTRATIONS OF SOILS, GRASSES AND BLOOD SERA OF GRAZING CATTLE FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	Soil Zn	Grass Zn	Serum Zn		
			Cows	Heifers	Calves
	ppm	DM ppm	ug/ml serum		
Overall	1.34 (0.064)	50.83 (0.612)	0.96 (0.029)	1.04 (0.030)	1.11 (0.033)
Region I	1.44 (0.063)	31.06 (0.836)	0.83 (0.047)	0.91 (0.041)	0.99 (0.036)
Region II	1.24 (0.011)	70.61 (1.780)	1.08 (0.028)	1.17 (0.036)	1.23 (0.053)
Grass I* (Pangola)	1.44 (0.100)	34.20 (1.560)	0.87 (0.046)	0.94 (0.042)	1.04 (0.047)
Grass II (Llano)	1.35 (0.072)	29.27 (1.125)	0.96 (0.203)	1.05 (0.098)	1.01 (0.044)
Grass III** (Star)	1.33 (0.161)	67.70 (2.620)	0.96 (0.042)	1.05 (0.071)	1.10 (0.053)
Grass IV (Guinea)	1.21 (0.159)	71.71 (2.590)	1.11 (0.048)	1.20 (0.045)	1.28 (0.088)
Region I Grass I	1.52 (0.100)	31.51 (1.050)	0.83 (0.048)	0.91 (0.045)	0.98 (0.040)
Region I Grass II	1.35 (0.072)	29.27 (1.120)	0.96 (0.203)	1.05 (0.098)	1.01 (0.044)
Region II Grass III	1.32 (0.172)	69.79 (2.630)	1.03 (0.032)	1.13 (0.068)	1.10 (0.047)
Region II Grass IV	1.21 (0.159)	71.71 (2.595)	1.11 (0.048)	1.20 (0.045)	1.28 (0.088)

[a] Numbers in parenthesis are standard errors.

*Five samples from Region II are included.

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Soil to soil mineral correlations are shown in Table A11. Negative correlations were found between soil zinc and calcium (-.11), but correlations were variable for regions and grasses. Correlations also were variable between soil zinc and soil potassium, ranging from -.34 to .34, copper -.19 to .37, and selenium -.21 to .19. Positive correlations were found between soil zinc and soil magnesium (.12 to .74) with a mean value of .33, phosphorus (.12 to .57) with a mean of .32, iron (.05 to .24, excepting Grass III, -.08), and cobalt (.05 to .40, excepting Grass II). Correlation coefficients between soil zinc and soil pH were .14 and -.62 for Region I and II respectively. These results were expected, considering that zinc is more available in acid soils (14, 133). This result agrees with the report by Barradas (8).

Correlations between minerals in grasses are presented in Table A12. Positive correlations in the overall values were found between grass zinc and grass calcium, potassium, phosphorus, copper, iron and grass dry matter, although for regions and grasses the values were variable (negative, no correlation, and positive values). Similar observations were reported by Barradas (8) and De Sousa (39).

Correlations between soil zinc and grass zinc were variable ranging from -.26 to .08. The same tendency was noticed for soil zinc and grass copper (-.17 to .31). The relationships between soil calcium with grass zinc were highly correlated, .78 for the mean and .75 for soil pH with grass zinc (Table A13).

Soil zinc to serum zinc correlations are presented in Table A14. Variable correlations were found between soil zinc and

serum zinc (-.08 for cows, .13 for heifers and .06 for calves), while the correlations between soil calcium and serum zinc and soil copper and serum zinc were positive for the three livestock types.

Grass zinc to serum zinc correlations were .26 for cows, .18 for heifers and .26 for calves. Grass copper to serum zinc and grass calcium to serum zinc correlation coefficients were .31 and .29 for cows, .11 and .33 for heifers, and .03 and .28 for calves, respectively. Similar results were reported by Barradas (8).

Interrelationships between livestock types for their zinc content in serum were low but consistent. The correlation coefficients were .24 between cows and heifers, .17 between cows and calves, and .34 between heifers and calves.

Soil Cobalt Relationship

Mean concentrations and standard errors for soil cobalt are presented in Table A9. The values range from .110 ppm in Farm 11 up to .287 ppm in Farm 4. Conrad (31) reported values of 0.3 ppm as adequate while less than .1 ppm are considered low. All the data found in this experiment fell within normal values. For Mexican soils mean cobalt values of .68 ppm have been reported (8). No significant differences were found between regions, but highly significant differences were found for farms within regions ($P<.00001$).

None of the correlation coefficients that were obtained for soil cobalt were consistent. The mean correlation coefficient for soil cobalt with other minerals or pH was: soil calcium -.15, potassium .08, magnesium 0, phosphorus 0, copper -.14, iron .13,

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selenium .13, zinc .19, and pH -.13. Similar results have been observed by De Sousa (39) and Barradas (8).

Soil pH Relationship

Means and standard errors for soil pH from individual farms are presented in Table A9. The pH ranges from 5.3 (Farm 2) to 8.1 (Farm 10). Tropical soils tend to have lower pH (5 to 6) than temperate soils. The pH of Haitian soils have been reported to range from 5.8 to 7.2 (68). For Venezuela a pH of 6.1 has been reported. Barradas (8) reported a pH of 7.0 for Mexican soils.

Soil pH values are presented in Table 9. Highly significant differences ($P<.00001$) were found in soil pH between regions, being higher in Region II, and within regions. High positive correlations between soil pH and soil calcium were found (.90 as overall value), soil pH with soil copper (.66), soil pH with selenium (.50), and soil pH with soil magnesium (.63). Inverse correlations were found between soil pH and soil iron (-.70) and soil zinc (-.20).

There were antagonistic effects between iron, zinc and soil pH, while there were synergistic effects with calcium, copper, selenium, magnesium and soil pH. The correlation coefficients between soil pH and magnesium for Region I was .14 with a pH of 5.6. For Region II the correlation was -.71 with a pH of 7.7. This situation can be explained taking in consideration that the maximum rate of cation absorption is at a pH of 5 to 7 (112). Similar values have been reported for Mexican tropical soils (8).

Soil pH to grass mineral correlations are shown in Table A13.

TABLE 9.

Overall	
Region I	
Region II	
Grass I* (Pangola)	
Grass II (Llano)	
Grass III (Star)	
Grass IV (Guinea)	
Region I Grass I	
Region I Grass II	
Region I Grass II	
Region I Grass IV	

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TABLE 9. MEAN SOIL pH, COBALT, AND GRASSES DRY MATTER FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	Soil	Soil Co	Grass DM
	pH	ppm	%
Overall	6.70 (0.074)	0.199 (0.001)	27.59 (2.870)
Region I	5.60 (0.046)	0.224 (0.010)	26.12 (0.332)
Region II	7.79 (0.036)	0.175 (0.011)	29.05 (0.429)
Grass I* (Pangola)	5.82 (0.988)	0.214 (0.019)	26.59 (0.495)
Grass II (Llano)	5.72 (0.065)	0.235 (0.002)	25.44 (0.501)
Grass III** (Star)	7.60 (0.103)	0.176 (0.017)	29.53 (0.568)
Grass IV (Guinea)	7.77 (0.044)	0.175 (0.015)	28.69 (0.651)
Region I Grass I	5.65 (0.067)	0.220 (0.021)	26.51 (0.430)
Region I Grass II	5.72 (0.065)	0.235 (0.026)	25.44 (0.501)
Region II Grass III	7.80 (0.061)	0.179 (0.001)	29.58 (0.591)
Region II Grass IV	7.77 (0.044)	0.175 (0.001)	28.69 (0.651)

[a]Numbers in parenthesis are standard errors.

*Five samples from Region II are included.
**Five samples from Region I are included.

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High correlations were found in the overall figures for soil pH and grass calcium (.74) and soil pH and grass zinc (.75). From similar studies positive correlations have been found for soil pH and grass calcium and negatively correlated with iron (8). Final conclusions cannot be drawn since the effect of pH on mineral absorption may be modified by plant species and by the amounts and form of the element in the soil (112).

Grass Dry Matter Relationship

Means and standard errors for grass dry matter from individual farms are presented in Table A9. The dry matter ranged from 25% of fresh weight in Farm 2 to 35.7% in Farm 12. No significant differences were found for Pangola grass and Llano grass in Region I, but significant differences were found between farms ($P<.004$). No difference was found between grasses in Region II, but significant differences were found between farms ($P<.00001$). Correlations between grass variables are presented in Table 22. Grass dry matter was positively correlated with grass calcium (0 to 31), potassium (.06 to .39), and copper (.01 to .32). Variable responses were found between grass dry matter and phosphorus, iron, selenium and zinc levels.

Correlations between some of these parameters were reported by Barradas (8) for forages from Mexico. He reported positive correlations between grass dry matter and grass calcium and negative correlations between potassium, phosphorus and zinc.

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between grass dry matter and phosphorus (-.24) and potassium (-.76), from tropical forages.

Blood Hemoglobin and
Hematocrit Relationship

Means and standard errors for these variables are shown in Table 10. Hemoglobin values ranged from 7.9 g/dl for cows in Farm 8 to 12.5 g/dl for calves in Farm 1. Normal values in blood of beef cattle range from 9.5 to 13.5 g/dl for animals less than one year old, and 9.6 to 14.25 g/dl for mature cattle (115). From cattle under subtropical conditions Rodriguez (114) reported average values of 11.8 g/dl for animals under one year of age. Hemoglobin values were significantly different among livestock types ($P<.00001$). Differences between cows and heifers and cows and calves were found using Bonferroni t test ($P<.005$), in the overall values.

Correlations between blood hemoglobin and soil iron and copper are shown in Table A14. Positive correlations were found between soil iron and blood hemoglobin. The values were .41 for cows, .30 for heifers and .34 for calves. Negative correlations were observed for copper. The values were -.36, -.23 and -.31 for cows, heifers and calves respectively.

Negative correlations were found between grass iron and blood hemoglobin (-.35 for cows, -.34 for heifers and -.35 for calves) and grass copper and blood hemoglobin (-.27 for cows, -.21 for heifers and -.14 for calves).

Blood hematocrit values ranged from 26.2% for heifers in Farm 11 to 38.7% in Farms 7 and 12. Normal values for beef cattle

TABLE 10. ME
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Overall	
Region I	
Region II	
Grass I * (Pangola)	
Grass II (Llano)	
Grass III ** (Star)	
Grass IV (Guinea)	
Region I Grass I	
Region I Grass II	
Region II Grass III	
Region II Grass IV	

[a]Numbers in
*five sample
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TABLE 10. MEAN HEMOGLOBIN AND HEMATOCRIT VALUES OF GRAZING CATTLE FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	COHB	HEHB	CAHB	COHT	HEHT	CAHT
	g/dl			%		
Overall	12.80 (1.230)	11.10 (0.174)	11.10 (0.199)	31.10 (0.421)	31.80 (0.571)	34.40 (0.548)
Region I	10.80 (0.237)	11.80 (0.245)	12.00 (0.334)	29.70 (0.561)	31.40 (0.704)	33.80 (0.814)
Region II	14.80 (2.450)	10.30 (0.207)	10.30 (0.160)	32.50 (0.577)	32.20 (0.901)	35.00 (0.731)
Grass I * (Pangola)	10.79 (0.251)	11.51 (0.207)	11.38 (0.323)	29.45 (0.592)	30.49 (0.801)	32.67 (0.875)
Grass II (Llano)	11.06 (0.570)	13.87 (1.04)	14.31 (0.954)	32.75 (0.940)	34.00 (1.430)	35.87 (1.060)
Grass III ** (Star)	9.14 (0.236)	10.52 (0.243)	10.37 (0.298)	30.60 (0.711)	31.93 (1.360)	34.69 (0.989)
Grass IV (Guinea)	8.87 (0.275)	10.31 (0.346)	10.63 (0.248)	34.16 (0.863)	33.90 (1.110)	37.03 (1.038)
Region I Grass I	10.88 (0.272)	11.59 (0.219)	11.50 (0.348)	29.39 (0.647)	31.00 (0.825)	33.14 (0.917)
Region I Grass II	11.06 (0.570)	13.87 (1.040)	14.31 (0.954)	32.75 (0.940)	34.00 (1.430)	35.87 (1.060)
Region II Grass III	9.11 (0.261)	10.44 (0.262)	9.98 (0.223)	31.20 (0.755)	32.20 (1.560)	34.20 (0.898)
Region II Grass IV	8.87 (0.275)	10.31 (0.346)	10.63 (0.248)	34.16 (0.863)	33.90 (1.110)	37.03 (1.030)

[a]Numbers in parenthesis are standard errors.

*Five samples from Region II are included.

**Five samples from Region I are included.

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are 27 to 50.5% for young animals and 31 to 49% for mature cattle (115). Low values were found for cows from both regions. Blood hematocrit values differed significantly among livestock types ($P<.00001$). Bonferroni's t test shows significant differences ($P<.005$) for cows vs calves and heifers vs calves.

Blood hematocrit correlations with soil iron and copper are presented in Table A14. For iron the correlations were variable (-.21 for cows, -.01 for heifers and .02 for calves). Similarly, the values were variable for soil copper (.20 for cows, .21 for heifers and 0 for calves). Low but positive correlations were found for grass iron and blood hematocrit (.20, .07 and .05, for cows, heifers and calves), and variable correlations for grass copper and blood hematocrit (Table A15).

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SUMMARY AND CONCLUSIONS

Soil calcium was low in Region I, where all the soil samples had less than 700 ppm. In Region II all the soil samples had more than 4400 ppm extractable calcium. This was reflected in grasses growing in these soils. For Pangola grass 75% of the samples had less than 0.25% calcium, which is inadequate for grazing beef cattle, while 56.4% of the Llano grass samples were below 0.25% calcium. For the grasses growing in Region II, 11.7% of Star grass samples were inadequate, but all the samples of Guinea grass had adequate calcium levels for grazing cattle.

Low serum calcium concentrations were found for cattle grazing in the two regions. Taking 9.0 to 12.0 mg/dl calcium serum as a normal range, 65% of the cows, 71% of heifers and 36.7% of the calves in Region I were deficient in calcium. In th Temporal area (Region II) 58.7% of the cattle sampled were below the normal range.

Soil phosphorus levels were low in 89.2% of the total samples. In Region I, 105 samples out of 120 (or 87.6%) had less than 5ppm phosphorus. In Region II, 90.8% of the soil samples also were below that level.

The comparison between the results of this sampling with the value of 0.3% phosphorus, considered adequate in grazing areas, showed that most of the forages were below 0.3%. In Region I, 87.7% (52 out of 60) of Pangola grass and 94.5 of Llano grass samples were borderline or deficient. For Region II, 26.7% of Star

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grass and only 8.3% of Guinea grass had low phosphorus concentrations.

Forty-seven percent of the total animal population sampled had low serum phosphorus concentrations. The percentage for animals grazing on Pangola and Llano grass was 55% and for the animals grazing on Star and Guinea grass was 39.3%.

Magnesium was deficient in forages from Region II. More than 76% of the Star grass and Guinea grass samples had less than 0.18% magnesium which is the minimum considered adequate for grazing cattle. Low magnesium concentrations in forages were reflected in serum magnesium concentrations. Thirty-one percent of the cattle grazing in Region II had low serum magnesium values (less than 1.7 mg/dl).

Copper levels lower than 0.6 ppm were found in 72.5% (174 out of 240) of the soil samples, where 91.7% were from Region I and 53.3% from Region II were deficient. About 33.7% of the forages sampled had concentrations below 6 ppm, which is accepted as borderline or deficient in plants. Deficient concentrations were found in 43.1% of the Pangola samples and in 49.1% of Guinea grass samples from Region II. These deficient levels were reflected in the serum copper concentrations.

Thirty-three percent of the animals grazing on Pangola and Llano grass in Region I were considered deficient in their serum copper levels (less than 0.5 ug/ml), and 50.5% of the animals from Region II grazing on Star and Guinea grass also were deficient.

Twenty-six percent (or 62 out of 240) of the total soil samples

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had extractable iron content lower than 20 ppm (considered deficient for crops). All of them were from Region II. Only 1.2% of the forages sampled had less than 50 ppm. All the Pangola and Guinea grass iron concentrations were within the normal range.

Thirteen percent of the total serum samples were below the normal iron range (1 to 2 ug/ml). For Region I, 51.6% of the cows, 15.9% of the heifers and 16.7% of the calves had low values. For Region II, 5.0% of the cows, 0.7% of the heifers and 8.3% of the calves were below the 1 ug/ml level. It appears that Guinea grass is better able to utilize the iron available in alkaline soils.

Selenium levels below 0.1 ppm were detected in 42.4% of the soil samples from Region I. All the soil samples from Region II were within normal values. For grass samples, 56% of the total samples (49% from Region I and 63% from Region II) had lower values than the 0.1 ppm considered deficient.

More than 58% of the calves sampled in Region I had serum selenium concentrations lower than 0.05 ppm, (below this level is considered deficient). Thirty-five percent of the cows, and 40% of the heifers were deficient in selenium. In Region II, 27% of the cows, 32% of the heifers and 28% of the calves were deficient.

One-half of the soil samples from Region II showed low zinc levels (less than 0.5 ppm), but grasses from that region had adequate zinc concentrations. Twelve samples from Region I were less than 0.5 ppm. Only 1.6% (5 out of 360) of the cattle grazing in these areas had zinc serum concentrations lower than 0.40 ug/ml indicative of zinc deficiency.

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Soil pH values found in Region II were high for tropical conditions. Only six soil samples were below pH 7.

Low blood hemoglobin values (less than 9.5 g/dl) were found in 13% of cattle from Region I and in 38% of the animals from Region II. Hematocrit values were low (less than 27%) in 20% of the animals from Region I and 16% from Region II.

In conclusion, deficiencies of calcium, phosphorus, magnesium, copper and selenium, were located in the two regions studied in the state of Veracruz.

APPENDIX

ABLE A1. ME
BL
FE
VE

Farm 1	
Farm 2	
Farm 3	
Farm 4	
Farm 5	
Farm 6	
Farm 7	
Farm 8	
Farm 9	
Farm 10	
Farm 11	
Farm 12	

[a]Number

TABLE A1. MEAN CALCIUM CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO.[a]

	Soil Ca	Grass Ca	Serum Ca		
			Cows	Heifers	Calves
	ppm	% of DM	mg/dl		
Farm 1	245.25 (17.74)	0.188 (0.014)	9.23 (0.688)	8.27 (0.509)	8.57 (0.468)
Farm 2	157.80 (20.94)	0.221 (0.013)	6.58 (0.619)	7.24 (0.628)	9.00 (0.265)
Farm 3	340.50 (34.52)	0.234 (0.021)	6.95 (0.475)	8.39 (0.415)	9.91 (0.323)
Farm 4	195.15 (22.93)	0.274 (0.015)	9.13 (0.617)	7.85 (0.480)	9.92 (0.544)
Farm 5	228.30 (37.16)	0.201 (0.013)	8.01 (0.598)	6.19 (0.606)	9.39 (1.030)
Farm 6	264.85 (24.48)	0.219 (0.010)	8.24 (0.582)	8.62 (0.737)	9.42 (0.519)
Farm 7	6958.25 (269.74)	0.714 (0.029)	5.69 (0.294)	5.03 (0.224)	6.85 (0.458)
Farm 8	6965.95 (285.63)	0.503 (0.041)	5.78 (0.201)	5.60 (0.274)	6.50 (0.275)
Farm 9	7063.68 (310.30)	0.548 (0.027)	9.63 (0.498)	9.66 (0.485)	11.39 (0.777)
Farm 10	7850.10 (223.95)	0.576 (0.037)	10.44 (0.764)	9.05 (0.402)	9.49 (0.906)
Farm 11	6997.25 (201.56)	0.619 (0.025)	9.25 (0.910)	9.96 (1.00)	11.66 (0.058)
Farm 12	8095.20 (231.73)	9.686 (0.013)	9.50 (0.770)	9.79 (0.633)	8.70 (0.706)

[a]Numbers in parenthesis are standard errors.

TABLE A2. VEL
BL
FR
VE

Farm 1	
Farm 2	
Farm 3	
Farm 4	
Farm 5	
Farm 6	
Farm 7	
Farm 8	
Farm 9	
Farm 10	
Farm 11	
Farm 12	

[a]Numbers

TABLE A2. MEAN PHOSPHORUS CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO.[a]

	Soil P	Grass P	Serum P		
			Cows	Heifers	Calves
	ppm	% of DM	mg/dl		
Farm 1	0.62 (0.079)	0.168 (0.008)	3.45 (0.208)	4.68 (0.248)	6.10 (0.069)
Farm 2	1.705 (0.268)	0.154 (0.007)	3.60 (0.328)	4.11 (0.281)	8.04 (0.550)
Farm 3	3.50 (0.364)	0.272 (0.016)	3.70 (0.502)	5.48 (0.505)	7.27 (0.504)
Farm 4	3.01 (0.162)	0.170 (0.010)	5.08 (0.464)	6.75 (0.612)	7.37 (0.373)
Farm 5	4.45 (0.389)	0.28 (0.018)	2.24 (0.273)	3.70 (0.334)	4.89 (0.245)
Farm 6	1.57 (0.575)	0.173 (0.008)	2.05 (0.175)	2.55 (0.117)	3.06 (0.258)
Farm 7	4.74 (0.470)	0.422 (0.018)	2.61 (0.162)	2.47 (0.095)	2.72 (0.159)
Farm 8	3.24 (0.262)	0.316 (0.017)	2.21 (0.056)	2.42 (0.064)	2.41 (0.123)
Farm 9	2.99 (0.239)	0.363 (0.023)	6.58 (0.604)	7.11 (0.467)	6.70 (1.089)
Farm 10	2.40 (0.293)	0.422 (0.001)	7.84 (0.258)	7.02 (0.038)	7.11 (0.534)
Farm 11	1.60 (0.071)	0.413 (0.019)	8.14 (0.347)	7.76 (0.282)	7.98 (0.263)
Farm 12	2.14 (0.101)	0.417 (0.017)	6.64 (0.563)	7.05 (0.368)	7.89 (0.437)

[a]Numbers in parenthesis are standard errors.

ABLE A3. ME
BL
FR
VE

Farm 1	
Farm 2	
Farm 3	
Farm 4	
Farm 5	
Farm 6	
Farm 7	
Farm 8	
Farm 9	
Farm 10	
Farm 11	
Farm 12	

[a]Numbers

TABLE A3. MEAN MAGNESIUM CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO[a]

	Soil Mg	Grass Mg	Serum Mg		
			Cows	Heifers	Calves
	ppm	% of DM	mg/dl		
Farm 1	67.15 (3.75)	0.246 (0.012)	2.61 (0.154)	2.91 (0.180)	2.59 (0.168)
Farm 2	32.90 (3.17)	0.315 (0.276)	2.22 (0.215)	2.62 (0.173)	2.85 (0.138)
Farm 3	91.00 (9.22)	0.273 (0.078)	2.36 (0.180)	2.04 (0.122)	2.46 (0.127)
Farm 4	65.70 (12.22)	0.214 (0.009)	2.72 (0.131)	1.98 (0.216)	2.14 (0.189)
Farm 5	56.35 (7.61)	0.213 (0.008)	1.97 (0.183)	1.17 (0.133)	2.00 (0.210)
Farm 6	78.45 (16.18)	0.239 (0.010)	2.29 (0.175)	2.12 (0.214)	2.24 (0.165)
Farm 7	510.72 (21.20)	0.177 (0.005)	1.49 (0.043)	1.44 (0.081)	1.56 (0.067)
Farm 8	291.85 (20.57)	0.201 (0.006)	1.61 (0.072)	1.52 (0.006)	1.41 (0.093)
Farm 9	264.10 (15.04)	0.149 (0.008)	2.36 (0.095)	2.29 (0.098)	2.53 (0.103)
Farm 10	239.50 (6.96)	0.125 (0.008)	2.25 (0.186)	3.16 (0.156)	2.27 (0.073)
Farm 11	206.10 (10.17)	0.138 (0.007)	2.53 (0.157)	2.21 (0.075)	2.41 (0.098)
Farm 12	295.60 (16.11)	0.196 (0.007)	2.16 (0.094)	2.10 (0.068)	2.25 (0.047)

[a]Numbers in parenthesis are standard errors.

BLE A4.

Farm 1	
Farm 2	
Farm 3	
Farm 4	
Farm 5	
Farm 6	
Farm 7	
Farm 8	
Farm 9	
Farm 10	
Farm 11	
Farm 12	

[a]Number i

TABLE A4. MEAN POTASSIUM CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO[a]

	Soil K	Grass K	Serum K		
			Cows	Heifers	Calves
	ppm	% of DM	mg/dl		
Farm 1	39.86 (4.18)	1.62 (0.061)	25.52 (1.124)	25.73 (1.126)	26.36 (0.957)
Farm 2	26.45 (2.85)	1.64 (0.097)	22.07 (1.294)	27.02 (1.165)	29.09 (0.441)
Farm 3	53.50 (8.92)	2.55 (0.129)	21.92 (0.870)	23.40 (1.136)	26.41 (0.731)
Farm 4	52.03 (4.61)	2.38 (0.094)	23.85 (0.865)	24.05 (0.552)	25.31 (0.485)
Farm 5	9.97 (1.02)	2.24 (0.160)	19.83 (0.881)	20.12 (1.948)	24.74 (2.346)
Farm 6	13.12 (0.79)	2.24 (0.095)	23.51 (0.906)	18.04 (0.665)	23.65 (0.430)
Farm 7	50.85 (2.27)	2.24 (0.073)	23.40 (1.304)	24.80 (1.394)	24.80 (1.080)
Farm 8	49.74 (3.53)	2.00 (0.060)	22.53 (1.003)	22.91 (1.119)	28.05 (1.772)
Farm 9	54.53 (1.83)	1.54 (0.081)	21.40 (0.548)	20.99 (0.614)	22.58 (1.699)
Farm 10	62.45 (1.74)	2.49 (0.122)	18.03 (1.262)	23.43 (1.210)	19.54 (0.963)
Farm 11	60.24 (2.34)	3.06 (0.120)	16.26 (0.840)	15.74 (0.603)	18.77 (1.389)
Farm 12	63.56 (2.07)	3.08 (1.010)	17.86 (1.010)	18.07 (0.380)	18.18 (0.918)

[a]Number in parenthesis are standard errors.

TABLE A5. MEA
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Farm 1	
Farm 2	
Farm 3	
Farm 4	
Farm 5	
Farm 6	
Farm 7	
Farm 8	
Farm 9	
Farm 10	
Farm 11	
Farm 12	

[a]Number

TABLE A5. MEAN COPPER CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO[a]

	Soil Cu	Grass Cu	Serum Cu		
			Cows	Heifers	Calves
	ppm	DM ppm	- - - - - ug/ml serum - - - - -		
Farm 1	2.10 (0.123)	6.55 (0.246)	0.752 (0.047)	0.700 (0.064)	0.619 (0.048)
Farm 2	3.11 (0.380)	6.09 (0.298)	0.496 (0.050)	0.623 (0.056)	0.680 (0.033)
Farm 3	4.40 (0.448)	7.235 (0.501)	0.522 (0.029)	0.653 (0.055)	0.544 (0.029)
Farm 4	2.39 (0.255)	6.23 (0.431)	0.587 (0.033)	0.550 (0.043)	0.570 (0.021)
Farm 5	2.48 (0.130)	6.43 (0.241)	0.518 (0.051)	0.445 (0.072)	0.477 (0.061)
Farm 6	3.93 (0.394)	6.04 (0.392)	0.470 (0.047)	0.480 (0.046)	0.484 (0.039)
Farm 7	5.56 (0.201)	6.35 (0.399)	0.429 (0.031)	0.416 (0.040)	0.463 (0.054)
Farm 8	4.45 (0.306)	11.53 (0.663)	0.430 (0.030)	0.452 (0.027)	0.551 (0.055)
Farm 9	6.26 (0.264)	5.49 (0.397)	0.540 (0.016)	0.629 (0.032)	0.623 (0.054)
Farm 10	5.76 (0.118)	10.36 (0.560)	0.474 (0.031)	0.415 (0.021)	0.454 (0.072)
Farm 11	6.05 (0.180)	10.14 (0.650)	0.443 (0.027)	0.599 (0.060)	0.471 (0.052)
Farm 12	6.61 (0.156)	11.40 (0.331)	0.522 (0.030)	0.524 (0.036)	0.467 (0.022)

[a]Number in parenthesis are standard errors.

TABLE A6. ME
BL
PR
VE

Farm 1	
Farm 2	
Farm 3	
Farm 4	
Farm 5	
Farm 6	
Farm 7	
Farm 8	
Farm 9	
Farm 10	
Farm 11	
Farm 12	

[a]Number

TABLE A6. MEAN IRON CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO[a]

	Soil Fe	Grass Fe	Serum Fe		
			Cows	Heifers	Calves
	ppm	DM ppm	- - - - - ug/ml serum - - - - -		
Farm 1	13.86 (1.296)	450.05 (45.39)	1.03 (0.076)	1.10 (0.103)	1.11 (0.213)
Farm 2	11.49 (0.866)	223.60 (21.85)	1.08 (0.124)	1.14 (0.169)	1.48 (0.187)
Farm 3	12.21 (1.576)	204.10 (23.13)	1.04 (0.076)	1.17 (0.130)	1.45 (0.099)
Farm 4	13.24 (1.296)	168.00 (12.84)	1.31 (0.149)	1.20 (0.067)	1.34 (0.119)
Farm 5	14.12 (1.493)	113.75 (9.29)	1.78 (0.199)	2.27 (0.131)	2.27 (0.127)
Farm 6	13.82 (2.171)	232.50 (19.15)	1.63 (0.177)	2.01 (0.107)	1.76 (0.234)
Farm 7	2.72 (0.139)	331.50 (24.90)	1.72 (0.125)	2.17 (0.074)	1.91 (0.159)
Farm 8	1.50 (0.229)	331.95 (79.49)	2.03 (0.100)	2.24 (0.107)	1.92 (0.148)
Farm 9	3.74 (0.932)	842.50 (81.22)	1.95 (0.107)	2.52 (0.133)	2.25 (0.183)
Farm 10	2.12 (0.275)	624.75 (65.91)	1.72 (0.172)	1.83 (0.081)	1.42 (0.171)
Farm 11	1.95 (0.309)	752.55 (87.39)	2.06 (0.126)	2.41 (0.192)	2.15 (0.186)
Farm 12	3.89 (0.638)	129.62 (7.34)	1.94 (0.185)	2.02 (0.166)	2.36 (0.192)

[a]Number in parenthesis are standard errors.

TABLE A7. ME
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FI
VE

Farm 1	
Farm 2	
Farm 3	
Farm 4	
Farm 5	
Farm 6	
Farm 7	
Farm 8	
Farm 9	
Farm 10	
Farm 11	
Farm 12	

[a]Number

TABLE A7. MEAN SELENIUM CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO[a]

	Soil Se	Grass Se	Serum Se		
			Cows	Heifers	Calves
	ppm	DM ppm	ug/ml serum		
Farm 1	0.141 (0.002)	0.102 (0.004)	0.074 (0.004)	0.064 (0.003)	0.058 (0.002)
Farm 2	0.109 (0.002)	0.104 (0.006)	0.075 (0.005)	0.055 (0.005)	0.053 (0.002)
Farm 3	0.121 (0.003)	0.147 (0.001)	0.020 (0.005)	0.040 (0.005)	0.012 (0.001)
Farm 4	0.099 (0.002)	0.054 (0.005)	0.027 (0.003)	0.026 (0.008)	0.022 (0.008)
Farm 5	0.088 (0.002)	0.101 (0.081)	0.062 (0.001)	0.057 (0.001)	0.050 (0.002)
Farm 6	0.071 (0.001)	0.106 (0.007	0.066 (0.003)	0.056 (0.003)	0.052 (0.002)
Farm 7	0.147 (0.004)	0.061 (0.005)	0.172 (0.010)	0.108 (0.004)	0.096 (0.003)
Farm 8	0.192 (0.002)	0.105 (0.006)	0.132 (0.003)	0.107 (0.004)	0.091 (0.002)
Farm 9	0.223 (0.008)	0.137 (0.005)	0.128 (0.007)	0.102 (0.010)	0.103 (0.007)
Farm 10	0.143 (0.003)	0.179 (0.013)	0.097 (0.003)	0.106 (0.004)	0.094 (0.005)
Farm 11	0.141 (0.003)	0.059 (0.003)	0.041 (0.007)	0.038 (0.004)	0.029 (0.004)
Farm 12	0.120 (0.002)	0.069 (0.003)	0.040 (0.005)	0.022 (0.002)	0.033 (0.004)

[a]Number in parenthesis are standard errors.

TABLE A8.

Farm 1	
Farm 2	
Farm 3	
Farm 4	
Farm 5	
Farm 6	
Farm 7	
Farm 8	
Farm 9	
Farm 10	
Farm 11	
Farm 12	

[a]Number

TABLE A8. MEAN ZINC CONCENTRATIONS OF SOILS, GRASSES, AND BLOOD SERA OF GRAZING CATTLE FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO[a]

	Soil Zn	Grass Zn	Serum Zn		
			Cows	Heifers	Calves
	ppm	DM ppm	- - - - - ug/ml serum - - - - -		
Farm 1	1.40 (0.078)	27.63 (0.712)	0.94 (0.106)	1.22 (0.065)	1.03 (0.090)
Farm 2	1.27 (0.076)	27.11 (1.139)	0.95 (0.161)	1.06 (0.090)	0.99 (0.041)
Farm 3	2.09 (0.020)	32.10 (2.097)	0.89 (0.031)	0.98 (0.061)	1.22 (0.103)
Farm 4	1.07 (0.552)	28.18 (1.952)	1.12 (0.132)	0.96 (0.052)	1.01 (0.057)
Farm 5	1.37 (0.179)	37.71 (2.70)	0.54 (0.040)	0.59 (0.074)	0.90 (0.129)
Farm 6	1.46 (0.178)	32.62 (1.963)	0.59 (0.064)	0.67 (0.107)	0.84 (0.060)
Farm 7	3.25 (0.134)	47.67 (2.047)	1.04 (0.074)	1.31 (0.099)	1.42 (0.212)
Farm 8	1.71 (0.154)	85.40 (2.36)	1.22 (0.117)	1.20 (0.049)	1.41 (0.119)
Farm 9	0.65 (0.136)	57.92 (2.98)	1.16 (0.030)	1.27 (0.057)	1.38 (0.131)
Farm 10	0.22 (0.020)	61.43 (2.48)	1.07 (0.036)	1.09 (0.070)	1.01 (0.058)
Farm 11	0.27 (0.026)	78.74 (3.04)	0.94 (0.052)	1.06 (0.092)	1.03 (0.071)
Farm 12	1.33 (0.266)	92.50 (2.02)	1.09 (0.050)	1.10 (0.133)	1.14 (0.071)

[a]Number in parenthesis are standard errors.

TABLE

Farm 1

Farm 2

Farm

Farm

Farm

Farm

Farm

Farm

Farm

Farm

Farm

[a]Nu

TABLE A9. MEAN SOIL COBALT CONCENTRATIONS, SOIL, PH, AND GRASS DRY MATTER FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO[a]

	Soil Co	Soil	Grass DM
	ppm	pH	%
Farm 1	0.267 (0.051)	5.84 (0.074)	27.10 (0.809)
Farm 2	0.185 (0.031)	5.39 (0.071)	25.00 (0.741)
Farm 3	0.216 (0.038)	6.01 (0.085)	27.42 (0.750)
Farm 4	0.287 (0.049)	5.96 (0.106)	26.91 (0.614)
Farm 5	0.172 (0.027)	5.43 (0.134)	26.31 (0.959)
Farm 6	0.215 (0.028)	5.42 (0.112)	23.96 (0.777)
Farm 7	0.232 (0.030)	7.14 (0.080)	25.62 (0.776)
Farm 8	0.265 (0.046)	7.94 (0.056)	26.95 (0.640)
Farm 9	0.170 (0.022)	7.87 (0.063)	27.90 (0.918)
Farm 10	0.115 (0.012)	8.13 (0.015)	29.00 (0.567)
Farm 11	0.110 (0.011)	7.88 (0.031)	29.13 (0.982)
Farm 12	0.160 (0.014)	7.79 (0.057)	35.70 (0.723)

[a]Numbers in parenthesis are standard errors.

TABLE A10. N
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Farm	
Farm 1	
Farm 2	
Farm 3	
Farm 4	
Farm 5	
Farm 6	
Farm 7	
Farm 8	
Farm 9	
Farm 10	
Farm 11	
Farm 12	

[a]Number in

TABLE A10. MEAN HEMOGLOBIN AND HEMATOCRIT VALUES OF GRAZING CATTLE FOR INDIVIDUAL FARMS FROM NORTHERN (FARMS 1-6) AND SOUTHERN (FARMS 7-12) VERACRUZ, MEXICO[a]

	COHB	HEHB	CAHB	COHT	HEHT	CAHT
	g/dl			%		
Farm 1	11.98 (0.456)	11.99 (0.418)	12.59 (0.856)	32.10 (1.110)	31.00 (0.775)	35.40 (2.04)
Farm 2	10.91 (0.4732)	14.07 (0.885)	14.20 (0.816)	32.10 (0.862)	34.40 (1.240)	36.20 (0.940)
Farm 3	10.72 (0.366)	11.96 (0.427)	12.32 (0.784)	30.90 (1.000)	36.40 (1.240)	37.40 (1.310)
Farm 4	11.24 (1.000)	10.49 (0.408)	10.28 (0.507)	24.80 (1.770)	23.30 (1.660)	27.50 (1.650)
Farm 5	9.66 (0.381)	11.13 (0.323)	11.98 (0.876)	27.30 (0.746)	30.70 (0.955)	35.50 (2.270)
Farm 6	10.31 (0.379)	11.51 (0.363)	10.63 (0.475)	31.10 (0.912)	32.70 (0.883)	30.90 (1.820)
Farm 7	8.82 (0.475)	11.36 (0.716)	11.31 (0.388)	36.20 (1.134)	38.70 (2.241)	41.20 (1.236)
Farm 8	7.99 (0.410)	9.09 (0.440)	9.92 (0.365)	35.00 (1.422)	32.30 (1.202)	38.30 (1.390)
Farm 9	9.20 (0.396)	10.30 (0.390)	9.70 (0.310)	30.80 (0.987)	27.10 (1.240)	28.70 (1.350)
Farm 10	9.82 (0.389)	10.49 (0.403)	10.68 (0.450)	31.30 (1.390)	30.70 (1.257)	31.60 (1.240)
Farm 11	10.03 (0.337)	10.31 (0.462)	10.60 (0.325)	30.20 (0.904)	26.20 (1.940)	36.30 (0.932)
Farm 12	8.54 (0.364)	10.63 (0.4028)	9.75 (0.310)	31.90 (1.494)	38.70 (1.422)	34.40 (1.360)

[a]Number in parenthesis are standard errors.

TABLE A11. CORRELATION COEFFICIENTS BETWEEN DIFFERENT SOIL MINERALS AND SOIL pH FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

TABLE A11. CORRELATION COEFFICIENTS BETWEEN DIFFERENT SOIL MINERALS AND SOIL pH FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	SOCa SOK	SOCa SOMg	SOCa SOP	SOCa SOCu	SOCa SOFe	SOCa SOSe	SOCa SOZn	SOCa SOCo
Overall	.53 (.36,.59)	.76 (.70,.81)	.10 (-.03,.11)	.67 (.56,.73)	-.69 (-.77,-.63)	.46 (.35,.54)	-.11 (-.21,-.08)	-.15 (-.27,.05)
Reg I	.28 (.11,.42)	.59 (.50,.66)	.09 (.04,.20)	.36 (.19,.47)	-.11 (-.21,-.08)	.05 (-.15,.11)	.56 (.36,.64)	.06 (-.13,.20)
Reg II	.36 (.19,.50)	-.02 (-.20,.14)	-.01 (-.19,.14)	-.05 (-.22,.12)	.20 (.08,.30)	-.08 (-.41,.10)	-.12 (-.03,.05)	-.02 (-.20,.14)
Gru I	.32 (.09,.53)	.70 (.58,.80)	.11 (-.30,.12)	.49 (.29,.66)	-.39 (-.59,-.15)	.63 (.44,.74)	-.22 (-.44,.02)	-.15 (-.39,.10)
Gru II	.44 (.17,.61)	.42 (.16,.60)	.09 (-.19,.35)	.09 (-.19,.35)	-.23 (-.48,.05)	.10 (-.18,.36)	.39 (.14,.59)	.05 (.24,.32)
Gru III	.74 (.62,.82)	.34 (.09,.53)	-.54 (-.70,-.34)	.47 (.26,.54)	-.76 (-.84,-.63)	.15 (-.12,.38)	-.19 (-.44,.07)	.09 (-.17,.33)
Gru IV	.49 (.29,.66)	.18 (-.09,.41)	.26 (.01,.43)	.09 (-.16,.33)	.34 (.09,.53)	.05 (-.19,.31)	0 (-.26,.26)	-.10 (0.35,.15)
Reg I Gru I	.09 (-.16,.33)	.72 (.59,.80)	.10 (-.05,.34)	.61 (.41,.72)	-.02 (-.28,.25)	.02 (-.25,.26)	.74 (.62,.82)	.04 (-.20,.30)
Reg I Gru II	.44 (.17,.61)	.42 (.16,.60)	.09 (-.19,.35)	.09 (-.19,.35)	-.23 (-.48,.05)	.10 (-.18,.36)	.39 (.14,.59)	.05 (.24,.32)
Reg II Gru III	.29 (.03,.53)	-.22 (-.47,.03)	.33 (.08,.53)	-.17 (-.41,.11)	-.11 (-.38,.16)	-.10 (-.37,.19)	-.37 (-.59,-.13)	.08 (-.20,.35)
Reg II Gru IV	.49 (.29,.66)	.18 (-.09,.41)	.26 (.01,.43)	.09 (-.16,.33)	.34 (.09,.53)	.05 (-.19,.31)	0 (-.26,.26)	-.10 (-.35,.15)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A11. (cont'd)

	SOCa SOpH	SOK SOMg	SOK SOP	SOK SOCu	SOK SOFe	SOK SOSe	SOK SOZn	SOK SOCo
Overall	.90 (.80,.91)	.40 (.28,.59)	.03 (-.10,.13)	.36 (.24,.42)	-.45 (-.54,-.37)	.33 (.20,.42)	-.07 (-.12,.16)	.08 (-.22,.02)
Reg I	.28 (.12,.42)	.15 (.04,.30)	0 (-.17,.19)	0 (-.17,.19)	-.14 (-.30,.05)	.29 (.12,.42)	.19 (.03,.34)	.01 (-.18,.14)
Reg II	.13 (-.07,.25)	-.14 (-.30,.05)	-.13 (-.30,.07)	.04 (-.16,.20)	-.04 (-.22,.11)	.02 (-.19,.14)	-.31 (-.45,-.12)	-.08 (-.27,.09)
Gru I	.74 (.64,.82)	.18 (-.08,.41)	.06 (-.19,.26)	.04 (-.20,.30)	-.13 (-.39,.10)	.33 (.09,.52)	.03 (-.22,.27)	-.11 (-.37,.13)
Gru II	.35 (.09,.55)	.37 (.11,.59)	.13 (-.17,.40)	.12 (.18,.39)	-.24 (-.48,.04)	.39 (0.13,.59)	.34 (.08,.54)	.04 (-.22,.28)
Gru III	.78 (.69,.85)	.17 (-.09,.40)	-.49 (-.65,-.29)	.49 (.29,.66)	-.64 (-.75,-.46)	.24 (.01,.45)	-.34 (-.54,-.13)	-.07 (-.32,.20)
Gru IV	.05 (-.19,.31)	0 (-.26,.26)	.06 (-.22,.30)	.08 (-.18,.31)	-.05 (-.33,.22)	-.20 (-.44,.05)	-.18 (-.42,.06)	0 (-.26,.26)
Reg I Gru I	.17 (-.09,.40)	-.07 (-.32,.20)	.03 (-.26,.27)	-.13 (-.37,.11)	0 (-.26,.26)	.17 (-.19,.40)	.15 (-.12,.38)	-.07 (-.32,.20)
Reg I Gru II	.35 (.09,.55)	.37 (.11,.59)	.13 (-.17,.40)	.12 (-.18,.39)	-.24 (-.48,.04)	.39 (.13,.59)	.34 (.08,.54)	.04 (-.22,.28)
Reg II Gru III	.28 (.02,.51)	-.35 (-.57,-.13)	-.27 (-.51,-.03)	.06 (-.21,.30)	-.08 (-.36,.19)	.11 (-.27,.36)	-.51 (-.66,-.28)	-.17 (-.43,.10)
Reg II Gru IV	.05 (-.19,.31)	0 (-.26,.26)	.06 (-.22,.30)	.08 (-.18,.31)	-.05 (-.33,.22)	-.20 (-.44,.05)	-.18 (-.42,.06)	0 (-.26,.26)

[a]The numbers in parenthesis are .95 confidence limits.

TABLE AII. (cont'd)

TABLE A11. (cont'd)

	SOK SOpH	SOMg SOP	SOMg SOCu	SOMg SOFe	SOMg SOSe	SOMg SOZn	SOMg SOCo	SOMg SOpH
Overall	.57 (.49,.58)	.31 (.19,.40)	.57 (.49,.58)	-.55 (-.62,-.48)	.44 (.33,.56)	.43 (-.43,-.22)	0 (-.11,.12)	.63 (.52,.68)
Reg I	.27 (.27,.52)	.13 (-.07,.25)	.47 (.32,.60)	-.07 (-.25,.11)	.01 (-.19,.18)	.43 (.27,.54)	.10 (-.10,.25)	.14 (-.03,.27)
Reg II	.19 (.03,.34)	.59 (.48,.67)	-.16 (-.31,.02)	.18 (.01,.35)	.10 (-.10,.25)	.73 (.60,.78)	.34 (.18,.50)	-.71 (-.77,-.59)
Gru I	.44 (.20,.61)	.06 (-.19,.26)	.75 (.62,.83)	-.39 (-.60,-.15)	.48 (.25,.65)	.12 (-.15,.36)	-.07 (-.31,.16)	.58 (.39,.73)
Gru II	.43 (.20,.62)	.42 (.16,.60)	.19 (-.10,.44)	-.01 (-.29,.28)	.18 (-.10,.44)	.14 (-.12,.38)	.21 (-.08,.45)	.15 (-.15,.45)
Gru III	.68 (.54,.79)	.30 (.04,.51)	.21 (-.06,.42)	-.39 (-.58,-.15)	.24 (.01,.45)	.62 (.43,.74)	.23 (-.04,.43)	.06 (-.21,.30)
Gru IV	.20 (-.07,.41)	.50 (.27,.66)	-.14 (-.38,.10)	.34 (.10,.56)	.02 (-.25,.26)	.74 (.63,.82)	.46 (.20,.62)	-.69 (-.80,-.56)
Reg I Gru I	.32 (.07,.54)	0 (-.26,.26)	.68 (.57,.80)	-.15 (-.38,.09)	-.12 (-.36,.15)	.57 (.40,.72)	.01 (-.22,.25)	.05 (-.19,.31)
Reg I Gru II	.43 (.20,.62)	.42 (.16,.60)	.19 (-.10,.44)	-.01 (-.29,.28)	.18 (-.10,.44)	.14 (-.12,.38)	.21 (-.08,.45)	.15 (-.15,.45)
Reg II Gru III	.20 (-.09,.45)	.72 (.57,.82)	-.13 (-.39,.12)	.02 (-.30,.26)	.15 (-.15,.41)	.73 (.59,.82)	.24 (.03,.49)	-.75 (-.85,-.61)
Reg II Gru IV	.20 (-.07,.41)	.50 (.27,.66)	-.14 (-.38,.10)	.34 (.10,.56)	.02 (-.25,.26)	.74 (.63,.82)	.46 (.20,.62)	-.69 (-.80,-.56)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE AII. (cont'd)

TABLE A11. (cont'd)

	SOP SOCu	SOP SOFe	SOP SOSe	SOP SOZn	SOP SOCo	SOP SOpH	SOCu SOFe
Overall	.08 (-.05,.17)	-.01 (-.22,.01)	.04 (-.09,.15)	.32 (.19,.41)	0 (-.11,.12)	.05 (.09,.16)	-.52 (-.59,-.43)
Reg I	.10 (-.10,.25)	.10 (-.10,.25)	-.20 (-.36,.02)	.18 (.01,.35)	-.09 (-.26,.05)	.08 (-.01,.27)	-.07 (-.25,.11)
Reg II	-.12 (-.03,.05)	.10 (-.10,.25)	.09 (.04,.20)	.49 (.34,.62)	.21 (.03,.36)	-.40 (-.52,-.25)	.14 (-.03,.27)
Gra I	.09 (-.16,.34)	-.01 (-.25,.23)	-.06 (-.32,.20)	.12 (-.16,.36)	-.13 (-.39,.10)	.17 (-.38,.05)	-.21 (-.53,-.05)
Gra II	.30 (.04,.54)	.19 (-.10,.44)	-.17 (-.42,.11)	.23 (-.05,.46)	-.01 (-.29,.28)	.04 (.22,.32)	-.01 (-.29,.28)
Gra III	.16 (-.09,.40)	.45 (.20,.61)	-.03 (-.28,.25)	.57 (.40,.72)	-.16 (-.37,.07)	-.60 (-.74,-.43)	-.54 (-.69,-.37)
Gra IV	-.29 (-.52,.05)	.11 (-.16,.34)	.13 (-.05,.36)	.36 (.11,.54)	.25 (-.01,.46)	-.25 (-.48,.01)	.18 (-.10,.44)
Reg I Gra I	-.11 (-.36,.16)	.03 (-.36,.27)	-.18 (-.41,.07)	.16 (-.09,.40)	-.11 (-.36,.16)	.16 (-.09,.40)	.32 (.04,.51)
Reg I Gra II	.30 (.04,.54)	.19 (-.10,.44)	-.17 (-.42,.11)	.23 (-.05,.46)	-.01 (-.29,.28)	.04 (.22,.32)	-.01 (-.29,.28)
Reg II Gra III	-.02 (-.29,.27)	.04 (-.25,.31)	.08 (-.21,.33)	.66 (.47,.79)	.22 (.05,.46)	-.53 (-.69,-.30)	0 (-.29,.28)
Reg II Gra IV	-.29 (-.52,.05)	.11 (-.16,.34)	.13 (-.05,.36)	.36 (.11,.54)	.25 (.01,.46)	-.25 (-.48,.01)	.18 (-.10,.44)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A11. (cont'd)

TABLE A11. (cont'd)

	SOCu SOSe	SOCu SOZn	SOCu SOCo	SOCu SOpH	SOFe SOSe	SOFe SOZn	SOFe SOCo
Overall	.27 (.17,.39)	-.03 (-.14,.21)	-.14 (-.26,.03)	.66 (.57,.73)	-.35 (-.44,-.16)	.11 (.04,.21)	.13 (0,.23)
Reg I	-.05 (-.20,.12)	.37 (.19,.50)	.08 (-.10,.27)	.10 (-.10,.25)	-.06 (-.21,.11)	.05 (-.15,.20)	.05 (-.15,.20)
Reg II	-.17 (-.31,.02)	-.19 (-.36,-.02)	-.32 (-.46,-.14)	.05 (-.15,.20)	.06 (-.12,.21)	.10 (-10,.25)	-.04 (-.21,.11)
Gra I	.29 (.04,.50)	.24 (-.03,.37)	0 (-.27,.26)	.44 (.20,.61)	-.14 (-.38,.09)	.24 (-.03,.37)	.27 (.03,.48)
Gra II	-.06 (-.34,.22)	.23 (-.08,.49)	.10 (-.18,.36)	.05 (.24,.32)	-.34 (-.56,-.08)	-.08 (-.36,.19)	-.08 (-.36,.19)
Gra III	-.04 (-.29,.23)	-.10 (-.35,.15)	-.34 (-.54,-.10)	.47 (.24,.63)	-.27 (-.49,.04)	.11 (-.16,.34)	-.07 (-.31,.24)
Gra IV	-.09 (-.34,.16)	-.24 (-.46,-.02)	-.15 (-.38,.09)	.14 (-.10,.38)	.27 (.01,.49)	.12 (-.10,.34)	-.01 (-.27,.28)
Reg I Gra I	-.06 (-.32,.20)	.48 (.25,.63)	.06 (-.22,.30)	.14 (-.10,.38)	.24 (.01,.45)	.12 (-.10,.34)	.24 (.01,.45)
Reg I Gra II	-.06 (-.34,.22)	.23 (-.08,.49)	.10 (-.18,.36)	.05 (.24,.32)	-.34 (-.56,-.08)	-.08 (-.36,.19)	-.08 (-.36,.19)
Reg II Gra III	-.25 (-.50,.01)	-.10 (-.37,.18)	-.48 (-.68,-.26)	-.02 (-.29,.27)	-.19 (-.46,.08)	.15 (-.15,.41)	-.17 (-.41,.11)
Reg II Gra IV	-.09 (-.34,.16)	-.24 (-.46,-.02)	-.15 (-.38,.09)	.14 (-.10,.38)	.27 (.01,.49)	.12 (-.10,.34)	-.01 (-.27,.28)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A11. (cont'd)

TABLE A11. (cont'd)

	SOFe SOph	SOSe SOZn	SOSe SOCo	SOSe SOph	SOZn SOCo	SOZn SOph	SOCo SOph
Overall	-.70 (-.76,-.60)	-.05 (-.16,.09)	.13 (0,.23)	.50 (.40,.65)	.19 (.09,.30)	-.20 (-.31,-.08)	-.13 (-.23,0)
Reg I	-.14 (-.30,.02)	.08 (-.09,.21)	.08 (-.10,.27)	.32 (.13,.46)	.05 (-.15,.20)	.14 (-.03,.27)	.10 (-.10,.25)
Reg II	-.20 (-.36,.34)	-.02 (-.19,.17)	.41 (.22,.57)	.12 (-.09,.29)	.31 (.12,.44)	-.62 (-.67,-.53)	-.11 (-.21,-.07)
Gru I	-.35 (-.56,-.10)	-.21 (-.44,.05)	-.01 (-.25,.23)	.67 (.52,.76)	.21 (-.06,.43)	-.17 (-.38,.05)	-.12 (-.32,.11)
Gru II	-.31 (-.54,-.05)	.19 (-.10,.44)	.09 (-.19,.35)	.38 (.12,.58)	-.12 (-.38,.18)	.04 (.22,.32)	.25 (-.02,.49)
Gru III	-.66 (-.76,-.48)	.04 (-.20,.30)	.56 (.32,.69)	.29 (.06,.51)	.23 (-.04,.43)	-.28 (-.51,-.05)	.09 (-.16,.33)
Gru IV	-.26 (-.48,0)	-.13 (-.37,.14)	.11 (-.16,.34)	-.10 (-.35,.15)	.40 (.16,.54)	-.69 (-.80,-.56)	-.41 (-.59,-.16)
Reg I Gru I	-.04 (-.31,.22)	.05 (-.19,.31)	.05 (-.19,.31)	.29 (.06,.51)	.21 (-.06,.42)	.12 (-.10,.34)	-.03 (-.27,.25)
Reg I Gru II	-.31 (-.54,-.05)	.19 (-.10,.44)	.09 (-.19,.35)	.38 (.12,.58)	-.12 (-.38,.18)	.04 (.22,.32)	.25 (-.02,.49)
Reg II Gru III	-.19 (-.46,.09)	.05 (-.33,.22)	.57 (.37.72)	.20 (-.09,.45)	.25 (-.02,.49)	-.58 (-.73,-.38)	.09 (-.19,.35)
Reg II Gru IV	-.26 (-.48,0)	-.13 (-.37,.14)	.11 (-.16,.34)	-.10 (-.35,.15)	.40 (.16,.59)	-.69 (-.80,-.56)	-.41 (-.59,-.16)

[b]Numbers in parenthesis are .95 confidence limits.

TABLE A12. CORRELATION COEFFICIENTS BETWEEN DIFFERENT GRASS MINERALS AND DRY MATTER FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

TABLE A12. CORRELATION COEFFICIENTS BETWEEN DIFFERENT GRASS MINERALS AND DRY MATTER FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	GRACa GRAK	GRACa GRAMg	GRACa GRAP	GRACa GRACu	GRACa GRAFe	GRACa GRASe	GRACa GRAZn	GRACa GRADM
Overall	.29 (.19,.37)	-.40 (-.49,-.30)	.70 (.62,.74)	.38 (.25,.42)	.48 (.40,.59)	-.11 (-.22,.08)	.66 (.55,.70)	.31 (.19,.43)
Reg I	.03 (-.13,.11)	.14 (-.05,.24)	-.15 (-.30,.30)	-.20 (-.36,-.34)	-.29 (-.45,-.12)	-.27 (-.40,-.10)	-.06 (-.22,.11)	0 (-.18,.13)
Reg II	.30 (.10,.41)	.24 (.10,.40)	.35 (.19,.46)	.01 (-.18,.14)	-.18 (-.32,-.03)	-.19 (-.36,-.03)	.01 (-.18,.14)	.09 (-.26,.05)
Gru I	-.21 (-.44,.05)	-.37 (-.55,-.15)	.25 (.02,.40)	-.28 (-.48,-.05)	.66 (.48,.75)	.17 (-.08,.35)	.67 (.52,.76)	.11 (-.30,.13)
Gru II	.08 (-.21,.33)	.11 (-.19,.36)	-.17 (-.41,.11)	-.14 (-.40,.19)	-.32 (-.55,-.09)	-.35 (-.57,-.08)	-.26 (-.49,.02)	.11 (-.19,.36)
Gru III	.20 (-.07,.41)	-.03 (-.28,.25)	.56 (.32,.69)	-.02 (-.45,.49)	-.06 (-.32,.20)	-.17 (-.41,.11)	-.11 (-.36,.16)	.07 (-.18,.32)
Gru IV	.17 (-.09,.40)	.22 (-.05,.45)	.09 (-.16,.33)	.05 (-.19,.31)	0 (-.26,.26)	-.22 (-.44,.03)	.09 (-.17,.33)	.16 (-.09,.40)
Reg I Gru I	.15 (-.10,.38)	.26 (.01,.43)	.01 (-.22,.25)	-.22 (-.44,.03)	-.25 (-.46,.01)	-.24 (-.45,.02)	.10 (-.05,.34)	.02 (-.25,.26)
Reg I Gru II	.08 (-.21,.33)	.11 (-.19,.36)	-.17 (-.41,.11)	-.14 (-.40,.19)	-.32 (-.55,-.09)	-.35 (-.57,-.08)	-.26 (-.49,.02)	.11 (-.19,.36)
Reg II Gru III	.30 (.04,.54)	.19 (-.10,.44)	.48 (.22,.62)	-.17 (-.41,.11)	-.31 (-.54,-.05)	-.16 (-.43,.11)	-.07 (-.35,.20)	.03 (-.26,.30)
Reg II Gru IV	.17 (-.09,.40)	.22 (-.05,.45)	.09 (-16,.33)	.05 (-.19,.31)	0 (-.26,.26)	-.22 (-.44,.03)	.09 (-.17,.33)	.16 (-.09,.40)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A12. (cont'd)

TABLE A12. (cont'd)

	GRAK GRAMg	GRAK GRAP	GRAK GRACu	GRAK GRAFe	GRAK GRASe	GRAK GRAZn	GRAK GRAMn
Overall	-.15 (-.24,.05)	.41 (.29,.46)	.49 (.40,.57)	.09 (-.22,.01)	-.12 (-.21,.01)	.37 (.28,.46)	.29 (.17,.40)
Reg I	-.09 (-.26,.05)	.45 (.30,.53)	.39 (.22,.52)	-.24 (-.40,.10)	.09 (-.15,.20)	.25 (.04,.39)	.06 (-.13,.20)
Reg II	.02 (-.19,.14)	.36 (.20,.47)	.49 (.34,.60)	-.03 (-.11,.13)	-.25 (-.40,-.08)	.40 (.22,.52)	.35 (.19,.50)
Gra I	-.01 (-.25,.23)	.31 (.05,.51)	.39 (.15,.55)	-.48 (-.65,-.32)	.06 (-.19,.26)	-.12 (-.32,.11)	.06 (-.19,.26)
Gra II	-.14 (-.40,.19)	.42 (.12,.55)	.51 (.29,.64)	-.07 (-.34,.21)	-.08 (-.36,.21)	.42 (.12,.55)	.20 (-.07,.42)
Gra III	.26 (.01,.43)	.39 (.11,.58)	.35 (.12,.53)	.07 (-.18,.32)	-.21 (-.45,.05)	.31 (.04,.51)	.18 (-.09,.41)
Gra IV	-.17 (-.41,.11)	.21 (-.06,.42)	.50 (.27,.66)	-.07 (-.32,-.20)	-.19 (-.44,.07)	.41 (.15,.58)	.39 (.12,.57)
Reg I Gra I	-.20 (-.44,.05)	.48 (.25,.63)	.32 (.04,.51)	-.36 (-.56,-.10)	.14 (-.10,.38)	.26 (.01,.43)	.11 (-.16,.34)
Reg I Gra II	-.14 (-.40,.19)	.42 (.12,.55)	.51 (.29,.64)	-.07 (-.34,.21)	-.08 (-.36,.21)	.42 (.12,.55)	.20 (-.07,.42)
Reg II Gra III	.12 (-.16,.32)	.42 (.12,.55)	.37 (.11,.59)	.07 (-.22,.32)	-.26 (-.49,.01)	.42 (.12,.55)	.34 (.08,.54)
Reg II Gra IV	-.17 (-.41,.11)	.21 (-.06,.42)	.50 (.27,.66)	-.07 (-.32,-.20)	-.19 (-.44,.07)	.41 (.15,.58)	.39 (.12,.57)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A12. (cont'd)

TABLE A12. (cont'd)

	GRAMg GRAP	GRAMg GRACa	GRAMg GRAFe	GRAMg GRASe	GRAMg GRAZn	GRAMg GRAMM	GRAP GRACa
Overall	-.42 (-.51,-.30)	-.16 (-.27,.01)	-.29 (-.40,-.17)	-.10 (-.22,.01)	-.41 (-.50,-.30)	-.20 (-.32,-.08)	.48 (.40,.57)
Reg I	-.07 (-.24,.10)	.11 (.11,.27)	.11 (.11,.27)	.03 (.15,.19)	-.13 (-.30,.07)	-.08 (-.41,.10)	.29 (.13,.43)
Reg II	.07 (-.13,.21)	.20 (.01,.37)	.23 (.02,.40)	-.28 (-.45,-.14)	.24 (.02,.41)	.04 (-.16,.20)	.19 (.02,.37)
Gra I	-.23 (-.45,.25)	.19 (-.75,.41)	-.27 (-.47,-.07)	-.17 (-.38,.05)	-.32 (-.52,.10)	-.08 (-.31,.15)	.21 (-.06,.42)
Gra II	-.04 (-.30,.25)	.10 (-.18,.36)	.14 (-.12,.38)	.09 (-.19,.35)	-.09 (-.38,.15)	0 (-.29,.28)	.27 (-.01,.50)
Gra III	.11 (-.16,.34)	.24 (.01,.45)	-.02 (-.28,.25)	-.15 (-.38,.09)	.11 (-.16,.34)	-.04 (-.29,.23)	.30 (.04,.51)
Gra IV	-.11 (-.36,.16)	0 (-.26,.26)	.38 (.11,.55)	-.34 (-.54,-.13)	.19 (-.07,.42)	.04 (-.20,.30)	.02 (-.25,.26)
Reg I Gra I	-.13 (-.37,.11)	.09 (-.16,.33)	.08 (-.18,.31)	-.12 (-.36,.15)	-.08 (-.35,.16)	-.05 (-.33,.22)	.30 (.04,.51)
Reg I Gra II	-.04 (-.30,.25)	.10 (-.18,.36)	.14 (-.12,.38)	.09 (-.19,.35)	-.09 (-.38,.15)	0 (-.29,.28)	.27 (-.01,.50)
Reg II Gra III	.23 (-.07,.45)	.36 (.10,.55)	.11 (-.19,.36)	-.19 (-.46,.08)	.32 (.04,.55)	.03 (-.26,.30)	.20 (-.07,.42)
Reg II Gra IV	-.11 (-.36,.16)	0 (-.26,.26)	.38 (.11,.55)	-.34 (-.54,-.13)	.19 (-.07,.42)	.04 (-.20,.30)	.02 (-.25,.26)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A12. (cont'd)

TABLE A12. (cont'd)

	GRAP GRAFe	GRAP GRASc	GRAP GRAZn	GRAP GRADM	GRACu GRAFe	GRACu GRASc	GRACu GRAZn
Overall	.36 (.24,.42)	.01 (-.11,.13)	.63 (.52,.68)	.26 (.14,.37)	.54 (.42,.60)	.02 (-.11,.13)	.71 (.63,.76)
Reg I	-.13 (-.30,.07)	.11 (.11,.27)	.33 (.20,.41)	.06 (-.13,.20)	.23 (.05,.36)	.15 (.04,.30)	.41 (.22,.53)
Reg II	-.32 (.14,.44)	-.03 (-.19,.17)	0 (-.17,.19)	0 (-.17,.19)	.36 (.19,.49)	-.01 (-.20,.20)	.68 (.58,.76)
Gra I	.13 (-.12,.35)	.15 (-.08,.33)	.54 (.35,.66)	-.01 (-.25,.23)	-.03 (-.26,.11)	.31 (.05,.51)	0 (-.25,.22)
Gra II	-.16 (-.39,.12)	.12 (-.18,.39)	.31 (.03,.51)	.16 (-.12,.42)	.16 (-.12,.42)	-.15 (-.40,.12)	.82 (.70,.86)
Gra III	-.03 (-.28,.25)	-.03 (-.28,.25)	.13 (-.06,.35)	.02 (-.25,.26)	.49 (.29,.66)	-.13 (-.37,.11)	.70 (.54,.80)
Gra IV	-.37 (-.56,-.14)	-.07 (-.31,.24)	-.07 (-.32,.20)	0 (-.26,.26)	.38 (.11,.55)	.12 (-.10,.34)	.69 (.53,.80)
Reg I Gra I	-.16 (-.37,.07)	.11 (-.16,.34)	.52 (.31,.69)	-.02 (-.28,.25)	.24 (.01,.45)	.39 (.11,.58)	.30 (.04,.51)
Reg I Gra II	-.16 (-.39,.12)	.12 (-.18,.39)	.31 (.03,.51)	.16 (-.12,.42)	.16 (-.12,.42)	-.15 (-.40,.12)	.82 (.70,.86)
Reg II Gra III	-.28 (-.50,.02)	.03 (-.26,.30)	.03 (-.26,.30)	.04 (-.25,.31)	.43 (.20,.62)	-.11 (-.38,.16)	.69 (.52,.81)
Reg II	-.37 (-.56,-.14)	-.07 (-.31,.24)	-.07 (-.32,.20)	0 (-.26,.26)	.38 (.11,.55)	.12 (-.10,.34)	.69 (.53,.80)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A12. (cont'd)

TABLE A12. (cont'd)

	GRACu GRADM	GRAFe GRASe	GRAFe GRAZn	GRAFe GRADM	GRASe GRAZn	GRASe GRADM	GRAZn GRADM
Overall	.32 (.19,.41)	0 (-.11,.12)	.76 (.69,.77)	.38 (.25,.42)	-.07 (-.12,.16)	-.01 (-.22,.01)	.40 (.28,.59)
Reg I	.15 (.04,.30)	.13 (-.07,.25)	-.07 (-.24,.10)	.02 (-.06,.19)	.05 (-.15,.20)	.03 (.15,.19)	0 (-.17,.19)
Reg II	.23 (.05,.36)	-.04 (-.21,.11)	.60 (.47,.70)	.30 (.13,.45)	-.18 (-.33,.01)	-.04 (-.21,.11)	-.08 (-.25,.10)
Gra I	.08 (.02,.45)	.20 (-.05,.41)	.55 (.33,.65)	.15 (-.08,.33)	.06 (.01,.42)	-.12 (-.32,.11)	.08 (-.15,.31)
Gra II	.01 (-.27,.28)	.19 (-.09,.43)	.20 (-.07,.42)	-.14 (-.40,.19)	-.28 (-.48,.01)	.16 (-.12,.42)	-.05 (-.33,.32)
Gra III	.32 (-.05,.45)	-.30 (-.54,-.06)	.70 (.54,.80)	.35 (.12,.53)	-.28 (-.51,-.05)	.02 (-.25,.26)	.47 (.23,.62)
Gra IV	.24 (.01,.45)	.13 (-.05,.36)	.55 (.32,.69)	.26 (.01,.43)	-.08 (-.36,.19)	-.06 (-.32,.20)	.27 (.01,.49)
Reg I Gra I	.36 (.11,.54)	.13 (-.05,.36)	-.12 (-.36,.15)	.16 (-.09,.40)	.20 (-.07,.41)	-.11 (-.36,.16)	-.18 (-.41,.07)
Reg I Gra II	.01 (-.27,.28)	.19 (-.09,.43)	.20 (-.07,.42)	-.14 (-.40,.19)	-.28 (-.53,-.06)	.16 (-.12,.42)	-.05 (-.33,.32)
Reg II Gra III	.25 (-.02,.49)	-.39 (-.52,-.04)	.68 (.51,.79)	.39 (.14,.59)	-.31 (-.54,-.05)	.04 (-.25,.31)	.51 (.27,.69)
Reg II Gra IV	.24 (.01,.45)	.13 (-.05,.36)	.55 (.32,.69)	.26 (.01,.43)	-.08 (-.36,.19)	-.06 (-.32,.20)	.27 (.01,.49)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A13. CORRELATION COEFFICIENTS BETWEEN MINERALS OR pH IN SOILS AND MINERALS IN FORAGES FROM NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	SOCa GRACa	SOK GRAK	SOMg GRAMg	SOP GRAP	SOCu GRACu	SOFe GRAFe	SOSe GRASe
Overall	.82 (.74,.86)	.20 (.06,.31)	-.38 (-.47,-.29)	.20 (.06,.31)	.34 (.23,.44)	-.47 (-.57,-.40)	.10 (-.02,.22)
Reg I	-.05 (-.22,.12)	.06 (-.13,.20)	-.04 (-.22,.11)	.35 (.19,.50)	.10 (-.10,.25)	.13 (-.07,.25)	.12 (-.09,.29)
Reg II	.07 (-.13,.21)	.24 (.02,.41)	-.14 (-.30,.05)	.02 (-.06,.19)	-.03 (-.19,.17)	-.04 (-.22,.11)	.13 (-.07,.25)
Gra I	.78 (.68,.85)	-.04 (-.31,.21)	-.24 (-.48,.02)	.42 (.17,.60)	-.06 (-.32,.20)	-.18 (-.41,.06)	.24 (-.03,.47)
Gra II	-.19 (-.46,.08)	.10 (-.18,.36)	-.24 (-.48,.04)	.36 (.06,.54)	.09 (-.19,.35)	-.06 (-.34,.22)	.12 (-.18,.39)
Gra III	.41 (.15,.57)	.15 (-.12,.38)	0 (-.26,.26)	-.37 (-.59,-.16)	.06 (-.25,.31)	-.41 (-.59,-.17)	.04 (-.20,.30)
Gra IV	.05 (-.24,.32)	.30 (.04,.51)	.34 (.09,.53)	.21 (-.06,.42)	.14 (-.10,.38)	.01 (-.22,.25)	.21 (-.06,.42)
Reg I Gra I	0 (-.26,.26)	.09 (-.17,.33)	.09 (-.17,.33)	.41 (.15,.58)	.08 (-.18,.31)	.26 (.01,.43)	.14 (-.10,.38)
Reg I Gra II	-.19 (-.46,.08)	.10 (-.18,.36)	-.24 (-.48,.04)	.36 (.06,.54)	.09 (-.19,.35)	-.06 (-.34,.22)	.12 (-.18,.39)
Reg II Gra III	0 (-.29,.28)	.26 (-.04,.47)	.19 (-.08,.44)	-.18 (-.43,.08)	-.15 (-.40,.10)	-.18 (-.43,.08)	.07 (-.22,.32)
Reg II Gra IV	.05 (-.24,.32)	.30 (.04,.51)	.34 (.09,.53)	.21 (-.06,.42)	.14 (-.10,.38)	.01 (-.22,.25)	.21 (-.06,.42)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A13. (cont'd)

	SOZn GRAZn	SOCa GRAK	SOCa GRAMg	SOCa GRAP	SOCa GRACu	SOCa GRAFe	SOCa GRASe
Overall	-.18 (-.33,-.06)	.23 (.09,.32)	-.53 (-.60,-.47)	.75 (.68,.77)	.50 (.40,.65)	.65 (.56.70)	0 (-.11,.12)
Reg I	.08 (-.01,.27)	.12 (-.09,.29)	.01 (-.18,.14)	.10 (-.10,.25)	.13 (-.07,.25)	.05 (-.15,.11)	.27 (.10,.42)
Reg II	-.24 (-.40,.10)	0 (-.17,.19)	.12 (-.09,.29)	.23 (.03,.39)	.24 (.02,.41)	.03 (-.13,.11)	.03 (-.13,.11)
Gra I	-.09 (-.16,.34)	-.36 (-.53,-.11)	-.37 (-.55,-.15)	.25 (.02,.40)	-.28 (-.48,-.05)	.66 (.48,.75)	.17 (-.38,.05)
Gra II	0 (-.29,.28)	.21 (-.08,.45)	-.11 (-.37,.17)	.26 (-.04,.48)	.17 (-.12,.41)	.03 (-.26,.29)	.36 (.09,.55)
Gra III	-.26 (-.49,-.02)	.11 (-.16,.34)	-.16 (-.37,.07)	.48 (.25,.63)	.48 (.25,.63)	.44 (.20,.63)	-.12 (-.36,.15)
Gra IV	-.24 (-.46,-.02)	.03 (-.26,.27)	0 (-.26,.26)	.25 (-.01,.46)	-.01 (-.27,.28)	-.01 (-.27,.28)	.17 (-.09,.40)
Reg I Gra I	.25 (-.01,.46)	.17 (-.09,.40)	.16 (-.12,.42)	.02 (-.25,.26)	.14 (-.10,.38)	.09 (-.17,.33)	.23 (-.04,.43)
Reg I Gra II	0 (-.29,.28)	.21 (-.08,.45)	-.11 (-.37,.17)	.26 (-.04,.48)	.17 (-.12,.41)	.03 (-.26,.29)	.36 (.09,.55)
Reg II Gra III	-.25 (-.50,.01)	.24 (-.03,.47)	.24 (-.03,.47)	.21 (.11,.43)	.51 (.27,.69)	.18 (-.10,.44)	-.09 (-.37,.18)
Reg II Gra IV	-.24 (-.46,-.02)	.03 (-.26,.27)	0 (-.26,.26)	.25 (-.01,.46)	-.01 (-.27,.28)	-.01 (-.27,.28)	.17 (-.09,.40)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A13. (cont'd)

	SOCa GRAZn	SOK GRAMg	SOMg GRAK	SOCu GRAFe	SOCu GRASe	SOCu GRAZn	SOFe GRACu
Overall	.78 (.74,.83)	-.31 (-.42,-.17)	.11 (.04,.21)	.41 (.29,.46)	.05 (-.09,.16)	.58 (.49,.64)	-.33 (-.42,-.19)
Reg I	.09 (.04,.20)	.01 (-.19,.18)	0 (-.17,.19)	-.06 (-.21,.11)	.15 (-.04,.30)	.16 (-.05,.32)	.10 (-.10,.25)
Reg II	.08 (-.01,.27)	-.26 (-.41,-.09)	-.12 (-.03,.05)	-.12 (-.03,.05)	0 (-.17,.10)	.04 (-.16,.20)	-.07 (-.25,.11)
Gra I	.67 (.52,.76)	-.12 (-.32,.11)	-.30 (-.52,-.04)	.32 (.09,.53)	.28 (.02,.45)	.52 (.29,.66)	.39 (.15,.55)
Gra II	.13 (-.17,.40)	-.04 (-.30,.25)	.14 (-.12,.38)	-.15 (-.40,.12)	.04 (-.22,.28)	.09 (-.19,.35)	-.09 (-.37,.18)
Gra III	.46 (.20,.62)	-.42 (-.60,-.19)	-.12 (-.36,.15)	.16 (-.09,.40)	-.04 (-.30,.25)	.24 (.01,.45)	-.31 (-.53,-.06)
Gra IV	-.10 (-.35,.15)	-.22 (-.44,.03)	-.17 (-.41,.11)	-.16 (-.37,.07)	-.08 (-.35,.16)	.06 (-.22,.30)	-.03 (-.28,.25)
Reg I Gra I	.10 (-.05,.34)	0 (-.26,.26)	-.05 (-.33,.22)	-.05 (-.33,.22)	.23 (-.04,.43)	.31 (.05,.50)	.32 (.07,.54)
Reg I Gra II	.13 (-.17,.40)	-.04 (-.30,.25)	.14 (-.12,.38)	-.15 (-.40,.12)	.04 (-.22,.28)	.09 (-.19,.35)	-.09 (-.37,.18)
Reg II Gra III	.37 (.10,.47)	-.34 (-.56,-.09)	-.16 (-.43,.11)	-.12 (-.37,.16)	.01 (-.27,.28)	.04 (-.25,.31)	-.16 (-.43,.11)
Reg II Gra IV	-.10 (-.35,.15)	-.22 (-.44,.03)	-.14 (-.41,.11)	-.16 (-.37,.07)	-.08 (-.35,.16)	.06 (-.22,.30)	-.03 (-.28,.25)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A13. (cont'd)

	SOSe GRACu	SOZn GRACu	SOpH GRACu	SOpH GRAFe	SOpH GRASe	SOpH GRAZn	SOpH GRACa
Overall	0 (-.11,.12)	-.10 (-.22,.01)	.49 (.40,.57)	.65 (.56,.71)	.06 (-.08,.17)	.75 (.68,.77)	.74 (.67,.77)
Reg I	.12 (-.09,.29)	.15 (.04,.30)	-.03 (-.11,.13)	.02 (-.19,.14)	-.02 (.20,.14)	.16 (-.05,.32)	0 (-.17,.19)
Reg II	-.26 (-.41,-.09)	-.12 (-.03,.05)	.32 (.13,.46)	.24 (.02,.41)	.39 (.23,.54)	.33 (.20,.41)	-.27 (-.43,.13)
Gru I	.31 (.05,.51)	.31 (.05,.51)	-.17 (-.38,.05)	.62 (.43,.72)	.08 (-.15,.31)	.53 (.30,.66)	.56 (.35,.70)
Gru II	-.16 (-.41,.11)	0 (-.29,.28)	-.17 (-.41,.11)	-.14 (-.40,.19)	.12 (-.18,.39)	-.21 (-.46,.08)	.06 (-.24,-.31)
Gru III	-.09 (-.37,.14)	-.17 (-.41,-.06)	.40 (.14,.57)	.46 (.20,.64)	.10 (-.05,.34)	.42 (.18,.59)	.23 (-.04,.43)
Gru IV	-.41 (-.59,-.16)	-.15 (-.38,.09)	.38 (.11,.55)	.21 (-.06,.42)	.42 (.18,.59)	.33 (.09,.51)	-.20 (-.44,.05)
Reg I Gru I	.33 (.09,.51)	.25 (-.01,.46)	.06 (-.22,.30)	.08 (-.18,.31)	-.08 (-.34,.17)	-.11 (-.36,.16)	-.11 (-.36,.16)
Reg I Gru II	-.16 (-.41,.11)	0 (-.29,.28)	-.17 (-.41,.11)	-.17 (-.40,.19)	.12 (-.18,.39)	-.21 (-.46,.08)	.06 (-.24,.31)
Reg II Gru III	-.17 (-.41,.11)	-.17 (-.41,.11)	.35 (.09,.56)	.25 (-.02,.49)	.37 (.10,.57)	.35 (.09,.56)	-.29 (-.52,-.04)
Reg II Gru IV	-.41 (-.59,-.16)	-.15 (-.38,.09)	.38 (.11,.55)	.21 (-.06,.42)	.42 (.18,.59)	.33 (.09,.51)	-.20 (-.44,.05)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A14. CORRELATIONAL COEFFICIENTS BETWEEN MINERALS IN SOILS AND MINERALS IN SERUM AND BETWEEN SOIL MINERALS AND HEMOGLOBIN OR HEMATOCRIT FROM SAMPLES OF THE NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	COWS	HEIFERS	CALVES
Soil-Serum Calcium	.07 (-.13,.21)	.11 (-.11,.27)	-.06 (-.22,.11)
Soil-Serum Potassium	-.19 (-.36,-.03)	-.10 (-.27,.09)	-.26 (-.41,-.09)
Soil-Serum Magnesium	-.38 (-.55,-.23)	-.13 (-.30,.07)	-.36 (-.53,-.19)
Soil-Serum Phosphorus	-.14 (-.30,.05)	-.14 (-.30,.05)	-.19 (-.36,-.03)
Soil-Serum Copper	-.24 (-.40,.10)	-.06 (-.22,.11)	-.18 (-.33,.01)
Soil-Serum Iron	-.45 (-.57,-.29)	-.43 (-.56,-.24)	-.25 (-.41,-.05)
Soil-Serum Selenium	.43 (.27,.54)	.47 (.32,.60)	.49 (.34,.60)
Soil-Serum Zinc	-.08 (-.41,.10)	.13 (-.07,.25)	.06 (-.13,.20)
Soil Iron Serum Copper	.35 (.19,.46)	.28 (.11,.46)	.13 (-.07,.25)
Soil Iron Blood HB	.41 (.22,.57)	.30 (.10,.41)	.34 (.18,.50)
Soil Iron Blood HT	-.27 (-.40,-.10)	-.01 (-.20,.20)	0.20 (-.19,.14)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A14. (cont'd)

	COWS	HEIFERS	CALVES
Soil Calcium Serum Magnesium	-.22 (-.39,-.03)	.02 (-.19,.14)	-.25 (-.41,-.05)
Soil Calcium Serum Phosphorus	.49 (.34,.60)	.27 (.10,.42)	-.01 (-.19,.14)
Soil Calcium Serum Copper	-.29 (-.45,-.12)	-.20 (-.36,-.34)	-.18 (-.32,-.03)
Soil Calcium Serum Zinc	.35 (.19,.50)	.35 (.19,.50)	.26 (.06,.42)
Soil Potassium Serum Magnesium	.02 (-.19,.14)	.15 (.04,.30)	-.09 (-.25,.11)
Soil Copper Serum Iron	.40 (.23,.55)	.43 (.27,.54)	.27 (.10,.42)
Soil Copper Serum Selenium	.21 (.03,.36)	.23 (.03,.39)	.23 (.03,.39)
Soil Copper Serum Zinc	.19 (.02,.37)	.21 (.03,.36)	.15 (.04,.30)
Soil Copper Blood HB	-.36 (-.50,-.19)	-.23 (-.40,-.04)	-.31 (-.46,-.11)
Soil Copper Blood HT	.20 (.08,.30)	.21 (.03,.36)	0 (-.17,.19)
Soil Zinc Serum Copper	-.08 (-.41,.10)	-.02 (-.20,.19)	.01 (-.19,.18)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A15. CORRELATIONAL COEFFICIENTS BETWEEN MINERALS IN GRASSES AND MINERAL AND HEMOGLOBIN AND HEMATOCRIT FROM SAMPLES OF THE NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

	COWS	HEIFERS	CALVES
Grass-Serum Calcium	0 (-.17,.19)	.03 (-.13,.11)	-.10 (-.27,.09)
Grass-Serum Potassium	-.35 (-.50,-.18)	-.24 (-.40,.10)	-.24 (-.40,.10)
Grass-Serum Magnesium	.04 (-.16,.25)	.04 (-.16,.25)	.14 (-.05,.24)
Grass-Serum Phosphorus	.35 (.19,.46)	.21 (.03,.36)	-.04 (-.21,.11)
Grass-Serum Copper	-.15 (-.30,.30)	-.13 (-.30,.07)	-.19 (-.36,-.03)
Grass-Serum Iron	.39 (.23,.54)	.30 (.10,.41)	.23 (.03,.39)
Grass Serum Selenium	.08 (-.01,.27)	.27 (.10,.42)	.23 (.03,.39)
Grass-Serum Zinc	.26 (.06,.42)	.18 (.01,.35)	.26 (.06,.42)
Grass-Iron Serum Copper	-.14 (-.30,.05)	-.06 (-.22,.11)	-.07 (-.25,.11)
Grass Iron Blood HB	-.35 (-.50,-.18)	-.34 (-.49,-.18)	-.35 (-.50,-.18)
Grass Iron Blood HT	.20 (.08,.30)	.07 (-.13,.20)	.05 (-.15,.11)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A15. (cont'd)

	COWS	HEIFERS	CALVES
Grass Calcium Serum Magnesium	-.26 (-.41,-.08)	-.08 (-.41,.10)	-.27 (-.40,-.10)
Grass Calcium Serum Phosphorus	.37 (.21,.54)	.14 (-.05,.24)	-.07 (-.25,.11)
Grass Calcium Serum Copper	-.30 (-.45,-.12)	-.24 (-.40,-.10)	-.24 (-.40,-.11)
Grass Calcium Serum Zinc	.29 (.12,.46)	.33 (.12,.48)	.28 (.11,.42)
Grass Potassium Serum Magnesium	.05 (-.15,.11)	-.12 (-.03,.05)	-.10 (-.27,.09)
Grass Copper Serum Iron	.20 (.03,.37)	.13 (-.07,.25)	.05 (-.15,.11)
Grass Copper Serum Selenium	-.02 (-.20,.14)	.10 (-.10,.25)	.03 (.10,.41)
Grass Copper Serum Zinc	.13 (-.07,.25)	.11 (-.11,.27)	.03 (.10,.41)
Grass Copper Serum HB	-.27 (-.40,-.10)	-.21 (-.37,-.02)	-.14 (-.32,.02)
Grass Copper Serum HT	.25 (.04,.39)	.18 (.01,.35)	-.06 (-.22,.11)
Grass Zinc Serum Copper	-.25 (-.40,-.06)	-.18 (-.32,-.03)	-.19 (-.36,-.03)

[a]Numbers in parenthesis are .95 confidence limits.

TABLE A16. CORRELATIONAL COEFFICIENTS BETWEEN MINERALS IN SERA OF COWS, HEIFERS AND CALVES, FROM SAMPLES OF THE NORTHERN (REGION II) AND SOUTHERN (REGION I) VERACRUZ, MEXICO.[a]

PAIR		PAIR		PAIR	
COCA HECA	.32 (.13,.46)	COCA CALCA	.25 (.04,.39)	HECA CALCA	.36 (.15,.50)
COK HEK	.32 (.13,.46)	COK CALK	.28 (.11,.42)	HEK CALK	.44 (.27,.56)
COMG HEMG	.23 (.03,.39)	COMG CALMG	.35 (.19,.46)	HEMG CALMG	.34 (.18,.50)
COP HEP	.70 (.60,.77)	COP CALP	.49 (.34,.64)	HEP CALP	.64 (.52,.72)
COCU HECU	.15 (-.04,.30)	COCU CALCU	.20 (.01,.37)	HECU CALCU	.10 (-.10,.25)
COFE HEFE	.56 (.36,.64)	COFE CALFE	.33 (.20,.41)	HEFE CALFE	.42 (.24,.54)
COSE HESE	.75 (.64,.80)	COSE CALSE	.80 (.73,.84)	HESE CALSE	.83 (.73,.85)
COZN HEZN	.24 (.02,.41)	COZN CALZN	.17 (-.03,.32)	HEZN CALZN	.34 (.18,.50)

[a]Numbers in parenthesis are .95 confidence limits.

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