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THE MINERAL STATUS OF DAIRY CATTLE IN ECUADOR AND IN MICHIGAN

By

Telmo B. Oleas

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ABSTRACT

THE MINERAL STATUS OF DAIRY CATTLE
IN ECUADOR AND IN MICHIGAN

By

Telmo B. Oleas

The mineral status of dairy cattle was studied in five regions in the Chimborazo province of Ecuador, and one region in Shiawassee county, Michigan.

In order to diagnose mineral deficiencies, imbalances and toxicities, minerals in blood serum, pasture and soil were analyzed. Three farms were sampled in each region of Ecuador and one farm in Michigan. Blood samples were collected from 10 lactating dairy cows and 10 animals under one year of age from each farm. Pasture and soil samples were taken from five fields in each farm. Half of each pasture sample was washed with distilled water and the other half was not, to establish the extent of soil contamination through mineral analysis.

Several mineral deficiencies for both plants and animals were found in the regions studied.

Most of the soils needed liming. Nitrogen fertilization is necessary for corn and pasture grasses. Phosphorus and potassium fertilization is needed for crops in most of the soils studied. Molybdenum is needed in one region of Ecuador and in Michigan for legume crops. Zinc is needed in Michigan for corn cultivation. Copper fertilization is needed for legumes in all the regions

studied. Sulfur is needed for legumes in one region in Ecuador and in Michigan.

It was concluded that animals from all the regions studied needed nitrogen, calcium, phosphorus, sodium and copper supplementation. Zinc, manganese and selenium was deficient for animals in several regions of Ecuador and in Michigan.

Nematodes and trematodes eggs, and coccidia oocysts were found in the feces of animals from all the regions in Ecuador, but not in Michigan.

In general soils and pastures in Ecuador are deficient in nitrogen, phosphorus, potassium, calcium, molybdenum, zinc, copper, sulfur, manganese and selenium. These mineral deficiencies dramatically decrease livestock production.

DEDICATED TO

My father, brother and sisters in Ecuador,
to the memory of my mother,
and to
the Robert Cook family in Michigan.

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INTRODUCTION

In 1976 Ecuador had an estimated 1,088,224 milking cows that produced 704 million kg of milk (647 kg or 1,426 lb/cow/year) (M.A.G., Ecuador, 1976). This production is low when compared to the production of the State of Michigan in 1983 (Michigan Department of Agriculture, 1984), where 404,000 dairy cows produced 2,507 million kg of milk for an average of 6,207 kg (13,883 lb)/cow/year. One of the most important causes for low production is inadequate mineral nutrition: deficiencies, toxicity and imbalances. A sound mineral nutrition program is easy to implement, with minimal work and low cost. The benefits are immediate.

The University of Florida is a leader in mineral research in Latin America. Several investigations have been carried out in different countries (McDowell et al., 1983) to diagnose mineral deficiencies and toxicities. In Ecuador (Wilson, 1975) soils, pastures and animal tissues have been analyzed in different regions. Clinical signs, reproductive problems, low production and laboratory studies indicate probable mineral problems.

Although severe mineral deficiencies or toxicities in animals show dramatic signs, borderline problems, which are the most common, are difficult to diagnose by clinical signs alone, and the use of chemical analysis of soils, pastures and animal tissues is necessary. Furthermore, improper mineral nutrition can be confused with other nutritional problems, parasitism and infectious disease (Underwood, 1981).

The objectives of this study were to detect possible mineral deficiencies or toxicities in the Chimborazo region of Ecuador through the elemental analysis of soils, pastures and blood; to compare these findings with the mineral status of a dairy farm in Michigan; and to provide recommendations for proper mineral nutrition.

LITERATURE REVIEW

The literature review deals with 1) mineral content of soils; 2) nutrient content of pastures; 3) minerals in blood; and 4) gastrointestinal parasitism in ruminants.

This review tries to relate the mineral status of the soil to the mineral status and productivity of forages. The effect of elemental concentration in plants on the mineral status of cattle and other animals is discussed, as is the use of soil, plant and animal tissue analyses as a mean of diagnosing mineral deficiencies or toxicities.

The mineral content of soils is compared to the mineral requirements of plants, particularly forages for ruminants. The expected consequences of nutrient deficiencies in the soil on crop yield are mentioned, as well as the possible effects of fertilization.

Each mineral found in pastures is discussed in five sections: 1) content of the mineral in plants in relation to soil status and fertilization; 2) content of the mineral in forages, 3) requirements of dairy cattle for the minerals; 4) deficiencies or toxicities of the mineral in ruminants; and 5) sources of the mineral for dietary supplementation.

Minerals in blood are first discussed in terms of the effects of the diet on their concentration. Next, blood tests that can be used to diagnose deficiencies or toxicities are discussed. When blood is not a good indicator of the status of a particular mineral, alternative means of diagnosis are mentioned.

Parasitism is discussed because visual and clinical signs of parasite infestation can be confused with mineral deficiencies. The contrary can also occur: mineral deficiency signs can be attributed to parasitism. The detrimental economic implications of parasitism in cattle are mentioned, and some measures of control are discussed.

Mineral Status of Soil

The mineral status of soils depends on their geological formation. The parent material of the soil is rock so the composition of the soil is determined by the elemental composition of the parent rock. Throughout the history of the earth, parent rock has been subjected to disintegration, weathering, mixing, transportation and deposition. These factors, along with current climate and crop practices, influence the abundance and availability of mineral elements available for plant use (Beeson and Matrone, 1976).

Plant growth depends on several environmental variables such as temperature, moisture supply, radiant energy, composition of the atmosphere, gas content of the soil, soil reaction, biotic factors such as diseases and weeds and the supply of mineral nutrient elements. Some of these factors are difficult or impossible to change. In any given climate, however, there are some practices that can be adopted to improve agricultural production. In several areas of the world, soil fertility is the limiting factor for production. Fertility in the soil can be improved by several agricultural practices such as crop rotation, correction of acidity, proper tillage, and fertilization (Tisdale and Nelson, 1975).

Soil pH and the Effect of Liming

Soil pH is one of the most important factors for crop production. Different plant species and varieties have different soil pH requirements, but most of them thrive at pH values close to neutral. However, potatoes grow well at pH 6.0. The growth of common scab in potatoes, caused by *Streptomyces scabies*, is inhibited when the soil pH is 5.2 or lower (Agrios, 1978). Scab resistant varieties, however, produce better at a soil pH of 6.5 (Warncke and Christenson, 1980).

In general, the recommended pH for field crops is 6.5, and 6.8 for alfalfa and legumes (Christenson et al., 1983). In the case of mixed pastures, it is often desirable to favor growth of legumes; consequently a soil pH of around 6.8 is recommended. Several mineral investigations in Latin America have shown soil pH values under 6.0 (Sousa, 1978; McDowell et al., 1982; Tejada, 1984). In Ecuador a mean pH value of 5.6 was found in the soil of natural pastures at altitudes of around 3600 m (Wilson, 1976).

When soil pH is not in the desired range for a specific crop, an amendment is needed. Low or acidic pH values can be corrected with the addition of calcium and magnesium oxides, hydroxides or carbonates. This practice is known as liming. The most common liming material is calcium carbonate or limestone. Other materials are calcium oxide or lime, calcium hydroxide or slaked lime, calcium and magnesium carbonates or dolomitic limestones, and marls (unconsolidated deposits of calcium carbonate). Byproducts of the iron and phosphorus industry, or slag (calcium silicate), are also used when available to neutralize the soils. Cement kiln dusts can be used to neutralize the soil. This last byproduct has around 28% calcium (Jordan et al., 1980), compared with 31% or more calcium in limestone (Robertson et al., 1981a), and about the same neutralizing capacity (Noller et al., 1980). Cement kiln dusts also have a variable content of potassium, ranging from 0.40 to 3.60% (Jordan et al., 1980).

In general, nitrogen, phosphorus, potassium, sulfur, calcium and magnesium in soils are more available for plants at neutral or above neutral pH values, while aluminum, manganese, iron, and boron are more available at acid pH values. Zinc is available up to a pH value of around 7.0, and copper at almost all pH values, except in very alkaline soils (Christenson et al., 1983). Aluminum and manganese in high concentrations are toxic to the plants (Tisdale and Nelson, 1975). Liming or neutralizing the soil has several advantages for improved crop production (Christenson et al., 1983), including:

1) liming reduces the availability of aluminum and manganese in the soil to levels that are not harmful to crops;

2) liming increases the availability of nitrogen, phosphorus, potassium, magnesium, calcium, sulfur and molybdenum;

3) limestone supplies calcium to the soil and dolomitic limestone supplies calcium and magnesium;

4) liming promotes favorable microbial activity which results in an increased availability of soil nitrogen and a decreased loss of gaseous nitrogen from the soil;

5) liming promotes better soil structure and tilth due partly to increased microbial activity, partly to increased crop residues from higher crop yields and partly to chemical effects of decreasing hydrogen ion concentration and increasing calcium and magnesium ion concentration; and

6) liming promotes longevity of legume stands, particularly

alfalfa, due to the high calcium requirement of legumes. It also increases nitrogen fixation in the roots.

Nitrogen

Nitrogen from the air becomes available for the plants through fixation by Rhizobia or other microorganisms and atmospheric fixation by biochemical reduction. Nitrogen is also fixed in the form of ammonia, nitrates or cyanides by any of the various industrial processes for the manufacture of synthetic nitrogen fertilizers (Tisdale and Nelson, 1975).

In the case of legumes, nitrogen fixation by Rhizobia represents the main source on the element for the plant. Indeed, in alfalfa cultivation, for example, no nitrogen fertilizer is used. To ensure a good nitrogen fixing microbial population, the seed is inoculated at the time of planting (Tesar, 1983). When the pastures are mixed grasses and legumes, the legume provides the necessary nitrogen to the pasture. Some additional nitrogen comes from the manure of the grazing animals. Therefore, chemical fertilization with nitrogen is unnecessary.

There is a loss of clover from clover-grass pastures heavily fertilized with nitrogen. This is possibly due to competition for moisture and nutrients, particularly potassium. According to Donald (1958), clover is lost because of:

1) increased rates of nitrogen application give increased yields of grass;

2) increased yields of grass give higher leaf areas of grass disposed above the clover-leaf canopy;

3) higher leaf areas above the clover reduce the light

density at the clover-leaf canopy; and

4) reduced light density at the clover leaf canopy causes reduced growth of clover.

In addition to providing "free" nitrogen to the soil, legumes improve the nutritive quality of the pasture because they usually have a higher protein content than grasses and are more palatable. Compared to grasses, legumes have characteristically high concentrations of calcium, magnesium, sulfur, and frequently copper. They tend to be lower in manganese and zinc than grasses (Church and Pond, 1974).

Calcium

All higher plants require calcium. Legumes in general extract more calcium from the soil than grasses or cereals. Nine thousand kg of alfalfa (1.40% calcium) from one hectare (4 tons/acre) remove 125 kg of calcium from the soil. Nine thousand five hundred kg of corn grain (0,03% calcium) from one hectare (150 bushels/acre) remove 2.85 kg of calcium and 10000 kg of stover (0.30% calcium) from the same crop (4.5 tons/acre) remove 30 kg of calcium (Robertson et al., 1976a). Calcium deficiency is not a common problem in soils. Nevertheless, fertilization with calcium salts, particularly carbonate, is essential to neutralize the soil pH, to maintain a suitable degree of base saturation of the soil colloids, and to precipitate aluminum that is toxic to plants (Tisdale and Nelson, 1975). The main source of calcium for the soil is liming. Most of the phosphate fertilizers are calcium salts (Robertson et al., 1976a).

Calcium deficiency can occur in soils in humid regions under conditions in which rainfall exceeds evapotranspiration for most of the year and where bases have been depleted and soil acidity has developed (Kamprath and Foy, 1971). The actual level of calcium in soil is not important as long the pH is within an adequate range (Robertson et al., 1976a). Plants absorb calcium as the ion Ca^{++} in balance with magnesium and potassium. Too much of any of these three elements may cause insufficiencies of the other two (Vitosh et al, 1981). Indeed, the value of exchangeable calcium and potassium in the soil is used to determine the need for magnesium fertilizer (Robertson et al., 1976a).

Plant analysis can be used to help determine the calcium status of the soil. The percent of calcium in corn and alfalfa (Table I.1, Appendix I) represents the "sufficiency range", which is a level essential for high yields. Levels below those reported imply the possibility of production problems, while those above reflect excessive levels and the possibility of other nutrient deficiencies. These sufficiency levels can be interpreted correctly only when the samples are collected in the way indicated in the reference tables. Corn samples, for example, are collected from the ear leaf of initial silk of the plant (Robertson et al., 1976a). In the case of alfalfa, the sufficiency range is 1.76 to 3.00% in the top six inches prior to initial flowering. The calcium content of the whole plant cut for hay in early vegetative state is 1.72% (NRC, 1978).

Phosphorus

Phosphorus, with nitrogen and potassium, is classed as a major nutrient element. Soils usually require the addition of these three nutrients for commercial production of crops. Phosphorus deficiency in soils, pastures and animals is one of the most common and critical mineral problems throughout the world (Reid and Horvath, 1980; McDowell et al., 1983). The first effect of phosphorus deficiency on the plant is decreased root growth, which in turn results in decreased plant growth and lower yields. Plants with adequate phosphorus fertilization mature faster and in the case of cereals have greater strength in the straw. Pastures in general have better nutritional quality when the phosphorus supply from the soil is adequate (Tisdale and Nelson, 1975). Phosphorus -and sulfur and potassium- fertilization, without nitrogen fertilization, of mixed pastures favor the growth of legumes over the grasses. This usually results in better nutritional quality: higher protein, digestible energy, mineral concentration and yield (Heady, 1975).

Phosphorus availability depends on the total concentration of the element, pH, organic matter, clay content and clay structure, soil moisture, temperature and aeration in the soil (Reid and Horvath, 1980). At low soil pH values, phosphorus supplied as fertilizer reacts with aluminum to form aluminum orthophosphate, which is not available for the plant. When the soil is neutralized with lime before phosphorus fertilization, aluminum is precipitated as aluminum hydroxide (Kamprath and Foy, 1971). The addition of organic materials to mineral soils increases the availability of phosphorus. Soils containing large amounts of clay will fix more phosphorus than those containing small amounts. Clays of the 1:1 type retain more phosphorus than clays of the type 2:1. In general, soils in warmer climates fix more phosphorus than soils in colder climates (Tisdale and Nelson, 1975). Increasing soil moisture and temperature increase the rate of diffusion of phosphorus to the root system (Reid and Horvath, 1980).

Recommendations for phosphorus fertilization are made on the basis of the crop considered, organic matter content of the soil, phosphorus content of the soil and removal of phosphorus by the crop (Vitosh and Warncke, 1979). Tables I.6 and I.7 (Appendix I) show the recommendations for phosphorus fertilization made by the Extension Service of Michigan State University (Warncke and Christenson, 1980). The values can be used only when the phosphorus content of the soil has been obtained by the Bray-1 extracting procedure (Knudsen, 1980).

Phosphate fertilizers are manufactured from phosphate rock. The basic phosphate compound in phosphate rock is apatite. Most of the naturally occurring apatite is fluoroapatite or calcium phosphate fluoride. Phosphate rock is treated with sulfuric acid to yield ordinary superphosphate with 7-9.5% available phosphorus and 8-10% sulfur as calcium sulfate. Triple or concentrated superphosphate is manufactured by treating phosphate rock with phosphoric acid, and contains 19 to 23% phosphorus. Among other phosphates available in the market are ammoniated superphosphates, ammonium phosphates and nitric phosphates. Defluorinated phosphates are manufactured by heat treatment of phosphate rock, and are used for animal feeds (Tisdale and

Nelson, 1975).

Potassium

Potassium is one of the most abundant elements in the soil, but the fraction of the total potassium in the exchangeable, or plant available, form is usually small. Plant requirements for potassium are high. When the element is in short supply, the first symptom is a reduction in yields and the quality of the crops. There is a weakening of the straw of cereals and grasses that are then subject to lodging, and stalk breakage in corn and sorghum. A usual symptom in alfalfa is the decolorization of the lower leaves. This is because potassium is a mobile element which is translocated to the younger meristematic tissues if a shortage occurs. Plants differ in their ability to use potassium. Grasses are better able to survive at low levels of soil potassium than clovers and legumes in general. Therefore to maintain a good legume population in mixed grass-legume pastures and meadows, it is important to provide an adequate potassium fertilization (Tisdale and Nelson, 1975).

Potassium in the soil exists in four forms: 1) mineral, or the potassium held in the molecules of feldspar and mica, which is unavailable to the plant; 2) "difficultly available", or the potassium in clays like illite, vermiculite, and chlorite; 3) exchangeable potassium, held by electrostatic forces, which is very readily exchanged from the solid phase of the soil to solution by other cations; and 4) potassium in solution, as the K^+ ion, which is the form that is absorbed by the roots (Barber et al., 1971).

Potassium added to the soil as fertilizer is readily available to the plant at the time of application, but after some time the process of "fixation" occurs. This is the entrapment of the potassium ion in between the layers of 2:1 type clays. The fixed element is unavailable to the plant. The factors that influence the conversion of soil and added potassium to less available forms are the following (Tisdale and Nelson, 1975):

1) Type and amount of colloids: clays of the 2:1 type fix more potassium than the 1:1 types. Independent of the clay type, soils with a higher percentage of clay will fix more potassium than sandy soils.

2) Temperature: there is evidence that changes in temperature, such as freezing an thawing have some effect on the release of fixed potassium. The same effect has been observed with wetting and drying of the soil.

3) Soil pH: the effect of soil pH per se on potassium fixation is not known. Liming of soils with clays that are saturated with potassium releases the potassium to the soil solution by substitution. Potassium fertilizer added to soils with calcium ions adsorbed to the clay interchanges calcium for potassium on the surface of the clay particle. This potassium is still exchangeable. Fixation of the exchangeable potassium will depend on the amount and type of clay and the degree of potassium saturation.

Potassium fertilization recommendations are made on the basis of:

1) the amount of the element removed from the soil by the

crop. Corn silage (56 metric tons/hectare or 25 tons/acre) will remove 220 kg of K2O from the soil. Alfalfa (11 metric tons/hectare or 5 tons/acre) will remove 250 kg of K2O from the soil (Warncke and Christenson, 1980).

2) the exchangeable amount of potassium present in the soil as determined by chemical analysis; and

3) the texture of the soil. Sandy soils require less potassium than soils that have high contents of clay.

When enough potassium fertilizer is added to the soil it will eventually saturate the clay particles. All the extra potassium will then be in an exchangeable form that will not revert to the fixed form. In some situations it is desirable to build up the potassium concentration in the soil to the point of saturation. However, in soils with high content of 2:1 type of clay, the amount needed to reach saturation can be so great it is not economical to do so. In such a case, adding potassium to the soil more frequently is recommended, not in order to reach saturation, but to have enough exchangeable element during the period of growth. For corn, potassium is added at the time of planting. In the case of permanent crops as alfalfa , potassium can be added after the first harvest in spring, and after the third harvest in late automn in Michigan (Helsel et al., 1984). Recommendations for potassium fertilization for corn and alfalfa made by the Extension Service of Michigan State University (Warncke and Christenson, 1980) are shown in Tables I.6 and I.7 (Appendix 1).

The main potassium fertilizer is potassium chloride found in underground deposits and in the brines of dying seas and lakes. The potassium ore and the brines are found usually as mixtures of potassium chloride, sodium chloride, other salts and clay. Refining processes are necessary to obtain concentrated or pure potassium chloride. Other potassium fertilizers are potassium sulfate, potassium magnesium sulfate, and potassium nitrate.

Magnesium

The total magnesium content of soils is usually high, but ranges from 0.1% in highly weathered, sandy tropical soils, to 4% in soils of semiarid regions (Mortvedt and Cunningham, 1971). As in the case of potassium, not all the magnesium in the soil is available for the plant.

Magnesium is absorbed by the plants as the ion Mg^{++} from the soil solution. It is adsorbed and fixed by the clay particles in a way similar to that of potassium. The amount of magnesium absorbed by the plants depends on the amount present, the degree of saturation, and the nature of other exchangeable ions (Tisdale and Nelson, 1975). The Michigan State University Extension Service (Vitosh et al., 1981) recommends magnesium fertilization if one of the following criteria are met: 1) the exchangeable magnesium level is less than 37 ppm in mineral soils and 75 ppm in organic soils; or 2) when as a percent of the total bases (Ca + Mg + K, expressed as milliequivalents per unit of weight of soil), potassium levels exceed magnesium; or 3) when soil magnesium, as a percent of the total bases, is less than three percent. Some authors recommend at least 10% of magnesium as percent of the total bases to prevent magnesium tetany of animals fed magnesium deficient forages. Sufficiency ranges shown in table I.1 (Appendix I) can be used to assess magnesium deficiency in corn and alfalfa.

Magnesium is a mobile element and is readily translocated from older to younger plant parts in the event of deficiency. Consequently, symptoms often appear first on the lower leaves. In many species, such as corn, the deficiency results in an interveinal chlorosis of the leaf, in which only the veins remain green. In more advanced stages the leaf tissue becomes uniformly pale yellow, then brown and necrotic (Tisdale and Nelson, 1975). Magnesium deficiency can be induced by high potassium fertilization and inadequate liming (Vitosh et al., 1981).

To correct or prevent deficiencies, a good source of magnesium is dolomitic limestone which has variable magnesium contents. This material can be used instead of calcitic limestone to lime acid soils. When alkaline soils need magnesium, salts such as potassium-magnesium sulfate can be used (Tisdale and Nelson, 1975).

<u>Sulfur</u>

Sulfur is absorbed by the roots almost exclusively as the sulfate ion, SO_4^{--}. The symptoms of sulfur deficiency are similar to those of nitrogen deficiency: uniform chlorosis of the leaves, decreased growth and general weakness of the plant (Tisdale and Nelson, 1975).

Sulfur has several functions in plants, among them (Tisdale and Nelson, 1975):

1) it is required for the synthesis of sulfur containing

amino acids, and for protein synthesis;

2) it activates several enzymes and it is a constituent of some vitamins and enzymes;

3) it is present in the oils of some plants as garlic and onions and increases the oil content of plants like soybeans and flax;

4) it is required for nitrogen fixation by leguminous plants and is a part of the nitrogenase enzyme system that is associated with this reaction. Sulfur is also associated with cold resistance in plants.

The most direct benefit of sulfur fertilization in sulfur deficient soils is the increase in yield and quality of the crop. Increased persistency, winter hardiness and drought tolerance has been observed in alfalfa after sulfur fertilization (Beaton and Fox, 1971). In cereals and grasses sulfur fertilization decreases the accumulation of nitrates, that may be harmful to ruminants. On the other hand, an increased sulfur content in the plant after fertilization decreases the nitrogen to sulfur ratio (Tisdale and Nelson, 1975). A nitrogen to sulfur ratio of 10:1 is suggested for efficient utilization of nonprotein nitrogen (NRC, 1978). Grasses utilize soil sulfur better than legumes. In grass-legume pastures the grasses can absorb the available sulfate at a faster rate than the legumes. Unless an adequate soil level of this element is maintained, the legumes will disappear from the mixture (Tisdale and Nelson, 1975).

A soil test level of 6-7 ppm of sulfur is considered the threshold to diagnose deficiency in the Great Lakes area. Some soils in Michigan have sulfur concentrations below 6 ppm, but sulfur fertilization has failed to increase crop yields with the exception of field beans (Robertson et al., 1976b). It is possible that continuous cropping of high yielding varieties will eventually deplete the available sulfur in some soils and then fertilization will be needed.

There are several sulfur containing fertilizers on the market. Most of them are sulfates of different cations, and are readily available to the plant. With the exception of ammonium, aluminum, and iron sulfates, sulfate salts have no effect on soil pH. Elemental sulfur is a good sulfur fertilizer, but needs to be oxidized to sulfate before being absorbed by the roots. The velocity of oxidation depends on the particle size and the temperature and moisture of the soil. Elemental sulfur acidifies the soil. Three kg of calcium carbonate are necessary to neutralize one kilogram of elemental sulfur (Tisdale and Nelson, 1975). Calcium sulfate or gypsum (around 16% sulfur), if finely ground will usually produce a quick response with most crops. The same is true for normal superphosphate that has 10-12% of sulfur content (Beaton and Fox, 1971).

<u>Sodium</u>

Sodium is essential for the growth of plants. Different crops have different requirements for the element. The response of crops to sodium fertilization is usually dependent on the potassium status of the soil. Wheat, for example, will show increased yields in response to sodium fertilization if potassium is low in the soil, but not when potassium is adequate. When sodium nitrate is used as a source of nitrogen, the sodium ion helps to maintain the pH of the soil at a suitable high level, in contrast to ammonium sources whose continuous use lowers the soil pH. Sodium disperses both clay and organic matter. For this reason, large quantities of sodium in fine textured soils are undesirable. In semiarid regions, sodium accumulates in the soil, in some cases to a point where plant growth is limited. Amendment of the soil with gypsum and sufficient water to leach out the displaced sodium can alleviate this condition (Tisdale and Nelson, 1975). In several arid and semiarid regions of the world, the problem is not only sodium, but the accumulation of total soluble salts. This phenomenon is known as salinity of the soil (Bresler et al., 1982).

Chlorine

It has been demostrated that chlorine is essential for plant growth in several species. Deficiency of the chloride ion can produce chlorosis in some areas of the plant in some species, and leaf bronzing in others. In tomato plants, the effect of chlorine deficiency is decreased root growth. Corn is one of the crops susceptible to chlorine deficiency (Tisdale and Nelson, 1975). The chloride ion is highly soluble in water and loosly held by the clay particles, so it is easily leached from the surface horizon of soils after irrigation or rainfall. Potassium fertilization with potassium muriate should provide enough chlorine for the crops (Mortvedt and Cunningham, 1971).

Boron

Boron is indispensable for plants but not for animals.

Alfalfa is a crop highly responsive to boron fertilization, while clovers are medium responsive and corn and grasses are low responsive (Robertson et al., 1981a).

In alfalfa, boron deficiency produces a yellowish to reddish-yellow discoloration of the upper leaves, short nodes and few flowers. Growing tips of alfalfa may die, with regrowth coming after a new shoot is initiated at a lower axis. Boron deficiency and leafhopper damage can be confused in alfalfa. Leafhopper damage shows up as a V-shaped yellowing of the affected leaves and may appear on any or all parts of the plant. The growing tip is usually normal and the plant may support abundant flowers. Often, when the soil is dry and plant growth is retarded, both boron deficiency and leafhopper injury occur in the same field. Acute boron deficiency in corn appears on the newly-formed leaves as elongated, watery or transparent stripes. Later, the leaves become white and die. Growing points also die and, in severe cases, sterility is common. If ears develop, they may show corky brown bands at the base of the kernels (Vitosh et al., 1981).

In addition to visual symptoms, boron status can be diagnosed by soil tests. A concentration of less than 1 ppm when the soil is extracted with boiling water is an indication of boron deficiency in the soil. Correlations of yield responses to boron fertilization based on soil tests, however, have been low. Plant analysis can also be used to assess boron deficiencies or toxicities. The sufficiency range for alfalfa (top six inches prior to initial bloom) is 31-80 ppm. For corn, the sufficiency range measured in the ear leaf at first silk is 4-25 ppm (Robertson et al., 1981a).

Boron availability in the soil is greater when the texture is sandy than when the proportion of clay is high. Overliming reduces the availability of boron. Boron deficiencies are more manifest when the soil is dry and the plant can not extract the element from it (Tisdale and Nelson, 1975).

There are several compounds and preparations that can be used as fertilizer to correct or prevent boron deficiencies. Some of them are borax, sodium pentaborate and boric acid. Boron salts can be fused with glass to produce a slow release of the salt as the glass dissolves. This material is called "frit" (Tisdale and Nelson, 1975).

Boron toxicity usually occurs when boron containing fertilizers for highly responsive species like sugar beets are used at planting time fertilizer for highly sensitive crops such as field beans. Toxicity is characterized by yellowing of the leaf tip, interveinal chlorosis, and progressive scorching of the leaf margin (Vitosh et al., 1981). For alfalfa, especially when grown on coarse textured, arid soils, boron should be applied annually, but not at seeding, at a rate of one to two kg/hectare (Helsel et al., 1984).

Iron

A plant requires a continuous supply of iron to maintain proper growth (Brown et al., 1972). Iron deficiency in soils is related to high pH values such as those found in arid, calcareous regions, acid soils with low total iron content, and high soil concentrations of phosphorus (Mortvedt and Cunningham, 1971). Iron absorption by the plant is reduced by high concentrations of manganese, phosphorus and heavy metals in the soil. Grasses are highly responsive to iron fertilization, while alfalfa, clover and corn are medium responsive (Robertson et al., 1981a). In Michigan, iron deficiency is not common in forages, but some problems have been observed in trees, ornamentals and golf lawns (Vitosh et al., 1971).

Soil tests have not been a good indicator of extractable iron (Robertson et al., 1981a, Cox and Kamprath, 1972). Plant analysis is also difficult to interpret, but can be used to help diagnose toxicities or deficiencies when the values are well above or below the sufficiency ranges shown in table I.2 (Appendix I) (Robertson et al., 1981a).

Visual deficiency symptoms in plants are marked, and show up first in the young leaves. Interveinal chlorosis develops first, and progresses rapidly over the entire leaf. In severe cases the leaves turn completely white (Tisdale and Nelson, 1975). Iron deficiency symptoms are very similar to those of manganese deficiency (Vitosh et al., 1981).

Ferrous sulfate is the most commonly used salt to correct iron deficiencies. It can be put in the soil or used as a spray. Among other iron sources are ferric sulfate, ferrous and ferric oxide, iron frits. Iron chelates (FeEDDHA, FeDTPA and FeEDTA) are effective sources of iron under some conditions (Mortvedt and Cunningham, 1971). Under alkaline soil conditions, foliage sprays are recommended (Vitosh et al., 1981).

Manganese

According to the Extension Service of Michigan State University, manganese is the most common micronutrient problem in Michigan soils (Vitosh et al., 1981). Plants require manganese in small quantities; large amounts are toxic (Tisdale and Nelson, 1975). Manganese deficiency occurs more often on well-drained soils with a neutral or calcareous reaction. However, organic soils and some mineral soils with large quantities of organic matter may exhibit symptoms of deficiency with a slightly acid pH (Murphy and Walsh, 1972). Acid soils which have been limed are more likely to be manganese deficient than naturally neutral or alkaline soils (Vitosh et al., 1981). The minerals magnesium, and especially calcium interfere with manganese absorption by the roots. $Iron^{++}$, but not $iron^{+++}$, also decreases the absorption of manganese (Moore, 1972). Calcium and magnesium ions not only can produce manganese deficiency by competing for absorption, but also by raising the soil pH. $Manganese^{++}$ is the predominant species in the soil solution. This ion is very soluble at pH 4, but with each unit increase in pH, its solubility decreases 100 fold (Lindsay, 1972).

The sufficiency range for manganese in corn (ear leaf just before silking) is 20-150 ppm, and for alfalfa (top growth-6 inches to flowering) is 30-100 ppm (Robertson and Lucas, 1981). In the plant, manganese is a relatively immobile element. The symptoms of deficiency usually appear in the younger leaves. In broad-leaved plants the symptom interveinal chlorosis, which also occurs less conspicuously, in members of the grass family

(Tisdale and Nelson, 1975). Corn plants do not show marked symptoms, but when compared with a normal leaf, the deficient leaf is lighter green and has parallel, yellowish stripes (Vitosh et al., 1981).

Manganese excesses or toxicity commonly occur in strongly acid or in waterlogged soils (Murphy and Walsh, 1972). Symptoms of manganese toxicity are not very specific. Severe chlorosis followed by necrosis of leaves, leaf spots on margins, and stunting of the plant are the usual symptoms. High manganese concentrations in plants may induce deficiencies of other elements, especially iron. Reduction in the number of nodules on white clover roots due to excess manganese has been reported (Mortvedt and Cunningham, 1971).

Manganese sulfate is the most commonly used manganese fertilizer. Other sources of manganese are oxides, chlorides, carbonates. chelates (EDTA), and manganese frits (Tisdale and Nelson, 1975). In Michigan, manganese sulfate and manganous oxide have been effective to correct deficiencies. Manganic oxide is insoluble and has proved to be ineffective for Michigan soils. Chelated manganese materials in general have not been satisfactory on organic soils and have been less effective than manganese sulfate on mineral soils (Vitosh et al., 1981). Manganese toxicity in acid soils can be corrected by liming to a pH close to neutral (Lindsay, 1972).

When a soil manganese test is available after extraction with 0.1 N HCl, fertilizer can be applied at the rates shown in table I.8 (Appendix I). Broadcast application is not recommended because of high fixation of manganese in the soil. Residual carryover of available manganese fertilizer is usually low. For this reason, manganese must be applied every year on a deficient soil (Vitosh et al, 1981). Alfalfa, clover, corn and grasses are crops medium responsive to manganese fertilization (Robertson and Lucas, 1981a).

Selenium

This element is apparently not needed by plants, but must be present in forages and crop plants since is essential for animals. There are several regions in the world where the available selenium levels in soils are sufficiently high to produce forages containing levels of this element that are toxic to animals. There are other areas that produce plants that do not contain enough selenium to meet the nutritional requirements of animals (Kubota and Alloway, 1972). The availability of selenium to plants is closely related to the quantity of water-soluble selenium present in the soil. Selenium availability is higher in alkaline soils where the selenates predominate than in neutral-to-slightly acid soils. Liming generally results in slow release of selenites from their iron complexes and permits their oxidation to the water soluble selenate (Beeson and Matrone, 1976). The identification and mapping of selenium deficient areas and areas with excessive levels of selenium has been made on the basis of the selenium concentration of crops grown on those soils (Kubota and Allaway, 1972). Most of the samples for this survey were alfalfa plants. Areas where more than 80% of the plant samples contained less than 0.05 ppm selenium are considered low in selenium. When more than 80% of the samples contained more than 0.1 ppm selenium, the area is considered adequate in selenium. The state of Michigan has been identified as a selenium deficient area (Kubota and Allaway, 1972).

In the same soil, some plants can absorb and accumulate more selenium than others. Even in seleniferous soils, clover and some grasses do not accumulate selenium to levels toxic to the animals. Cereals, some asters, and sunflower absorb moderate quantities of selenium. Plants that absorb and accumulate selenium readily include some species of Astragalus, and sulfur accumulating plants such as the Cruciferae (Beeson and Matrone, 1976). The presence of selenium-accumulator plants containing more than 50 ppm selenium has helped to identify areas where selenium toxicity is a problem (Kubota and Allaway, 1972).

Fertilization of soil with selenium is not practiced in the United States, mainly because the reactions of selenium in soils are not well understood (Mortvedt and Cunningham, 1971). When the forages are deficient in selenium, animals can be fed a variety of selenium supplements, or given selenium injections that sometimes also contain vitamin E (Marczewski et al., 1982).

Cobalt

Cobalt has not been demonstrated to be an essential element for plant growth, but the legume root nodule bacteria system requires cobalt for the fixation of atmospheric nitrogen. The available cobalt requirements of this system cobalt are very low. Field cases of cobalt deficiencies affecting legume growth have been reported in Australia but not in the United States (Kubota and Allaway, 1972). Areas are considered cobalt deficient when the element concentration in pastures is too low to meet the requirements of ruminants. The cobalt requirement of dairy cattle is about 0.10 ppm in the feed (NRC, 1978).

A survey made in the United States by the US Plant, Soil and Nutrition Laboratory (Kubota and Allaway, 1972) of legumes shows that the northern part of the state of Michigan had samples containing from 0.05 to 0.10 ppm of cobalt. The authors state that grasses generally contain less than 0.10 ppm of cobalt throughout the United States. Among several factors that decrease cobalt availability from the soil, the most important are the class of clay in the soil and soil pH. Some clays like muscovite adsorb cobalt more strongly the others like bentonite. Raising the soil pH from 5.4 to 6.4 decreases the availability of cobalt by half (Tisdale and Nelson, 1975).

Cobalt is not usually added to fertilizers. In cobalt deficient areas, cobalt is supplied directly to the ruminants in the feed (Tisdale and Nelson, 1975).

Molybdenum

Molybdenum is one of the most recently recognized essential plant nutrient elements (Robertson et al., 1981). Molybdenum functions largely in the enzyme systems of nitrogen fixation and nitrate reduction. Plants which can neither fix nitrogen nor incorporate nitrate into their metabolic system because of inadequate molybdenum become nitrogen deficient (Vitosh et al., 1981).

Molybdenum deficiencies in the United States occur mostly on the acid sandy soils of the Atlantic and Gulf Coasts, although responses to fertilization with this element have also been reported in California and the Pacific Northwest, Nebraska, and the states bordering the Great Lakes (Tisdale and Nelson, 1976). Using legumes as an indicator plant, a map of molybdenum concentration in the United States has been prepared by Kubota (1976). In general, the south-western states had samples with a molybdenum content of 6-8 ppm, the north-western and central states 1.5-3.2 ppm, and the eastern states 0.3-1.0 ppm. Most of the samples collected in Michigan had about 0.4 ppm of molybdenum, except the south-eastern part of the state surrounding the lakes: the shores of the Saginaw Bay, Lake Huron, Lake St. Clair, and Lake Erie. In this area the median molybdenum concentration in legumes was 1.9 ppm. Molybdenum deficiency has been reported for onions, cabbage, clover, alfalfa, spinach, lettuce and cauliflowers grown in Michigan (Berger, 1962).

From the total molybdenum concentration in soils, only a fraction is available to the plant. The availability of molybdenum increases linearly with increasing soil pH values. Heavy applications of phosphatic fertilizers will increase the molybdenum uptake of plants. Heavy applications of sulfates, on the other hand, have a depressing effect on a plant's uptake. On soils with borderline molybdenum deficiencies, the application of excessive amounts of sulfate-containing fertilizers may induce a molybdenum deficiency in plants. Under such conditions the inclusion of molybdenum in the fertilizer may be advisable

(Tisdale and Nelson, 1976).

Alfalfa and clover are medium responsive to molybdenum fertilization, while grasses and corn are low responsive (Robertson et al., 1981). In clover, molybdenum deficiency shows up as a general yellow to greenish-yellow foliage color, stunting and lack of vigor. The symptoms are similar to those caused by nitrogen starvation (Vitosh et al., 1981). Deficiency symptoms should be confirmed with plant tissue analysis to compare with the sufficiency ranges shown in table I.2 (Appendix I).

When molybdenum deficiencies are suspected, liming to a convenient soil pH for the crop in consideration may increase the availability of molybdenum. When this is not enough, there are several compounds that can be applied as a fertilizer to the soil, used as foliar sprays or for seed treatment. The most commonly used carriers of molybdenum are ammonium molybdate, molybdenum trioxide, molybdenum frit and sodium molybdate (Robertson et al., 1981b). It has been demonstrated in Australia, New Zealand, and elsewhere that the application of molybdenum to clovers will in some cases produce yield increases equivalent to those obtained from the use of several tons of limestone. Seed treatment is now probably the most common way of correcting molybdenum deficiencies in the United States and elsewhere. The seed must be soaked in a solution containing the molybdenum salt (Tisdale and Nelson, 1976). Suppliers of molybdenum for seed treatment often sell the product in two-ounce (56 g) packages which will treat enough seed for four acres (1.6 hectares). For one acre (0.40 hectares), 1/2 ounce of the compound should be dissolved in three tablespoons of water and mixed with sufficient seed to plant the acre. Using excess water can cause the chemical to penetrate and injure the seed embryo. The seed-molydenum mixture should be mixed thoroughly and let dry. It is advisable to use a suitable fungicide dust to help dry the seed (Vitosh et al., 1981).

Zinc

Zinc is essential for plant growth because it controls the synthesis of indolacetic acid, which dramatically regulates plant growth. Zinc is also active in many enzymatic reactions and is necessary for chlorophyll synthesis and carbohydrate formation (Vitosh et al., 1981).

Zinc is most likely to be deficient for plants growing on soils with calcareous surface horizons or on leached, acid, sandy soils. Zinc deficiency may also be prevalent where the soil is high in available phosphorus. Interactions involving zinc, phosphorus and iron result in poor utilization of zinc by plants (Kubota and Allaway, 1972). The availability of zinc is closely related to the pH level of the soil. In general, the higher the pH in Michigan soils the greater the opportunity for a deficiency. Nevertheless, some crops grown in acid soils have also responded to zinc fertilization in Michigan (Robertson and Lucas, 1981). Zinc deficiency in Michigan has been reported in onions, potatoes, carrots, celery, corn, spinach, lettuce and soybeans (Berger, 1962).

Corn is highly responsive to zinc fertilization, while alfalfa, clover and grasses are low responsive (Robertson and

Lucas, 1981). Zinc deficiency symptoms appear first on the younger leaves, starting with an interveinal chlorosis followed by a great reduction in the rate of shoot growth. In many plants this produces a symptom known as "rosetting". In corn and sorghum the symptom has been called "white bud" (Tisdale and Nelson, 1976). In corn, the deficiency appears as a yellow striping of the leaves. Areas of the leaf near the stalk may develop a general white-to-yellow discoloration. In severe deficiencies, the plants have shortened internodes and the lower leaves show a red streak about one-third of the way from the leaf margin. Plants growing in dark sandy or organic soils usually show brown or purple nodal tissues when the stalk is split. This is particularly noticeable in the lower nodes (Vitosh et al., 1981).

Zinc sulfate is the most commonly used source of zinc for fertilizers, but oxides, chlorides, sulfides and carbonates of zinc are also used. Organic compounds such as zinc chelates (zinc EDTA and zinc NTA) are about five times more effective than equivalent amounts of zinc found in organic salts (Vitosh et al., 1981). Zinc can be applied to the soils at the rates shown in table I.9 (Appendix I). On highly responsive crops such as corn, 28 kg/hectare (25 lb/acre) of zinc showed good availability for seven years. Also, after several years of band fertilization where a total of 28 kg/hectare (25 lb/acre) of zinc was used, rates can be greatly reduced and in some instances, even eliminated (Robertson and Lucas, 1981b).

Copper

Copper is essential for plant growth and activation of many enzymes. A copper deficiency interferes with protein synthesis and causes a buildup of soluble nitrogen compounds (Vitosh et al., 1981).

Mineral soils are considered low in copper when the total content is less than 6 ppm, while organic soils are considered low in copper when they have less than 30 ppm of total copper (Lucas and Knezek, 1972). Most copper deficient areas are associated with a high organic matter content of the soil, but copper deficiency has also been found in mineral soils in some countries. Availability of copper to plants is dependent on several factors: amount of organic matter in the soil, pH, and the presence of metallic ions such as iron, manganese, or aluminum. As a general rule, the higher the organic matter content of the soil, the less copper is available from the total copper soil content. In some cases copper is retained so tightly in the organic matter that it is not plant available; in other cases, plants are able to absorb copper from the organic complexes (Tisdale and Nelson, 1976). The solubility of copper minerals decreases as the pH of the soil increases (Lindsay, 1972). The absolute level of a micronutrient in the rooting medium of the soil may not be the most important factor in its relation to plant growth. More important may be the amounts of the elements in relation to each other (Tisdale and Nelson, 1976). In the case of copper, aluminum ions interfere with copper absorption by plants (Moore, 1972). High levels of nitrogen, phosphorus and zinc in the soil can accentuate copper deficiency in plants (Lucas and Knezec, 1972).

Alfalfa is highly responsive to copper fertilization, corn, clover and sorghum are medium responsive, and grasses are low responsive (Robertson et al., 1981). In the United States, copper deficiency is not the most common micronutrient problem in soils. In the state of Michigan, deficiencies of copper have been reported for onions, spinach, lettuce, wheat, oats, and carrots (Berger, 1962).

Typical visual symptoms of copper deficiency in most crops are rosetting of terminal leaves, terminal die-back, and discoloration of leaves and fruits (Mortvedt and Cunningham, 1971). In many plants, copper deficiency shows up as wilting or lack of turgor and development of a bluish-green shade before leaf tips become chlorotic and die. In grain, the leaves are yellowish in color and the leaf tips show a disorder similar to frost damage (Vitosh et al., 1981).

When a deficiency is suspected, the Michigan State University Extension Service (Robertson et al., 1981) recommends copper fertilization for highly responsive crops grown on organic soils. Where the soil test is low, below 9 ppm, 6.7 kg/hectare (6 lb/acre) of copper are recommended as part of a banded fertilizer. On virgin organic soils or where copper has never been used on organic soil, the recommended rate should be doubled. Because copper is easily fixed and is not easily leached, fertilizer copper tends to accumulate in the soil. For this reason, no extra fertilizer copper is needed on organic soil after a total of 22.4 kg/hectare (20 lb/acre) for low responsive crops and 44.8 kg/hectare for highly responsive crops has been applied, or the soil test level exceeds 20 ppm copper (Robertson et al., 1981).

Soil Analysis

Knowledge of the fertility level of the soil is essential for optimum production of crops. Elemental analysis of soil helps to diagnose nutrient deficiencies or toxicities for the plant. In addition, based on soil analysis, the scientist can make recommendations on the amounts of fertilizer needed for maximum yields of a crop, suggest soil management practices and predict responses to different levels of fertilization. Soil test services are offered to the farmer almost everywhere in the world, either by government owned or private laboratories.

Sampling- A good representative sampling is the basis for a good soil test. A poor sample is worse than none at all, because it will produce misleading values that will lead to wrong recommendations.

For general rotation crops, soil tests should be done at least once every three years. Where large amounts of fertilizer are used, samples should be taken every year. Taking sample soils from the entire farm is a good practice. This can be done best in the off season. Knowing the soil test results and the recommended fertilizer materials required for all fields on the farm will make the use of both fertilizer and lime more efficient, particularly when the fertilizer contains micronutrients (Shicluna, 1983).

Soil characteristics in a farm are usually greatly varied. A sample should be taken in every area that is from 2 to 10 hectares (5 to 10 acres) in size. Areas that vary in appearance (color of the soil, for example), slope drainage, soil types, or past treatment should be sampled separately. Small areas that cannot be treated separately by lime and fertilizer applications might well be omitted from the sample. Fifteen to twenty different locations in a field should be sampled with a soil tube at the plow depth of 15 to 20 cm (6 to 9 inches) in order to make a composite sample. As a larger amount of fertilizer is applied in the row, careful attention must be given to sampling between visible rows (Tisdale and Nelson, 1976).

Sample preparation- Once the sample has arrived at the laboratory, it should be dried, ground and sieved. Moist soil samples can be dried by placing the open sample container in a drying rack or cabinet. If a large volume of moist samples are received, artificial drying is advised. Special drying cabinets equipped with exhaust fans expedite air movement and moisture loss. If heat is necessary, the temperature of the cabinet should not exceed 36^{o} C. Samples should be crushed until a major portion of the sample will pass a 10-mesh (U.S. No. 10, 2 mm sieve opening) sieve (Eik et al., 1980).

Extraction- Different extraction procedures are used in different laboratories. In the same laboratory, different extracting solutions are employed for each mineral or group of minerals. The proportion of soil sample weight or volume to extracting solution volume and the time of shaking or stirring also differs different minerals or group of minerals (Grava, 1980).

The choice of extracting solution and method of extraction is critical for the interpretation of the results. The choice depends on the class and type of soil, and, most importantly, of the correlation of laboratory analysis with the crop response in the field. Bray (1948) proposed that a good soil test should meet the following three criteria:

1) the extractant should extract all or a proportionate part of the available form or forms of a nutrient from soils with variable properties;

2) the amount of nutrient extracted should be measured with reasonable accuracy and speed; and

3) the amount of nutrient extracted should be correlated with the growth and response of each crop to that nutrient under various conditions.

There are no universal methods for extraction for all types of soils, and different procedures should be followed in different geographical areas. In the introduction of the Recommended Chemical Soil Test Procedures for the North Central Region of the United States, Dahnke (1980) states: "A word of caution to readers of this bulletin: A soil test is only as successful and usable for a region as the degree to which it is correlated and calibrated for the soils and crops of the area. The procedures described in this bulletin are especially suited to our region. Do not assume that they will work in your area without doing the necessary research."

There are several chemical methods of analysis that can be used for each mineral after the extraction procedure, and all should produce the same results within reasonable limits. The choice depends on factors such as cost, time, ease of operation, and safety. Some of the techniques now employed for elemental analysis are ultraviolet and visible spectroscopy (Cheng and Pratter, 1979), spectrofluorimetry (Schenk, 1979), atomic absorption and emission spectophotometry (Christian, 1979), plasma emission spectrophotometry, inductively coupled plasma discharge (Barnes, 1979), and neutron activation analysis (Ehmann and Janghorbani, 1979).

Mineral Status of Plants and Animal Requirements

Soil-Plant and Plant-Animal Relationships

Plants obtain most of their nutrients from the soil. The availability of elements in the soil solution is one of the main factors that determine the presence and concentration of minerals in plant tissue.

The addition of a plant nutrient to the soil may or may not change the concentration of this nutrient in the tissues of the plants that grow on that soil. The concentration of a nutrient element in a plant often tends to rise along a sigmoid curve as the available supply of that element in the soil is increased from a very low level to superabundance. Thus, when the first increments of a nutrient element are added to a deficient soil, crop growth may be increased without an appreciable increase in the concentration of this element in plant tissues. With further additions of this element to the soil, both crop growth and the tissue concentration of the element increase. With still further additions of the element, its concentration reaches a "critical value", or the concentration in the plant tissue required for optimum growth of the plant. This critical level varies due to different species and varieties, and may also vary among different temperature, moisture, and light conditions, as well as with different levels of supply of other nutrients. Additions of the element to the soil above those necessary to provide the critical value of tissue concentrations of this element cause only minor increases or even decreases in crop growth, but they may lead to further increases in the concentration of the element in the crop. The effect of addition of a nutrient fertilizer upon the concentration of this nutrient in the fertilized crop may, therefore, range from no increase in the nutrient in the plant, even though pronounced increases in crop yield are obtained, to increases in the concentration of the nutrient in the crop without any increase in crop yield (Allaway, 1971).

Some elements such as boron are essential for plants but not for animals. Some others such as selenium are essential for animals but not for plants. Furthermore, a healthy crop in which all the nutrient requirements have been met may not be sufficient in terms of mineral composition for the growth of animals. In other cases, plants can accumulate certain elements such as selenium or molybdenum that are not harmful for their growth, but that can be toxic to the animals. In other words, plants have different requirements than animals for minerals.

Nitrogen

Nitrogen content of plants in relation to soil status and fertilization- Application of nitrogen fertilizers to a nitrogen deficient soil frequently results in an increase in the concentration of total protein in the crop produced, and since the fertilized crop usually produces a higher yield, the total protein produced per hectare may be substantially increased (Allaway, 1971). Under the same environmental conditions, the limit for protein concentration in a crop is the genetics of the plant. In general legumes contain higher protein concentrations than grasses or cereals. The protein composition, in terms of amino acids, in the plant is also genetically controlled, and it is unlikely it will be changed by fertilization. The effects of nitrogen fertilization on protein concentration and quality in plants can be summarized as follows (Thompson et al., 1960),

1) The amount of protein produced per hectare of land will be significantly increased by use of nitrogen fertilizers on nitrogen deficient soils.

2) The concentration of protein will be increased somewhat under this condition, but nitrogen fertilization will not bring the protein level of low-protein crops such as rice to the level found in wheat or legumes.

3) The nutritional quality of the protein is generally unaffected by nitrogen fertilization.

Protein quality in terms of amino acid composition is not of primary importance for ruminants, since the microorganisms in the rumen are capable of synthesizing the amino acids required by the animal.

Normally, 75% or more of the nitrogen in the plant is in the form of protein. However, anything that interferes with the protein synthesis process, such as a shortage of energy within the plant, may cause an accumulation of nonprotein nitrogen compounds. The compounds that accumulate under conditions of slowed protein synthesis include nitrates, free amino acids, and amides (Allaway, 1971).

<u>Nitrates in forages</u>- Heavy application of nitrogen fertilizer or manure and severe drought or other factors which reduce plant metabolism will tend to cause some accumulation of nitrates. Under normal conditions, forages and pastures do not

contain over 0.5% nitrates. Occasionally plants will contain as much as 5% nitrates on a dry basis. Pigweed (Amaranthus sp.), lambsquarter (Chenopodium sp.), ragweed (Ambrosia sp.) and other weeds may accumulate very high levels of nitrate but generally comprise a small percent of the diet. Nitrates are normally reduced successfully to nitrites, to nitrous oxide and then to ammonia in the rumen. Numerous studies indicate that cattle can safely consume nitrates equivalent to no more than 2% of the total dry matter of the ration, or approximately 44 g of nitrate per 100 kg of body weight. If the nitrate content is sufficiently high, and conversion to ammonia is slow, then a major part of the nitrate is reduced to nitrite, and some of the nitrate and nitrite may enter the blood stream. Nitrate is excreted in the urine but nitrite may displace the oxygen from some of the hemoglobin of the blood resulting in methemoglobinemia. Animals can tolerate some methemoglobin in their blood without harm, and they possess an enzyme, methemoglobin reductase, for converting methemoglobin back to hemoglobin. Methemoglobin levels normally must approach 60 to 90% of the hemoglobin to be lethal. Cattle fed high levels of nitrates over a long period of time tend to adapt to the lower oxygen-carrying capacity of the blood by increasing the concentration of erythrocytes in the blood. Toxic levels of nitrates (over 2% of the diet) may result in peak levels of methemoglobin about four hours after feeding. Labored breathing, frothing at the mouth, and a brownish to bluish-grey color of the non-pigmented skin and mucous membranes are symptoms of nitrate toxicity. Pregnant cows may abort when the oxygen-carrying capacity of the blood is seriously reduced (Hillman, et al., 1983).

Nitrogen solubility in plants- Part of the protein in the feed is readily soluble. Highly soluble protein is quickly attacked in the rumen by bacterial enzymes and degraded to simpler compounds and to ammonia. When this released ammonia exceeds the capacity of rumen bacteria to use it to make protein there is an immediate loss of part of the dietary nitrogen via excretion in the urine. Direct cut grass silages and high-moisture corn and sorghum silages often contain more than 60% of water-soluble protein, and this is not utilized very efficiently by ruminants on all-silage diets. Some concentrate feeds have a high percentage of soluble crude protein, which makes them less suitable for feeding with silages than other concentrates; e.g., most by-product feeds have more soluble protein than corn grain. On the other hand, the solubility of protein in corn or other grains that have been fermented in moist storage is increased (NRC, 1978).

Nitrogen requirements of dairy cattle- A major component of animal tissues and organs is protein. All cells in the animal synthesize protein for part or all of their life cycle and without protein synthesis life could not exist. Protein turnover is rapid in the cells, especially for those in epithelial tissue such as in the intestinal tract. Consequently, providing replacement protein from the diet is essential to meet these turnover requirements in addition to providing for growth and other productive functions. The percent of protein required in the diet is highest for young growing animals. It declines gradually until maturity when only enough protein to maintain body tissues is required. Productive functions such as pregnancy and lactation increase the requirements because of increased output of protein in products of conception and in milk and because of an increased metabolic rate associated with the productive function (Church and Pond, 1974).

In the lactating cow, protein is excreted in milk. The protein concentration of milk from Holstein cows is around 3.22% (Cerbulis and Farrell, 1975). A cow producing 30 kg of milk secretes 0.97 kg of protein a day. That cow's diet must replace that protein, as well as replace the protein lost in feces, urine, hair, etc. and also provide the protein required for maintenance. The NRC (1978) reported the protein requirement for a 600 kg (1300 lb) cow producing 30 kg (66 lb) of milk with 3.5% fat content per day at around 2.95 kg protein per day. If this cow eats 20 kg (45 lb) of dry matter a day, the ration needs to be 14.75% protein to meet her requirements.

Nitrogen content of forages- Forages have variable concentrations of protein. In a given grass, the degree of maturity is the main factor affecting protein content. Orchard grass (*Dactylis glomerata*) for example (Ely et al., 1953), had 24.8% protein when cut early in the season, and 12.4% when cut at a late stage of maturity. First cut, sun cured alfalfa hay in its early vegetative state has around 24% protein. This protein content decreases to 16% when alfalfa is cut at mid-bloom, and to

13% when it is cut when mature (NRC, 1978). Corn silage does not change much in composition with maturity except dry matter content. Silage made from corn cut at a soft dough stage had 7.4% protein, 7.4% when cut at a medium-hard dough stage, and 7.3% when cut at at an early dent stage of maturity (Colovos et al., 1970). In Michigan, data from 1975-1976 show that corn silages had an average of 8.3% protein. Silage made from corn cut early in the season had 12% protein and 21% dry matter, while silage made from corn cut late in the season after the first frosts in November had 8.7 protein and 49.2% dry matter (Hillman and Fox, 1977).

Nitrogen deficiency in ruminants- While for nonruminants the amino acid composition of the protein is very important, for ruminants bacterial synthesis provides the essential amino acids that are deficient in the ration. Ruminants are likely to suffer first from insufficient amount of protein in the diet rather than suffering from insufficient quantity or imbalance of amino acids, or low-quality protein, as non-ruminants do. In general, protein deficiency in ruminants has the same effect as it does in non-ruminants. Protein deprivation symptoms are non-specific, resembling those seen in partial or total starvation. The growth of the protein depleted animal may be greatly slowed. Profound alterations in the skeletal tissues may be encountered. Depending on the severity of the deficiency state, varying degrees of retardation of epiphyseal or costal cartilage cell proliferation will be found. Cartilage is a critical index of the nutritive status of the organism (Follis, 1958). Cattle fed protein deficient diets will show slow growth, reduced feed intake and decreased protein content in the organs and skeletal muscle. Low albumin and urea in the blood indicate protein deficient diets. Milk production is decreased in protein deficient cows. Growth of the fetus is impaired and body condition is depressed in cows fed protein deficient diets for an extended period. In addition, protein deficient animals have low immune and transport proteins in their blood and reduced hormone secretions that may predispose them to infectious and metabolic diseases (NRC, 1978).

Cattle on pasture are not likely to suffer from severe protein deficiency. During a dry period when the pastures are old and scarce, however the protein level of pasture grass may be too low to sustain a good growth or milk production. Ryegrass (Lolium multiflorum), for example, can have a protein concentration as low as 4.0% dry basis (Crampton and Harris, 1969). Mixed pastures of legumes and grasses usually have protein concentrations higher than 10%. Corn silage, with an average of 8.3% protein, is not enough to meet the protein requirements of high producing dairy cows, which need a ration of about 15% protein during the first part of the lactation. Rations containing 14% protein are needed by 100 kg (220 lb) calves. The protein requirement decreases for 300 kg calves, which need rations with 11% protein (NRC, 1978). Good to medium quality alfalfa, 15 to 20% protein, may satisfy the protein requirements of most animals.

Calcium

Calcium content in plants in relation to soil status and fertilization- Calcium is always present in green plants. Usually the legumes contain more calcium than do grasses. Grain crops are generally lower in calcium than are forage crops, and is often necessary to add a calcium supplement to the diets of cattle that are being fed rations high in grain and low in forage. The calcium content of any one plant species does not change very much when calcium is added to the soil. Therefore, the level of calcium in the soil has few direct effects on the nutritional quality of plants. But the addition of calcium, in the form of limestone, to an acid soil frequently makes it easier to grow leguminous plants, like alfalfa, which are often high in protein and essential minerals (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965).

Calcium content in forages- Typical calcium concentrations in grasses range from 0.4 to 0.8%, but it can be lower than 0.3% and higher than 1.0 %. Alfalfa calcium concentrations are usually between 1.2 and 2.3%, but some samples can be higher than 2.5% or lower than 0.60% (Church and Pond, 1974). In Michigan in 1975-1976, corn silage had an average calcium content of 0.28% (Hillman and Fox, 1977). Ear corn samples analyzed in Penn State from 1969 to 1973 had an average of 0.05% calcium and shelled corn samples 0.03% (Adams, 1975). Soybean meal has a calcium concentration of around 0.36% (NRC, 1978).

Calcium content in forages remains quite constant with the stage of maturity or with the season of the year. In the

Southern Plains region of the United States, calcium content of perennial grasses ranged from 0.33% in January and August to 0.43% in April (Beeson and Matrone, 1976).

Calcium requirements of dairy cattle- A 600 kg (1300 lb) cow producing 30 kg (66 lb) of milk with 3.5% fat content per day requires about 100 g of calcium, or 0.5% of the diet when eating 20 kg (44 lb) of dry matter, daily. A 200 kg (440 lb) Holstein heifer needs about 21 g calcium, or 0.40% of the diet when eating 5.2 kg of dry matter, per day (NRC, 1978). Animals consuming legumes or mixed pastures are not likely to suffer from calcium deficiency. However, if the diet consist mainly of grasses, corn silage and grain, supplementary calcium may be needed to meet the requirements.

Calcium requirements are calculated in relation to phosphorus requirements for dairy cattle. The ratio of calcium to phosphorus in bone is about 2:1 in older animals and somewhat lower in young animals. In milk the ratio is approximately 1.3:1.0. Except for prepartum rations, a high ratio of calcium to phosphorus is far less critical for ruminants than it is for laboratory animals. However, a calcium to phosphorus ratio below 1:1 can reduce performance. Growth rate and feed utilization of calves have been satisfactory with calcium to phosphorus ratios ranging from 1:1 to 7:1 (NRC, 1978). For lactating cows, calcium to phosphorus ratios of 1:1, 1:4, and 8:1 produced no change in milk production (Smith et al., 1966). In long term experiments with pregnant heifers better absorption of both elements occurred with a 2:1 calcium to phosphorus ratio (Manston, 1967).

Calcium deficiency in ruminants- Adequate calcium and phosphorus nutrition is dependent upon three factors: a sufficient supply of each element, a suitable ratio between them, and the presence of vitamin D (Maynard and Loosli, 1969). The most obvious symptoms of severe calcium deficiency are rickets and osteomalacia. Rickets is a disease of the growing skeleton which is characterized by a decreasing concentration of hydroxyapatite in the organic matrices of cartilage and bone. Osteomalacia is rickets in the adult and, since cartilage growth has ceased, is a skeletal disease in adults which is characterized by a decreased content of hydroxyapatite in bone matrix (Follis, 1958). In young calves, a calcium-deficient diet prevents normal bone growth and retards general growth and development. The bones of affected calves are low in calcium and phosphorus and fracture spontaneously. In mature cows, the feeding of rations low in calcium over a long period of time may cause a depletion of calcium and phosphorus in the bones, resulting in fragile, easily fractured bones and reduced milk yield (NRC, 1978). With an adequate phosphorus intake (80 to 100 g/day), dairy cows fed 200 g calcium/day and vitamin D (300000 IU/day) showed better reproductive performance than cows receiving 100 g calcium/day. The variables measured in this experiment were completion of uterine involution, days to first ovulation, and days to first post-partum estrus (Ward, 1971).

Milk fever- Dry cows fed excessive amounts of calcium are likely to develop milk fever (parturient paresis) at calving. This metabolic disorder is caused by a disturbance in calcium metabolism manifested by a marked drop in blood serum calcium at parturition or soon thereafter (NRC, 1978).

Several preventive procedures to avoid parturient paresis have been tried. The first and most important practice to follow is to provide the dry cow with a diet well balanced in energy, protein and vitamins. Abrupt ration changes and excessive weight increases should be avoided. If corn silage that is relatively high in energy is the main ingredient of the diet, it should not be provided ad libitum to the cows, to prevent from becoming excessively fat. Adequate fiber to maintain rumen motility should be provided (Olson, 1979).

Calcium sources- There are several products that can be used as sources of calcium for dairy cattle. Limestone (calcium carbonate) has around 38% calcium, bone meals from 20 to 30%, oyster shell flour around 36%, monocalcium phosphate 16%, and dicalcium phosphate 22% (Hillman et al., 1983). Cement kiln dust consisting of around 27% calcium, can also be used as a calcium source for animals rations (Jordan et al., 1980).

Limestone has been proposed as a buffering, or more acurately as an alkalinizing, agent for ruminants in order to improve the efficiency of digestion and production (Wheeler and Noller, 1976; Wheeler, 1980a and b; Wheeler et al., 1981b, c and d; Bass, 1982). Cement kiln dusts have been used for the same purpose (Wheeler, 1979; Wheeler and Oltjen, 1979; Ward et al., 1979; Noller et al., 1980; Bush et al., 1981; Wheeler, 1981; Wheeler et al., 1981a).

Phosphorus

Phosphorus content of plants in relation to soil status and fertilization- Phosphorus is of critical importance to many of the life processes of both plants and animals. When the soil is deficient in phosphorus, certain plant species may contain too little of this element to meet the requirement of the animal that eats the plant (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965). In general, low concentrations of available phosphorus in the soil result in plants with insufficient amounts of the element to meet the requirements of animals. The successful use of phosphorus fertilization to correct phosphorus deficiency in grazing animals is dependent upon the soil and the plant species involved. On some soils, addition of phosphorus fertilizers will not bring about increases in the phosphorus concentrations in the plant grown, even though substantial increases in yield may be noted. Where mixed pastures containing both grasses and legumes are fertilized, the increase in percent of legumes in the mixture resulting from phosphorus fertilization may have important effects on the animals grazing the pasture, independent of the effect on the phosphorus concentration in the pasture plants. In general, decisions concerning use of phosphorus fertilizers are based upon the expected response in crop production. Where little or no response in plant growth can be expected, phosphorus should be supplemented directly to the animals' diets to meet their requirements (Allaway, 1972).

Phosphorus concentration in forages- Typical phosphorus concentration in grasses is 0.2 to 0.3%, but it can be lower than

0.2% and higher than 0.4%. In alfalfa, phosphorus concentrations are similar to those in grasses, usually 0.2 to 0.3%, and they can be lower than 0.15% and higher than 0.7% (Church and Pond, 1974). Corn silage samples in Michigan in 1975-1976 had an average 0.29% phosphorus content dry basis (Hillman and Fox, 1977). Ear corn in Pennsylvania, from 1969 to 1973, had an average of 0.28% phosphorus, and shelled corn 0.31% (Adams, 1975). Soybean oil meal has a phosphorus content of about 0.75% (NRC, 1978).

Phosphorus content in plants is related to the plants' maturity and to the season of the year. Grasses from the Southern Plains region of the United States had an average phosphorus content of 0.34% in April, when the plants were young and rainfall was 72 mm (2.83 in), and 0.10% in February when the rainfall was 26 mm (1.03 in) and the pastures were dry and dormant due to the winter (Beeson and Matrone, 1976).

Phosphorus requirements of dairy cattle- A 600 kg (1300 lb) cow, producing 30 kg (66 lb) of milk with 3.5% fat content a day, requires around 70 g of phosphorus daily. If the dry matter intake of this cow is 20 kg (44 lb), the ration should be 0.35% phosphorus. A 200 kg (440 lb) heifer eating 5.2 kg of dry matter a day requires 14 g of phosphorus or about 0.27% of the ration (NRC, 1978). Phosphorus requirements of lactating dairy cows are not usually met by forages or grains alone, so these animals generally require extra supplementation of the element.

Phosphorus deficiency in ruminants- Symptoms of phosphorus deficiency in ruminants are non-specific, except perhaps for osteophagia (craving for bones) and subnormal blood serum concentrations. Once the serum phosphorus values have declined in animals fed phosphorus deficient diets, a decline in appetite and feed efficiency is observed. Animals start showing signs of depraved appetite, or pica, craving abnormal materials such as bones, wood, and soil. This symptom, however, is not specific to phosphorus deficiency, since it has been observed in animals suffering from lack of sodium and potassium, and sometimes when protein or energy are deficient in the diet (Underwood, 1981). With phosphorus deficiency, the mineral content of the bones is low and they become fragile. Appetite declines, growth rate is retarded, and feed utilization efficiency is reduced. In chronic phosphorus deficiency, the animal sometimes becomes stiff in the joints (NRC, 1978).

One of the most important effects of phosphorus deficiency is on reproduction. Fertility problems were observed in a dairy herd when the heifers were fed a diet insufficient in phosphorus. The diet consisted of alfalfa, corn silage and legume-grass pasture. It was estimated that the animals were eating from 70 to 80% of their phosphorus requirement. When the animals were offered free choice dicalcium phosphate, reproductive parameters in the herd improved. Services per conception decreased from 2.8 to 1.3, the 30 day conception rate increased from 33 to 73%, and the 60 to 90 day conception rate increased from 36 to 76%. Their average blood serum concentration of phosphorus increased from 3.9 mg/100 ml before supplementation to 6.0 mg/100 ml when dicalcium phosphate was available at all times (Morrow, 1969).

In Australia (Scharp, 1979), addition of defluorinated superphosphate to the drinking water of an infertile herd increased the first service pregnancy rate from 36.5 to 63.2%, the mean calving to conception interval decreased from 109 days to 85 days and the number of cows culled each year for infertility fell from 15 to 5. Other experiments have failed to improve fertility by phosphorus supplementation (Call et al., 1978; Carstairs et al., 1980; Carstairs et al., 1981; De Boer et al.,1981).

Sources of phosphorus- Among several sources of phosphorus for ruminants, the most commonly used are bone meals, monocalcium and dicalcium phosphates, defluorinated phosphate rock, defluorinated superphosphate, and monosodium and disodium phosphates (Hillman et al., 1983). All these sources have high phosphorus availability for ruminants.

The starting material for almost all chemically processed feed phosphates is phosphate rock. This material contains 13 to 14% phosphorus and 3 to 4% fluoride (Thompson, 1980). Fluoride is toxic to animals (Suttie and Kolstad, 1977; Hillman, 1979; Suttie, 1980; Ammerman, 1980; Shupe, 1980), causing dental and skeletal lesions and, in severe cases, adversely influences the productive performance of domestic animals. Because of this, the Association of American Feed Control Officials (AAFCO, 1979) set standards for safe levels of fluoride in feed phosphates. Since 1952, any product sold to the feed industry as "defluorinated phosphate" has to have a phosphorus to fluorine ratio of at least 100:1 (Thompson, 1980).

Potassium

Potassium content of plants in relation to soil status and fertilization- In relation to other nutrients, potassium is required in fairly large amounts by both plants and animals (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965). The level of potassium in the soil has a direct effect on the potassium concentration in crops. Potassium fertilization increases the potassium content of the plant, but has a greater effect on increasing the yield of the crop. When large amounts of nitrogen fertilizer are used to increase yields, large amounts of potassium are removed from the soil by the crop. When the soil is fertilized with nitrogen without proportional increases in potassium, the potassium content of forages tends to decrease. In general, heavy potassium fertilization decreases magnesium content in pastures (Bolton, 1978; Penny et al., 1980; Penny and Widdowson, 1980).

Potassium content in forages- There is a large variation of the potassium content in pastures, due to potassium fertilization and soil status. Grasses typically contain 1.2 to 2.8% potassium, with low values of less than 1.0% and high values of more than 3.0%. Potassium concentration in legumes usually ranges from 1.5 to 2.2%, with values found lower than 0.4% and higher than 3.0% (Church and Pond, 1974). Corn silage samples in Michigan in 1975-1976 averaged 1.04% potassium on dry matter basis (Hillman and Fox, 1977). Ear corn in Pennsylvania, from 1969 to 1973, had an average of 0.49% potassium, and shelled corn 0.42% (Adams, 1975). Soybean oil meal has a potassium content of about 2.21%. Brewers grains have a very low potassium content: about 0.09% of the dry matter (NRC, 1978). Young, very lush forages in highly fertilized soils (especially those treated with potassium) in cool weather may be extremely high in potassium, often about three percent of the dry matter. Potassium concentration decreases with advancing maturity of forages and can be reduced further by leaching of mature standing forages in humid areas (NRC, 1978).

Potassium requirements of dairy cattle- The potassium requirement for dairy cows is about 0.8% of the dry matter in the ration (Dennis et al., 1976; Erdman et al., 1980). Other authors recommend 0.8 to 1.0% for lactating dairy animals (Underwood, 1981). Apparently the requirements are similar for other dairy cattle (NRC, 1978).

Potassium deficiency and toxicity in ruminants- Symptoms of relatively severe potassium deficiencies (0.06 and 0.15% of the dry matter of the ration) in lactating cows include a marked decrease in feed intake, reduced weight gains, decreased milk production, pica, loss of hair glossiness, decreased pliability of hides, lower plasma and milk potassium, and higher hematocrit readings. With borderline potassium deficiency (0.45-0.55% of the dry matter of the ration), the most noticeable sign is lower feed consumption (NRC, 1978).

Excess potassium in the diet is detrimental for animals. Bull calves fed 6% potassium added to the diet had decreased feed intake and decreased weight gains. The maximum dietary potassium which produced no clinical effect was between 2.8 and 7%

(Neathery et al., 1980). High levels of potassium in the diet of ruminants decrease magnesium absorption which can result in magnesium tetany (Suttle and Field, 1969; Field, 1970a and b; Greene et al., 1983a, b, and c).

Potassium sources- The most commonly used source of potassium for ruminants is potassium chloride, but other potassium salts such as acetate, carbonate and bicarbonate can be used (Neathery et al., 1980). Potassium bicarbonate can also be used as a buffering agent to prevent low milk fat syndrome in lactating dairy cows (Emery and Brown, 1961; Stout et al., 1972), to prevent lactic acidosis in beef cattle (Horn, 1979), or to alleviate the effects of shipping on calves transported to feedlots (Hutchenson et al., 1984).

Sodium

Sodium content in plants in relation to soil status and fertilization- In sodium deficient soils, sodium fertilization increases crop yields and raises the sodium concentration of the plant. This effect is particularly clear when potassium is also deficient in the soil. Sodium content in rye grass was increased from 0.15 to 0.20%, as long as 7.5 years after the last sodium application (Bolton and Penny, 1978). It would be difficult, however, to add sodium to soils in amounts sufficient to raise the sodium content of forages enough to meet the sodium requirements of animals. This is because soils high in sodium are very poor soils for plant growth. An excess of sodium is responsible for the low fertility and undesirable physical properties of the "alkali soils" of dry regions (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965). Heavy potassium fertilization decreases the sodium concentration in plants (Underwood, 1981).

Sodium content in forages- Forages, and feeds in general, have low sodium contents. Sunflower (*Helianthus sp.*) meal is one of the few feeds with a relatively high sodium content (1.30%) (NRC, 1978). Legumes in Pennsylvania from 1969 to 1973 had an average sodium concentration of 0.024%, grasses 0.014%, corn silage 0.005%, ear corn 0.007%, and shelled corn 0.003% (Adams, 1975). Soybean oil meal has a sodium concentration of about 0.31% (NRC, 1978).

Sodium requirements of dairy cattle- The NRC (1978) estimate of the sodium requirement of lactating cows is 0.18% (0.46% sodium chloride) of the dry matter in the ration. For nonlactating dairy cattle the estimated sodium requirement is 0.10% (0.25% sodium chloride) of the dry matter in the ration (NRC, 1978).

Sodium deficiency and toxicity in ruminants- Sodium deficiency can greatly decrease the performance of cattle. The deficiency is characterized by a decline in sodium concentration in the saliva and urine and an increase in the potassium levels in these fluids (Loosli, 1978). When a diet severely deficient in sodium is fed to dairy cows an intense craving for salt and pica, manifested by licking and chewing various objects, can occur within two weeks. Other symptoms, which may not develop for several months (the lenght of time taken is related to level of milk production), include decreased or loss of appetite, unthrifty haggard appearance, lusterless eyes, rough hair coat, decreased milk production, and rapid loss of weight (or in growing animals, reduced gains). Terminal symptoms include shivering, incoordination, weakness, cardiac arrythmia, and death. With adequate salt supplementation cows recover quickly and completely (NRC, 1978).

Cattle are able to tolerate a relatively high level of salt in the diet, especially when water is readily available. In contrast, the salt content in water required to produce toxicity is much lower than the content required in feed. The amount of salt that can be tolerated by lactating dairy cows has not been clearly established. However, it is suggested that salt (sodium chloride) not exceed five percent of the total dry matter intake (NRC, 1978). Salt poisoning can occur when animals depend on saline water sources, or when a sudden change to saline water from fresh water has occurred. Excessive ingestion following a period of salt deprivation has resulted in deaths of cattle. Poisoning has occurred as a result of excessive salt in prepared feed. Central nervous system and digestive tract derangement are the features of acute salt poisoning in cattle (Sandals, 1978).

Sodium sources- The most common and cheapest source of sodium for ruminants is sodium chloride, but other salts such as sodium carbonate or sodium bicarbonate can also be used. Sodium bicarbonate is used as a buffering agent to prevent low milk fat syndrome in dairy cows (Emery and Brown, 1961; Emery et al., 1964). Sodium chloride can be included in the concentrate formula and/or fed to the animals ad libitum in a block of salt or in granular form in a mineral feeder. Cows consume more granular or loose salt than block salt, but the intakes of block salt are adequate to meet the needs of lactation (NRC, 1978). Trace minerals, such as iodine, zinc, manganese, iron, copper, cobalt, and sometimes selenium are usually added to the salt for dairy cattle or other types of animals. Voluntary salt consumption by cattle is variable, but lactating dairy cows have an average consumption of 45 g per day. Dry cows and heifers consume from 15 to 30 g of salt per day (Crampton and Harris, 1969). These figures should be taken in consideration when calcium and phosphorus sources are added to salt for ad libitum consumption by the animals.

Magnesium

Magnesium concentration in plants in relation to soil status and fertilization- Magnesium fertilization tends to increase the concentration of magnesium in forages. Yields of responsive crops also increase after magnesium fertilization to magnesium deficient soils (Bolton and Penny, 1978). On certain coarse-textured soils, the use of magnesium fertilizers or dolomitic limestone has been effective in increasing the magnesium concentration in the grass. This practice has been less successful on finer textured soils. Grasses tend to have low magnesium concentrations in periods of active growth, especially in the spring (Scott, 1972) and after heavy potassium fertilization (Allaway, 1971).

Magnesium content in forages- Legumes nearly always contain more magnesium than do grasses. Although the magnesium levels in plants can be increased moderately by adding magnesium to the soil, the magnesium level in grasses is still below that in most legumes, even when the grasses are grown on a soil high in available magnesium (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965). Magnesium content in grasses ranges from 0.12 to 0.26%, with values found lower than 0.1% and higher than 0.3%. In legumes the typical magnesium concentration ranges from 0.3 to 0.4%, with values found lower than 0.1% and higher than 0.6% (Church and Pond, 1974). Corn silage samples in Michigan had an average magnesium content of 0.24% during the years 1975 and 1976 (Hillman and Fox, 1977). In Pennsylvania during the years 1969 to 1973, ear corn had average 0.12% magnesium, and shelled corn also had 0.12% magnesium on a dry matter basis (Adams, 1975). Soybean oil meal has an average magnesium content of 0.30% (NRC, 1978).

Magnesium requirements of dairy cattle- The magnesium requirement of dairy calves on a diet of milk replacer and calf starter concentrate mix is 0.07% of the dry matter of the ration. Growing heifers and bulls, mature bulls and dry pregnant cows require 0.16% magnesium on a dry matter basis. The magnesium requirement of lactating dairy cows is 0.20% of the ration's dry matter. Under conditions conducive to grass tetany (i.e. most of the feed comes from lush, highly fertilized pastures in cool seasons) in high producing lactating cows, 0.25% or more dietary magnesium is suggested (NRC, 1978).

Magnesium deficiency and toxicity in ruminants- Animals fed magnesium deficient diets show a stiff gait and gradual loss of condition for several weeks, without loss of appetite or a decline in milk yield. This condition can be followed by recovery if some form of magnesium is provided, or by tetany and death. This condition is usually known as grass tetany or magnesium tetany (Underwood, 1981). Experiments show that mortality is often high, even when the animals are receiving diets that are only marginally deficient in magnesium and where growth of the survivors may approach that of the control animals. Plasma magnesium levels are depressed markedly by magnesium deficiency (Scott, 1972). Animals showing sumptoms of magnesium tetany should be given parenteral magnesium immediately. To prevent a recurrence of the condition, animals should be fed a diet higher in magnesium. Usually a follow-up treatment that consists of 60 g of magnesium oxide per day for at least a week, and then withdrawn gradually, is given to the animals that had grass tetany (Merck, 1979).

Magnesium toxicity is not known to be a practical problem in dairy cattle. Male Holstein calves started showing diarrhea with magnesium (as magnesium oxide) levels higher than 0.7% of the diet (Quilliam et al., 1980). In another experiment, Holstein bull calves had diarrhea but not reduced weight gains when fed a diet containing 1.0% magnesium as magnesium oxide. Levels of 2.0 and 4.0% magnesium produced diarrhea and reduced weight gains (Gentry et al., 1978).

Magnesium sources- The most commonly used source of magnesium for ruminants is magnesium oxide. Other sources include magnesium sulfate and magnesium carbonate. Magnesium in dolomite is poorly utilized (Thompson, 1978).

Magnesium oxide, at a level of approximately 0.5% of the diet, along with sodium or potassium bicarbonate, is used as an alkalinizing agent to prevent low milk fat syndrome in lactating dairy cows (Emery et al., 1965; Jesse et al., 1981).

Copper and Molybdenum

Copper and molybdenum content in plants in relation to soil status and fertilization- Copper and molybdenum concentration in plants is responsive to fertilization with these two elements. Plant species vary considerably in their uptake of copper. Mitchell et al. (1956), quoted by Hodgson et al. (1962), observed variations from 1.7 to 12.3 ppm of copper in clover, while grasses growing with the clover varied only from 2.0 to 4.3 ppm. In Australia and New Zealand the addition of copper fertilizer to soils has been effective in meeting the needs of both the plant and the grazing animal. On some copper deficient soils of the United States applications of copper fertilizers have increased plant growth without producing a marked change in the copper content of the plants, and animals grazing these plants may still suffer from copper deficiency (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965). Copper fertilization at a rate of 2 kg/hectare (about 1.8 lb/acre) resulted in increased concentration of copper in legumes, grasses and weeds in a permanent pasture near Aberdeen, England. The average copper concentration without fertilization was 4.84 ppm, and 5.69 ppm after copper fertilization (Forbes and Gelman, 1981).

Molybdenum content in legumes in the United States goes from an average of 6 ppm in the west to around 0.5 ppm in the East. The pattern roughly parallels soil changes from neutral to alkaline (often calcareous) soils in the western United States to predominantly acid soils in the east (Kubota, 1976). Molybdenum fertilizers are mostly used in acid soils that are low in molybdenum. In acid soils molybdenum fertilizer becomes rapidly unavailable to the plant, so there is little danger of high molybdenum content in forages fertilized with the element under these conditions. There are, however, some acid soils with high molybdenum concentrations. When these soils are limed, molybdenum becomes available for the plant. In these conditions, legumes in particular, can contain toxic amounts of molybdenum (Hodgson et al., 1962).

Copper and molybdenum content in forages- Copper content in grasses goes from around 4 to 8 ppm, with values found lower than 3 ppm and higher than 10 ppm. In alfalfa, typical copper concentrations are from 6 to 12 ppm, with values found lower than 4 ppm and higher than 15 ppm (Church and Pond, 1974). Corn silage in Michigan in 1975 and 1976 had an average copper content of 9 ppm (Hillman and Fox, 1977). Soybean oil meal has an average copper content of around 40 ppm (NRC, 1978). In Pennsylvania from 1969 to 1973, corn silage had an average copper content of 8.1 ppm. Values as low as 2.0 ppm of copper were also found. In the same state, ear corn had an average of 4.7 ppm copper, and shelled corn 3.6 ppm (Adams, 1975). In British Columbia, Canada, legume hay had 7.2 ppm copper on the average, grass hay 4.5 ppm, and corn silage 4.5 ppm (Miltmore et al., 1970). In Alberta, Canada, copper contents in forages were higher: 12 ppm in grass roughage, 11 ppm in legume roughage, and 12 ppm in grass legume roughage (Redshaw et al., 1978).

Molybdenum in grasses ranges from 0.5 to 3.0 ppm, with values found lower than 0.4 ppm and higher than 5.0 ppm. In alfalfa, molybdenum concentrations vary from 0.5 to 3.0 ppm, with values found lower than 0.2 ppm and higher than 5.0 ppm (Church and Pond, 1974). In some areas, especially when the soils are calcareous, pastures can have extremely high molybdenum concentrations, ranging from 20 to 100 ppm (Underwood, 1981).

Copper requirements of dairy cattle- Copper requirements are dependent on several factors, such as the molybdenum and sulfate intake of the animals and whether or not the animal is grazing. Grazing animals seem to have higher copper requirements than nongrazing animals (NRC, 1978). Under some conditions, 4 ppm of copper in the diet are enough to meet the requirements of dairy cattle, but 10 ppm or more are needed when the forages contain high concentrations of molybdenum or other interfering substances (NRC, 1978). Cattle grazing pastures with around 10 ppm copper and 1.6 ppm molybdenum showed symptoms of hypocupremia (Givens and Hopkins, 1978). Supplementation of copper, through copper injections, to grazing Holstein heifers with low copper blood plasma concentrations increased the levels of copper in blood although growth was not affected during the four-month period of the experiment (Givens et al., 1981).

In an effort to account for substances that interfere with copper availability, Suttle and McLauchlan (1976), in Great

Britain, developed an equation to calculate true copper availability (TA Cu), as follows:

$$\log TA\ Cu = -0.0019\ Mo - 0.0755\ S - 0.0131\ Mo \times S - 1.153$$

Mo and S in the above equation are the concentrations of molybdenum (ppm) and sulfur (g/kg) in the dry matter of the ration. The calculated values of true copper availability are multiplied by the copper content of the ration and compared with dietary requirements of available copper that are as follows: 0.48 ppm for growing cattle with live weights of 100 to 200 kg, 0.42 ppm for growing cattle with a live weight of 400 kg, and 0.41 ppm for dairy cows (Givens and Hopkins, 1978).

There is not good agreement on what is a safe copper-to-molybdenum ratio in the diet of ruminants. This is probably because other factors besides molybdenum interfere with copper metabolism, including sulfates and protein and whether or not the animals are grazing. Grazing animals are likely to have higher copper requirements than nongrazing cattle. Some authors have suggested a copper to molybdenum ratio of 2:1, some 4:1 (Underwood, 1981). Under some circumstances, hypercupremia has been observed even with higher copper to molybdenum ratios, such as in Great Britain with a 6.5:1.0 ratio (Givens and Hopkins, 1978).

<u>Copper deficiency and toxicity in ruminants</u>- Copper deficiency in ruminants results in reduced growth or weight loss, unthriftiness, and decreased milk production. In an extreme deficiency, often (but not invariably) the following are observed: severe diarrhea; rapid weight loss; cessation of

growth; rough hair coat; a change in hair coat color, which may become faded, bleached, graying, dirty-yellowish (for white hair), or brownish (for black hair); a change in hair texture; swelling at the end of the leg bones, especially above the pasterns; fragile bones often resulting in multiple fracture of ribs, femur or humerus; stiff joints that may result in a "pacing gait" in older cattle; depressed or delayed estrus and reduced reproduction; difficulty in calving and retained placenta; birth of calves with congenital rickets; "falling disease" or sudden death due to acute heart failure; and anemia. Sometimes the black hair around the eyes loses pigment and develops a gray-spectacled appearance that is apparently is specific for copper deficiency. With inadequate copper intake, performance may be subnormal when there are no obvious deficiency symptoms other than nonspecific unthriftiness (NRC, 1978).

According to Ward (1978), copper deficiencies are produced by four classes of feeds: 1) high molybdenum feeds, generally above 100 ppm; 2) low copper to molybdenum ratio feeds: 2:1 or less; 3) copper deficient feeds, below 5 ppm; and 4) high protein feeds, those 20 to 30% protein in fresh forage form. The author speculates that the latter situation probably results from higher levels of sulfide produced from sulfur amino acids during rumen fermentation.

Sheep are very susceptible to copper poisoning and horses relatively tolerant to high copper levels in the diet. Bovines, in general, can tolerate higher amounts of copper than sheep without showing signs of toxicity. The amount of copper necessary to cause poisoning depends also on the relation of copper to interfering substances such as molybdenum and sulfates. It is estimated that cattle can safely tolerate 70-100 ppm copper continuously and higher levels for short periods such as a few weeks (NRC, 1978).

When excessive copper is consumed, cattle are able to accumulate extremely high amounts in the liver before obvious symptoms of toxicity appear. The toxicity symptoms are due to the sudden liberation of large amounts of copper from the liver to the blood causing a hemolytic crisis. This is characterized by considerable hemolysis, jaundice, methemoglobinemia, hemoglobinuria, generalized icterus, widespread necrosis, and often death (NRC, 1978).

Chronic copper poisoning may occur in farm animals from natural grazing conditions where the copper contents in the herbage are excessive, or are normal but abnormally low molybdenum and sulphur concentrations; from excessive consumption of copper-containing salt licks; or from the unwise use of copper drenches (Underwood, 1981).

Copper sources- Cupric sulfate, usually the pentahydrate form $CuSO4.5H2O$ containing 25% copper, is the most commonly used form of copper supplement for ruminants. Most trace mineral salts carry copper, but usually at the low level of about 0.03% of the salt mixture. In copper deficient areas, salt licks should contain 0.5 to 1.0% cupric sulfate (Underwood, 1977); which is equivalent to 0.125 to 0.25% copper. If the diet of the dairy cow in a hypothetical copper deficient area contains 5 ppm copper, and the cow is eating 20 kg (44 lb) of dry matter a day, a daily intake of 45 g of a trace mineral salt with 0.25% copper, will raise its copper intake in the total diet to an equivalent of around 10 ppm copper. This intake is probably adequate under most circumstances.

Other copper containing compounds that can be used for ruminants include cupric carbonate, cupric chloride and cupric nitrate, but copper in these forms is generally less available for the animal (Ammerman and Miller, 1978). Injectable forms of copper used for copper deficiency therapy are copper glycinate, copper calcium edetate (ethylenediaminetetraacetate), and copper gluconate (Underwood 1977).

Copper fertilization of pastures with 5 to 7 kg of copper sulfate per hectare (4 to 6 lb/acre) raises the copper content in the forages to levels high enough to prevent deficiencies. In some areas significant increases in total herbage production are coincidentally achieved (Underwood, 1977).

Sulphur

Sulphur content in plants in relation to soil status and fertilization- Sulfur is essential for both plants and animals. Sulfur deficiency in plants is especially common in the gray wooded soils of cool, temperate regions. Many of the soils developed from volcanic materials in northern California and in the Pacific Northwest are deficient in sulfur (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965). The use of ordinary superphosphate, which contains 11-12% sulfur, probably avoided sulfur deficiencies in these areas. Triple or concentrated superphosphate, in contrast, has almost no sulfur (0 to 1%), and it is possible that its use may result in sulfur deficiencies in susceptible crops such as legumes.

When sulfur fertilizers are added to a sulfur-deficient soil, increased crop yields and increased total sulfur concentration in the plant normally result. Increases in protein concentration are also frequently observed. But the ratio of the sulfur amino acids to other amino acids within the true protein fraction is generally unchanged. Sulfate, like nitrate, may accumulate in plant tissues under certain conditions, but unlike nitrate excess sulfates in plants are not toxic for the animal. The only concern with high levels of sulfate in forages for ruminants is in the case of copper deficiency produced by high levels of molybdenum. Sulfates can enhance the deficiency. Inorganic sulfur, like sulfate, can be used by the bacteria in the rumen of animals to produce sulfur containing amino acids. So, even when a high level of sulfate is present in forages, it usually only improves the nutritional quality of the forage (Allaway, 1971).

Sulfur content in forages- Typical sulfur content in grasses goes from 0.15 to 0.25%, with values found lower than 0.1% and higher than 0.3%. In alfalfa the sulfur content is higher, typically ranging typically from 0.3 to 0.4%, with values found lower than 0.2% and higher than 0.7% (Church and Pond, 1974). Corn silage is relatively low in sulfur. In Michigan in 1975-1976, corn silage samples had an average sulfur content of 0.11% (Hillman and Fox, 1977). In Pennsylvania from 1969 to

1973, the average sulfur content of ear corn was 0.13%, and 0.14% for shelled corn (Adams, 1975). Soybean oil meal has an average of 0.49% sulfur (NRC, 1978).

Sulfur requirements of dairy cattle- Unlike nonruminants, which that have a specific requirement for sulfur containing amino acids, ruminants can make use of inorganic sulfur in the ration. Bacteria and protozoa in the rumen can synthesize the sulfur-containing amino acids required by the ruminant starting from inorganic sulfur. Sulfur requirements are often calculated in relation to the nitrogen concentration in the diet. A nitrogen to sulfur ratio of 10:1 to 12:1 is suggested as appropriate for dairy cattle. The estimated sulfur requirement for lactating dairy cows is 0.20% in the average diet; that for nonlactating dairy cattle is calculated from the minimum protein requirement with a nitrogen to sulfur ratio of 12:1 (NRC, 1978).

Sulfur deficiency and toxicity in ruminants- In the practical feeding of dairy cattle, a sulfur deficiency is most likely to occur when considerable added nonprotein nitrogen and/or corn silage are fed (NRC, 1978). In these cases the deficiency is not severe, since the other ingredients of the diet provide some sulfur for the animal.

Sulfur deficiency symptoms in dairy cattle are not specific, especially when the deficiency is not severe. Sulfur is essential for the the synthesis of microbial protein, and thus for optimum fermentation of substrates (Quispe, 1982). Rumen metabolism is disrupted with sulfur deficient diets. This results in decreased dry matter digestibility, decreased dry matter intake, and decreased milk production of dairy cattle (Bouchard and Conrad, 1973a, b and c). The requirements of the animal for inorganic sulfur, and the effects of a deficiency are not well known (Follis, 1958).

The maximum amount of sulfur that can be tolerated by cattle is not well defined. It is suggested that the maximum should be limited to about 0.35% percent of the diet with no more than 0.20% coming from added sulfate sulfur. Apparently, dairy cattle can tolerate a higher level of sulfur from natural feed ingredients than from added sulfate (NRC, 1978).

Sulfur sources- Several sources, such as sodium sulfate, potassium sulfate, magnesium sulfate, ammonium sulfate, and calcium sulfate, are effective in meeting the sulfur requirement of ruminants. Elemental sulfur is also utilized but much less efficiently (NRC, 1978).

Iron

Iron content in plants in relation to soil status and fertilizers- Iron uptake by the plant from the soil depends to large extent on the plant species and variety. Alfalfa and corn, for example, take more iron from the soil than soybeans, and will produce good yields in soils that are iron deficient for soybeans (Tisdale et al., 1985). In iron deficient soils, iron fertilization is likely to increase crop yields, but not the iron concentration in the plant (Allaway, 1971).

Iron content of forages- Iron levels in forages are usually high enough to meet the requirements of dairy animals. Typical iron concentration in grasses is 50-100 ppm, with values found lower than 45 ppm and higher than 200 ppm. Alfalfa's iron concentration ranges from 50 to 200 ppm, with values found lower than 30 ppm and higher than 300 ppm (Church and Pond, 1974). Corn silage in Michigan in 1975 and 1976 had an average of 214 ppm iron in the dry matter (Hillman and Fox, 1977). Ear corn in Pennsylvania from 1969 to 1973 had an average of 94 ppm iron, and shelled corn 69 ppm (Adams, 1975). Soybean oil meal has an average iron content of 130 ppm (NRC, 1978).

Iron requirements of dairy cattle- An iron level of 100 ppm in the dry diet should be adequate for all needs of calves up to three months of age; with 50 ppm sufficient for other dairy cattle (NRC, 1978). About 30 to 40 ppm in the diet in the production of veal will provide sufficient iron to prevent loss of performance from a severe deficiency and still maintain the pale veal color (Miller, 1981).

Iron deficiency and toxicity in ruminants- Since most forages have adequate levels of iron, iron deficiency seldom occurs in dairy cattle unless as a result of severe loss of blood caused by parasitic infestations or disease. Young animals are susceptible to iron deficiency when they are fed exclusively on milk that is low in iron (NRC, 1978). Cows milk has an iron content of about 0.5 mg/liter (Thomas, 1970).

Even though some feeds contain a high percentage of iron, toxicity does not appear to be an important problem for dairy cattle. The effects of iron toxicity, which are not specific, include lower feed intake, lessened weight gains, and lower milk production. Limited data suggest that soluble iron compounds such as sulfates are more toxic than iron in natural feedstuffs (Miller, 1981). It is believed that cattle generally can tolerate 1000 ppm dietary iron under most conditions, especially if the iron is from natural feed sources and adequate levels of other minerals are supplied (NRC, 1978).

Iron sources- The availability of iron in different compounds varies enormously. Generally iron in soluble compounds such as ferrous sulfate and ferric citrate are much more available to cattle than in ferric oxide or iron phytate (Miller, 1981). Feed grade ferrous carbonates range from low to intermediate availability (Ammerman and Miller, 1978). An important source of iron, as well as of other minerals is soil. Soil intake of grazing animals can be as high as 10% of the dry matter intake, and even higher under some conditions such as high stocking rate or a rainy season (Healy, 1974).

Manganese

Manganese content in plants in relation to soil status and fertilization- As in the case of iron, manganese content in plants is generally not responsive to manganese fertilization. In manganese deficient soils, and with crops sensitive to low levels of available manganese in the soil such as alfalfa and soybeans, manganese fertilization will probably increase the yield of the crop but will have little effect on the manganese content of the plant (Allaway, 1971).

Manganese content in forages- Forages show a great variability in their manganese content. Grasses have a manganese concentration ranging from 40 to 200 ppm, with values found lower than 30 ppm and higher than 250 ppm. Typical concentration in alfalfa ranges from 25 to 45 ppm, but values lower than 20 ppm and higher than 100 ppm are also found (Church and Pond, 1974). Average manganese concentration in corn silage in Michigan in 1975-1976 was 33 ppm (Hillman and Fox, 1977). Ear corn in Pennsylvania from 1969 to 1973 had a manganese content of 7.3 ppm, and shelled corn 4.8 ppm (Adams, 1975). Soybean oil meal has an average manganese content of 31 ppm (NRC, 1978).

Manganese requirements of dairy cattle- The suggested manganese dietary requirement is 40 ppm in the diet on a dry matter basis (NRC, 1978). High levels of calcium and phosphorus in the diet seem to interfere with manganese absorption, increasing the requirement for it in the diet. Some authors have recommended an increase of the manganese content in the diet to 70-95 ppm to take care of reduced manganese absorption caused by high calcium intake (Hidiroglou, 1979); however, this recommendation is still controversial.

Manganese deficiency and toxicity in ruminants- Manganese deficiency is linked to silent heats, reduced conception, abortions, reduced birth weight, increased percentage of male offspring, paralysis, and skeletal damage in dairy cows (Puls, 1981). Symptoms of experimental manganese deficiency are well documented (Underwood, 1977 and 1981; Miller, 1981; Hidiroglou, 1979; Thomas, 1970), but severe deficiencies do not seem to be prevalent with practical diets. It is very possible that borderline deficiencies with nonspecific signs are widespread, especially in animals whose diets are based on corn silage and corn. These diets are very likely to contain less than 40 ppm manganese, the estimated requirement.

Manganese sources- Manganese sulfate, chloride, carbonate, dioxide, and potassium permanganate are all very available forms of manganese for ruminants (Ammerman and Miller, 1978), and can be included in trace mineral salts and rations.

Zinc

Zinc content in plants in relation to soil status and fertilization- A number of general factors affect the zinc content of natural feeds. Zinc is more available to plants in an acid soil. Thus, liming tends to lower the zinc content of the plants. Since liming usually increases crop production, zinc content may be lower on some of the better managed farms. Often the zinc content of forage plants declines somewhat with maturity of the plant. Likewise, some information suggests that the content is lower in a dry climate (Miller, 1979). Zinc fertilization, however, is expected to have a bigger effect on yield of the forage than on its zinc concentration (Allaway, 1971).

Zinc content in forages- In general, high protein feeds are good sources of zinc (Miller, 1979). Grasses have a zinc concentration ranging from 20-80 ppm, with values found lower than 15 ppm and higher than 100 ppm. Alfalfa's zinc concentration ranges from 12 to 35 ppm, with values found lower than 10 ppm and higher than 50 ppm (Church and Pond, 1974). During the years of 1975 and 1976, corn silage in Michigan had an average zinc content of 37 ppm (Hillman and Fox, 1977). Ear corn in Pennsylvania from 1969 to 1973 had an average zinc content of

27 ppm, and shelled corn an average of 25 ppm (Adams, 1975). Soybean oil meal has an average zinc content of 48 ppm (NRC, 1978).

Zinc requirements of dairy cattle- 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. According to Miller (1979), the requirement of 40 ppm of zinc in the diet provides a modest margin of safety, since in some cases animals consuming diets with 40 ppm or more of zinc have improved their performance after zinc supplementation. Nevertheless, it is believed that this level is adequate for normal cattle under most or all practical feeding conditions (Miller, 1979).

Zinc deficiency and toxicity in ruminants- Weak hoof horn with increased susceptibility to interdigital dermatitis, foot rot, and reduced conception rate are some of the symptoms of zinc deficiency in cattle. The effect of the deficiency is more severe on male fertility than on female fertility. Spermatozoan maturation is severely affected. Very common symptoms also include reduced growth rate, reduced feed intake, and parakeratosis (Puls, 1981). As with several of the other mineral deficiencies, a severe zinc deficiency does not appear to be a major practical problem in genetically normal ruminants. However, the extent of borderline deficiencies in practical situations is uncertain. A key reason for this uncertainty is the lack of good diagnostic procedures for detecting a borderline deficiency, especially under field conditions (Miller, 1970 and 1979).

Zinc toxicity in cattle is uncommon due to the high levels necessary to produce poisoning: at least 500 ppm of zinc in the diet (NRC, 1978).

Zinc sources- Zinc oxide is the most commonly used source of zinc for the formulation of trace mineral salts and rations for ruminants. Zinc sulfate and zinc chloride are also readily available sources of zinc (Miller, 1979).

Cobalt

Cobalt content in plants in relation to soil status and fertilization- Both plants and animals require cobalt for their normal function. The nitrifying bacteria in the nodules of legumes require cobalt for adequate nitrogen fixation (Kubota and Allaway, 1972). There is also some evidence that other nonlegume crops such as cotton have higher yields after cobalt fertilization (Tisdale et al., 1985). The amount of cobalt required for optimal plant growth is nevertheless very small, and in some areas of the world the concentration of cobalt in forages is not sufficient to meet the requirements of animals (Hodgson et al., 1962). In the United States the lower Atlantic Coastal Plain is a general region of exceedingly low soil cobalt. Some sandy soils of glaciated regions in the Northeast and in the Great Lakes states are also low in cobalt. Forages grown in the regions mentioned have a cobalt concentration too low to meet animal's requirements (Kubota and Allaway, 1972). Even though cobalt fertilization is likely to increase cobalt content of the crops, the use of cobalt fertilizers is not a common practice to correct deficiencies for animals (Kubota and Allaway, 1972).

<u>Cobalt content of forages</u>- Legumes generally contain more cobalt than do grasses, but even legumes are deficient in cobalt for grazing animals in some areas (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965). Grasses and alfalfa typically have a cobalt content of 0.08-0.25 ppm in the dry matter, with values found higher than 0.30 ppm, and in deficient areas, lower than 0.08 ppm (Church and Pond, 1974). Corn silage has an average cobalt concentration of 0.06 ppm, shelled corn 0.04 ppm, and soybean oil meal 0.10 ppm (NRC, 1978).

<u>Cobalt requirements of dairy cattle</u>- Cobalt is an essential component of vitamin B12, which is synthesized by rumen microorganisms. The minimum cobalt requirement of dairy cattle is about 0.10 ppm (NRC, 1978).

<u>Cobalt dificiency and toxicity in ruminants</u>- Generally, a cobalt deficiency becomes evident only after animals have been on a deficient diet for a considerable time, and then progresses slowly as vitamin B12 stores in liver and other tissues are depleted. Cattle do not store significant amounts of cobalt in usable forms; thus vitamin B12 synthesis declines very quickly when dietary cobalt is inadequate (NRC, 1978).

The most conspicuous early feature of a cobalt deficiency is decreased appetite and feed consumption resulting in listlessness, retarded growth or weight loss, and decreased milk production. Other symptoms, especially with an extreme and extended deficiency, can include emaciation or wasting of the musculature, paleness of the skin and mucous membranes, muscular incoordination, a stumbling gait, rough hair coat, and high mortality rate among calves (NRC, 1978).

The possibility of livestock poisoning caused by an excess of cobalt in the natural herbage of feedstuffs is extremely remote (Young, 1979). Calves fed excessive cobalt show reduced appetite, less growth, decreased water consumption, rough hair coat, lack of muscular coordination, increased hemoglobin and packed cell volume, and elevated liver cobalt compared to control animals. Ten ppm in the dry diet is generally accepted as a safe level; however, there is no evidence to indicate that 20 ppm would produce any adverse effects (NRC, 1978).

Cobalt sources- The carbonate, chloride, sulfate and nitrate forms of cobalt have been proposed as satisfactory dietary sources of the mineral. Because of its desirable physical characteristics, cobalt carbonate is frequently the cobalt source of choice in the feed industry. Cobalt pellets are usually made with cobalt oxide and clay (Ammerman and Miller, 1978).

There are several ways of treating or preventing cobalt deficiency in ruminants. Drenching with cobalt chloride or sulfate is effective for about 3 weeks. Bullets or pellets of cobaltic oxide given orally that lodge in the reticulo-rumen are effective for at least 3 years. Treatment of the pasture with 1 to 5 kg of cobalt sulfate per hectare is effective for at least one year. Subcutaneous injection of hydroxycobalamine can also be used: 2 mg initially and then 1 mg per month. By far, the most common practice to prevent cobalt deficiency is the incorporation of cobalt in the formulas of trace mineral salts at a rate of 0.004 to 0.01% of the salt (Puls, 1981). This last practice is followed even when there is no evidence of cobalt deficiency in the unsupplemented rations (Underwood, 1981).

Selenium

Selenium content in plants in relation to soil status and fertilization- Selenium is apparently not needed by plants. But it must be present in plants since it is essential for animals. Plants differ in their uptake of available selenium according to species, stage of growth, and the season. Certain species of Astragalus absorb more selenium than do other plants growing in the same soil. Plants such as the crucifers (cabbage and mustard, for example) and onions which require large amounts of sulfur absorb intermediate amounts of selenium. Grasses and grain crops absorb low-to-moderate amounts of selenium (Tisdale et al., 1985). For the most part, selenium-accumulator plants are not ones that are preferred by grazing animals. However, the selenium taken by these plants and returned to the soil in their organic residues is much more available to the common crop and pasture plants than other selenium compounds. Therefore, a cycle of plant succession in which several years' growth of selenium-accumulator plants is followed by the growing of forage grasses and cereals can result in toxic levels of selenium in the common forages and cereals (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965). Selenium concentration in forages is responsive to selenium fertilization. Selenites are preferred to selenates because they are slower acting and thus less likely to produce excessive levels of selenium in plants than the rapidly available selenates (Tisdale et al., 1985). Selenium fertilization is not, however, a common method to provide selenium to animals deficient in the mineral.

Selenium content of forages- The selenium concentration in forages and grain is dependent on the selenium levels in the soil. A survey carried out in 1957 showed that forages (mainly alfalfa) from some areas in the United States are low in selenium. Approximately 80% of the samples of the area surrounding the Great Lakes contained less than 0.05 ppm selenium (Kubota and Allaway, 1972). In some other areas in the center of the country the selenium content in the forages sampled was higher than 0.1 ppm. Finally in some localized spots in South Dakota, North Dakota, and Wyoming, selenium-accumulator plants were found with concentrations higher than 50 ppm (Kubota and Allaway, 1972).

Selenium requirements of dairy cattle- Although not well documented, the requirement for selenium by ruminants is approximately 0.1 ppm, the exact level depending upon the chemical form of selenium and the levels of interfering or enhancing factors in the diet, including vitamin E, sulfur, lipids, proteins, amino acids, and several microelements (NRC, 1978).

Selenium deficiency and toxicity- Acute selenium deficiency can cause white muscle disease, diarrhea, muscle stiffness, and occasionally recumbency, particularly in parturient cows (similar to milk fever syndrome). Sudden death due to cardiac failure with no prior sickness can also be caused by acute selenium deficiency. Marginal selenium deficiency can result in retained placentas, abortions, reduced fertility, decreased growth rate and decreased immune response (Puls, 1981).

Selenium toxicity, which occurs under practical conditions in several areas of the world, is often classified as acute or chronic alkali disease. The lowest toxic level is approximately 3 to 5 ppm, the exact amount depending upon the protein, sulfur, and arsenic levels (higher amounts of each reduce the toxicity) of the diet and on the chemical form of selenium. Apparently, the naturally occurring organic selenium of plants is much more toxic than the inorganic form. The range between the requirement and toxic levels is 30 to 50-fold. Acute selenium poisoning is characterized by dullness, slight ataxia, rapid weak pulse, labored respiration, diarrhea, lethargy, and death due to respiratory failure. Signs of chronic selenium toxicity (alkali disease) include lameness, loss of vitality, loss of appetite, emaciation, loss of hair from the tail, liver cirrhosis, nephritis, sore feet, and deformed, cracked and elongated hoofs (NRC, 1978).

Selenium sources- Sodium selenite and sodium selenate are good sources of selenium for ruminants. Since 1979, the Food and Drug Administration has granted approval for oral supplementation to sheep, dairy and beef cattle (Ammerman et al., 1980). For dairy cattle, selenium can be added to a level not to exceed 0.1 ppm selenium in the complete ration (Marckzewski, 1982). The most usual and convenient way to administer selenium to dairy animals is through the trace mineral salt or mineral mix. Selenium salts (selenate or selenite) can be include in the trace mineral salt formulation at a rate of 25 to 75 ppm of selenium and fed free choice or 40 g per day per mature cow (Puls, 1981).

Occasionally, selenium injections are recommended for animals under certain conditions. Newborn calves may receive a single injection of 5 mg of selenium for the prevention of white muscle disease. Cows may be injected with a commercial product three weeks prepartum, and again after calving. These injections may be given even when the diet contains the recommended amounts of added selenium (Marckzewski, 1982).

Iodine

Iodine content in plants in relation to soil status and fertilization- Iodine is required by animals but not by plants. Even so, plants will accumulate appreciable amounts of iodine in their tissues if it is present in an available form in the soil, and iodine from plants is one of the important sources of iodine in animal rations. Plants low in iodine are most often found growing on geologically young soils and in areas of low rainfall. It appears that the cycle of iodine in nature involves the vaporization of iodine compounds from the sea, their transport inland by wind, and their deposition on land by rainfall (U.S. Plant, Soil, and Nutrition Lab. Staff, 1965).

Iodine content in feeds- Iodine content in forages is extremely variable, and it depends not only on the iodine concentration in the soil but also on the plant species and season of the year (Underwood, 1981). Alfalfa hay samples had an average iodine content of 0.82 ppm and corn silage 0.52 ppm in

Illinois. Hay and corn silage samples from Maryland had an average irodine content of 1.87 and 1.64 ppm, respectively (Hemken et al., 1972). All edible materials obtained from the sea are rich in iodine, compared with similar materials obtained from fresh water or from the land. The edible flesh of sea-fish and shell-fish may contain 0.3 to 3.0 ppm iodine on a fresh basis, compared with 0.02 to 0.04 ppm for fresh water-fish and with intermediate values for fish which spend part of their life in the sea and part in fresh water (Underwood, 1981). Pastures, and crops in general, grown at high altitudes tend to be low in iodine, and endemic goiter has been observed in those areas (Kubota and Allaway, 1972).

Iodine requirements of dairy cattle- The iodine requirement of lactating cows and dry pregnant cows is 0.50 ppm, and is 0.25 ppm for bulls, heifers and calves. If the diet contains as much as 25% of strongly goitrogenic feed on a dry basis, iodine provided should be increased by two times or more (NRC, 1978).

Iodine deficiency and toxicity in ruminants- Iodine deficiency in dairy cattle results in reproductive failure, stillbirth, abortions and hairless or weak young. Another symptom is suppressed estrus with resultant infertility (Puls, 1981). One of first symptoms observed is an enlargement of the thyroid glands (goiter) in slaughtered cattle or newborn calves (NRC, 1978).

Iodine deficiency can be caused not only by low iodine content in the diet, but also by chemicals in feeds that likely to occur (Miller, 1974).

Generally the percentage of magnesium absorbed is not materially affected by the amount consumed. Likewise, magnesium content of tissues is not elevated with excess intake. Rather, homeostasis is maintained by the excretion of excess magnesium via urine. More than a trace of magnesium in urine indicates adequate magnesium to meet the animal's needs. Very low urine urine magnesium indicates either a deficiency or a barely adequate intake (Miller, 1974).

Analysis of forage for magnesium, nitrogen and potassium can aid in diagnosing the likelihood of a grass tetany problem; however, these are far less reliable than urine and serum magnesium analyses (Miller, 1974).

Sodium, Potassium and Chlorine

Normal concentrations in blood serum are around 300 mg/100 ml for sodium, 14 to 18 mg/100 ml for potassium, and around 360 mg/100 ml for chlorine (Church, 1976). Serum concentration of these three elements is not a good indicator of the adequacy of the diet or the nutritional status of the animal (Miller, 1974).

In humans, serum sodium is pathologically increased in dehydration, sodium intoxication, adrenocortical hyperfunctioning, corticosteroid therapy, brain injury, brain hemorrhage and encephalitis. It is decreased by severe sweating without adequate sodium intake, by loss of digestive juices (through diarrhea or vomiting), and because of burns, expansion of the extracellular fluid due to water intoxication or pneumonia, severe renal tubular injury, adrenocortical interfere with iodine absorption by the animal. Cruciferous plants contain variable amounts of goitrogens of the goitrin type which interfere with the process of hormonogenesis in the thyroid gland. Many pasture plants, such as clover, contain cyanogenetic glycosides that are goitrogenic (Underwood, 1981). Soybean oil meal is mildly goitrogenic (Hemken, 1970).

Iodine poisoning can result from excessive iodine intake, especially from medicated feeds. Ethylenediamine dihydriodide (EDDI) is sometimes added to the ration in excess of iodine dietary requirements to prevent foot rot and soft tissue lumpy jaw, and as an expectorant in treatment of mild respiratory infections. Signs of iodine toxicity include lacrimation, coryza, conjunctivitis, coughing, hair loss, and exophthalmus (Hillman and Curtis, 1980). Other symptoms observed in calves are bronchopneumonia and squamous metaplasia of the tracheal epithelium. The thyroids of the animals suffering from toxicity had large follicles, a flat epithelium, and large amounts of colloid (Mangkoewidjojo et al., 1980).

Iodine sources- Sodium and potassium iodide are well utilized as sources of of iodine but lack physical stability. Calcium iodate, diiododithymol and pentacalcium orthoperiodate are less water soluble, have greater physical stability and are similar to sodium and potassium iodide in availability. Diiodosalicylic acid is readily absorbed by ruminants but is excreted with little release of iodine from the cyclic structure. Injectable forms of iodized oils have been effective in supplying supplemental iodine to sheep (Ammerman and Miller, 1978).

Ethylenediamine dihydriodide can also be used as a source of iodine (Miller and Swanson, 1973). Trace mineral salts usually contain 0.007 to 0.01% iodine (NRC, 1978).

Plant Analysis

Plant analysis for soil fertility evaluation- Plant analyses are based on the premise that the amount of a given element in a plant is an indication of the supply of that particular nutrient and as such is directly related to the quantity of the nutrient in the soil. Since a shortage of an element will limit the plant's growth, other elements may accumulate in the cell sap and show high tests, regardless of supply. For example, if corn is low in nitrate, the phosphorus test may show high. This is no indication, however, that if adequate nitrogen were supplied to the corn the supply of phosphorus would be adequate (Tisdale et al., 1975). Plant analysis provides some unique advantages to evaluate soil fertility. The nutrient content of the plant is a reflection of the soil's available nutrient status: the plant's ability to absorb a nutrient in the established environment is reflected by the plant nutrient concentration at any one time. By comparison, a soil test does not always provide a measure of the soil-plant interaction. On the other hand, soil tests for some micronutrients are either nonexistent or not widely adapted for universal use (Jones, 1972).

Sampling- As a general principle for any type of sampling, samples for plant analysis should be representative of the population of plants in the field under study. There are several criteria to meet in order to interpret the results of plant analyses. Plant analysis laboratories provide instructions on the plant part to select, number of parts to collect, number of plants to sample, and time of sampling (Jones, 1972). The Cooperative Extension Service of Michigan State University provides guides on the part of the plant to sample, time of sampling, and the acceptable or sufficiency nutrient ranges required for high production of several crops (Vitosh et al., 1981).

Dust or soil contamination can change the mineral concentration of the sample, especially its iron and manganese content. When the parts of the plant sample have been close to the ground and there is soil contamination, or when there is too much dust on the leaves, washing of the samples may be necessary. There is no general agreement on which washing procedure should be used. Some laboratories recommend such means as hydrochloric acid solutions, detergents, EDTA, wiping of smooth leaves with a damp cloth, or combinations of these methods. When acids, detergents or other solutions are used to wash the samples, rinsing with distilled or deionized water must follow (Jones, 1972). In contrast, when forages are analyzed to assess the nutritional status of animals soil or dust contamination should not be removed in order to provide a better idea of what the animal is consuming.

Drying, grinding and ashing- Fresh samples should be dried preferably in a forced air oven. Relatively low temperatures for drying are preferred (45 to 60^{o} C) to avoid volatilization of organic compounds. Stainless steel screens and tool steel cutting faces in mills used to grind samples reduce the possibility of contamination. The mesh size of the sieve chosen is usually 1 mm, which achieves good homogenization of the sample (Jones, 1972; Fick et al., 1979).

The ashing procedure of the sample is chosen in view of the mineral to be analyzed. Dry ashing is necessary for boron analysis since this element is volatilized during wet ashing (Jones, 1972). Wet ashing is used for the analysis of elements that are volatile at high temperatures such as selenium. Dry ashing provides good precision and is an easy, rapid digestion method requiring minimal analyst attention. An additional benefit is that this method is relatively free from reagent contamination. Various digestion reagents are used for wet ashing including nitric, perchloric, sulfuric, hydrofluoric and hydrochloric acids, and hydrogen peroxide. The main advantage of this method is that it eliminates elemental loss by volatilization because the digestion takes place at a low temperature. Its main disadvantages are that it is subject to reagent contamination, is tedious and requires careful operator attention (Perkin, 1982). Special care should be taken when perchloric acid is used in the reaction mixture, since this acid forms explosive mixtures with organic matter. In this case the sample should be predigested first with other acids until the organic matter is oxidized completely.

Analytical techniques- Several analytical techniques are available for mineral analysis. The different methods take advantage of the physical and chemical characteristics of the element or elements analyzed. In several laboratories atomic absorption and emission techniques are the method of choice (Ullrey, 1977).

Several elements can be analyzed with the same sample preparation by atomic absorption. The method is fast, accurate and sensitive to low concentrations (Perkin, 1976). Some elements such as phosphorus, sulfur, nitrogen, and selenium are difficult to measure by atomic absorption. Phosphorus is commonly analyzed by colorimetric procedures (Fick et al., 1978). Nitrogen is determined by the Kjeldhal procedure, and selenium can be analyzed fluorimetrically (Whetter and Ullrey, 1978). Sulfur can be analyzed indirectly through atomic absorption, by measuring barium after the precipitation of the sulfates with barium chloride (Perkin, 1982).

Several elements can be determined at once by plasma emission spectrophotometry, inductively coupled plasma discharge (Barnes, 1979), and neutron activation (Ehmann and Janghorbani, 1979). These methods are fast and sensitive. Their main disadvantage is the high cost of the instruments acquired.

Blood Minerals and Deficiencies Diagnosis

Clinical and pathological observations of the animal are essential diagnostic tools for all mineral deficiencies and toxicities, although their value varies with the element and with the severity of the deficiency or toxicity in question. Mild mineral deficiencies or excesses are especially difficult to identify because their effects on the animal are frequently indistinguishable from those resulting from semistarvation or underfeeding, from protein deficiency or from intestinal parasitism. A depression in appetite, with resulting undernutrition, is a common symptom of all mineral deficiencies, as it is with deficiencies of other essential nutrients (Underwood, 1981).

When taken in conjunction with clinical and pathological observations, appropriate chemical analysis and biological assays of tissues and fluids of animals are valuable aids in the early detection of mineral abnormalities in livestock. They are also valuable in distinguishing between various functional and structural disorders of mineral origin, the causes of which are difficult to identify on the basis of clinical evidence alone. The diagnostic significance of such biochemical data arises primarily from the fact that a dietary deficiency of a mineral is sooner or later reflected in subnormal concentrations of the mineral in certain tissues and fluids (Underwood, 1981).

The choice of tissue or fluid for analysis varies with the mineral under investigation. Blood, urine, saliva and hair have obvious advantages because of their accessibility without sacrifice of the animal. Body tissue sampling presents more difficulties, although simple liver and tail bone biopsy techniques are now available. Whole blood, blood serum or plasma is more employed for studies in mineral nutrition than any other tissue or fluid of the body because it invariably reflects, in some aspect of its composition, the mineral status of the animal, and can be obtained easily and and frequently without harm to or death of the animal. It can also be readily transported and stored for subsequent attention. The normal values or normal range of concentrations in the blood of healthy farm animals consuming satisfactory diets are known for most of the nutritionally important minerals, making possible comparison with values found in the blood of domestic livestock under study (Underwood, 1981).

The mineral concentration in blood is, however, subject to high individual variation and to the control of homeostatic mechanisms. In contrast to the mineral content in forages and other animal feeds, which vary to a great extent, tissue concentrations of functional forms of essential trace elements is usually maintained within narrow limits (Miller, 1975).

Experimentally, some mineral deficiencies can be relatively easy to identify. However, under field conditions, diagnosing even acute deficiencies is frequently not easy, and borderline deficiencies are far more difficult to detect. Because they affect so many animals, borderline deficiencies are of much greater importance (Miller, 1974).

To diagnose nutritional mineral problems, all the available information should be considered. This includes animal performance, feed intake, clinical and pathological observations, soil analysis, forage and feed analysis, and tissue analysis. Even then, diagnosis is often difficult (Miller, 1974).

Calcium and Phosphorus

Calcium and phosphorus concentration in blood and in the animal's metabolism is controlled by the interaction of parathyroid hormone and calcitonin with the active metabolite of vitamin D3, 1,25-dihydroxycholecalciferol (Underwood, 1981). The homeostatic or physiological mechanisms regulating serum calcium are more effective than those for phosphorus or most other minerals (Miller, 1974). When there is a failure of the homeostatic mechanism, such as in milk fever, serum calcium gets very low. Normal serum calcium concentration is about 10 mg/100 ml, with a range of 9 to 12 mg/100 ml (Church, 1976). When a cow is affected by milk fever, serum calcium levels drop to 3 to 7 mg/100 ml, the average being 5 mg/100 ml. Signs usually appear when the serum calcium falls to 7 mg/100 ml or lower (Merck, 1979).

Normal phosphorus blood serum concentration in adult cattle is 4 to 6 mg/100 ml, and somewhat higher, 6-8 mg/100 ml, in very young animals (Underwood, 1981). According to Underwood (1981), the first known response to a dietary deficiency of phosphorus is a fall in the inorganic phosphate level of the blood plasma and a withdrawal of calcium and phosphorus from reserves in the bones. Accompanying this decline is a rise in plasma phosphatase and a small rise in serum calcium concentrations, to 13 or 14 mg/100 ml. After a few weeks or months on a phosphorus-deficient diet, the concentrations fall to 2-3 mg/100 ml, and concentrations of 1-2 mg/100 ml have been recorded in milking cows suffering from severe deficiency (Underwood, 1981).

Calcium and phosphorus deficiencies can be diagnosed by blood analysis combined with feed analysis and observation of clinical and pathological signs. A deficiency of calcium, phosphorus, or vitamin D can result in bone demineralization, and thus in a decrease of ash in the bone. If bones are available for analysis, therefore, bone ash values can also be used to help diagnose deficiencies (Miller, 1974).

Magnesium

The normal concentration of magnesium in blood serum of cattle is around 1.8 to 3.0 mg/100 ml (Church, 1976). Low concentration of magnesium in pastures results in a decline of serum magnesium. This may also be worsened by high levels of potassium and nitrogen in the pasture, because magnesium absorption from the gut is then impaired. This condition is more likely to occur at the beginning of spring when the pastures are growing rapidly. As hypomagnesemia develops, the serum magnesium drops. Usually when the serum magnesium is below 1.0 or 1.5 mg/100 ml, clinical symptoms of magnesium tetany are observed (Merck, 1979). Subnormal serum calcium (5 to 8 mg/100 ml) is usually also characteristic of magnesium tetany (Merck, 1979).

Serum magnesium analysis is one of best indicators of the magnesium status of cattle. Low serum magnesium in a substantial proportion of the animals suggests that a tetany outbreak is insufficiency (Addison's disease), medication with diuretic agents, and diabetic ketosis (Geigy, 1975).

The serum chloride level in humans is pathologically increased after protracted dehydration, in renal hyperchloremic acidosis (Lightwood and Albright types), in respiratory alkalosis, after head injuries and during treatment with corticosteroids. It is decreased by severe sweating without adequate chlorine intake, by loss of digestive juices (especially gastric juice), by burns, by expansion of the extracellular fluid, by in injury to the renal tubules, in adrenocortical insufficiency, because of medication with certain diuretic agents, in respiratory acidosis and occasionally in diabetic ketosis accompanied by diuresis (Geigy, 1975).

The serum potassium level in humans is pathologically increased by rapid infusion of potassium salts, in massive hemolysis, by acute tissue breakdown, in adrenocortical insufficiency, by renal failure accompanied by oliguria or anuria and by untreated diabetic ketosis. It is pathologically decreased by inadequate potassium intake or absorption, by loss of digestive juices, in adrenocortical hyperfuncioning due to hyperaldosteronism (Cushing's syndrome), or corticosteroid therapy), by kidney disease accompanied by polyuria, because of medication with diuretic agents, by renal tubular acidosis, by Fanconi's syndrome, and by diabetic ketosis during insulin treatment (Geigy, 1975).

Changes of sodium, chloride and potassium concentrations in ruminants due to pathological metabolism are not well documented.

It is expected, nevertheless, that these changes would be similar to those observed in humans.

Serum sodium, potassium and chloride are not good indicators of the nutritional status of ruminants. The analyses of saliva and feed for sodium and potassium levels are more useful measures of the status of these two minerals in cattle. Due to wide variations, hair, urine and fecal sodium have low reliability as a diagnostic measure (Miller, 1974).

Iron

Normal iron concentration in blood serum is around 150 ug/100 ml (Church, 1976). Iron occurs in blood as hemoglobin in the erythrocytes and as transferrin in the plasma in a ratio of nearly 1000:1. The levels of hemoglobin in the blood vary with nutritional level, pregancy and lactation status, altitude, and health of the animal (Underwood, 1977). For example, the hematocrit value of sheep kept in a hypobaric chamber for 32 days at 348 mm Hg of pressure (equivalent to 6200 m of altitude), rose to 37.3 compared with the measured value of 27.1 for control animals kept at a pressure of 620-640 mm Hg (Phillips, 1969). Serum iron concentration in steers maintained at an altitude of around 3000 m was 1123 ug/100 ml (Wilson, 1975).

Blood analysis is not a good indicator of the iron status of animals, especially for ruminants which are unlikely to suffer from severe iron deficiency. Calves fed exclusively on milk for several weeks may develop iron deficiency anemia (NRC, 1978). Nevertheless, low hemoglobin and hematocrit values are not sensitive indicators of the early stages of iron deficiency because they do not occur until storage iron is severely depleted. Their use is mainly limited to diagnosis and confirmation of acute iron deficiency (Miller, 1974). Analysis of the diet may be of value in diagnosing iron deficiency before clinical symptoms appear.

Zinc

The normal or adequate serum zinc level in cattle is 70 to 140 ug/100 ml, the deficient level is 20 to 40 ug/100 ml, the low borderline level is 50 to 60 ug/100 ml, and the toxic level is 520 to 7500 ug/100 ml (Puls, 1981). Plasma zinc is quickly reduced in animals fed a severely deficient diet. However, individual variability of plasma zinc levels is high compared to differences caused by a marginal deficiency, and many other factors and diseases affect these levels, so a borderline deficiency has much less effect on the levels of plasma zinc (Miller, 1974).

Since clinical symptoms of borderline deficiency are nonspecific, and given the individual variability in plasma or serum zinc (Miller, 1974), probably the best way to diagnose a deficiency is through analysis of the diet, combined with blood analysis and observation of clinical symptoms.

Copper

Adequate copper levels in blood serum in cattle are in the range of 80 to 150 ug/100 ml, deficient levels are 6 to 70 ug/100 ml, marginal or borderline deficient levels are 55 to 80 ug/100 ml, high levels are 250 to 400 ug/100 ml, and toxic levels are 400 to 1100 ug/100 ml (Puls, 1981). Copper poisoning causes the concentration of copper in the liver and blood to increase. Blood serum copper concentrations of 500 to 2000 ug/100 ml have been observed during the hemolytic crisis of copper poisoning (Merck, 1979).

Since the liver is the organ where copper is stored, analysis of the liver is a good indicator of copper status. However, because of the comparative ease in taking samples, blood plasma copper is often the measurement used. A better measure of copper status is ceruloplasmin activity in serum (Miller, 1974).

As with the other minerals, diagnosis of copper status is better made by a combination of observing clinical symptoms, animal performance, and response to supplementation, and taking biochemical measurements.

Cobalt

According to Puls (1981), adequate cobalt blood serum in ruminants is 0.04 to 0.06 ug/100 ml, marginal or borderline deficient is 0.025 to 0.035 ug/100 ml, and deficient is 0.004 to 0.02 ug/100 ml. Measurement of cobalt in serum is difficult due to the low concentrations present. Barfoot and Pritchard (1980) report a wide variation of human serum cobalt values depending on the technique used. The values reported range from 0.003 to 110 ug/100 ml. Using flameless atomic absorption spectrophotometry the authors measured an average of 0.12 to 0.20 ug/100 ml in serum of healthy adult human beings. McAdam and O'Dell (1982), also using atomic absorption, measured cobalt and other minerals in the plasma of dairy cows during a whole lactation and gestation. At the fourth week after calving plasma cobalt was between 8 and 9 ug/100 ml; then it dropped to values between 5 and 6 ug/100 ml in the tenth to the 22th week, and rose again to values between 7 and 8 ug/100 ml from the 28th to 46th week. The serum cobalt values were similar for young cows (first-calf heifers) and mature cows (two or more calvings), and for animals fed plain salt and trace mineral salt containing 0.007 cobalt. The general average for all treatments throughout lactation was 7.6 ug/100 ml.

Due to the analytical difficulties and the variation of the values reported, serum analysis is perhaps not the best way to diagnose cobalt deficiencies in cattle. The analyses of vitamin B12 in blood, liver and rumen fluid can be good methods to determine cobalt status. Since cobalt deficiency is a regional problem, cobalt analysis in the soil and in pastures is a helpful guide to the animal's cobalt status (Miller, 1974).

Manganese

Normal manganese levels in blood serum of cattle are around 2 to 3 ug/100 ml (Church, 1976). Puls (1981) considers 0.5 ug/100 ml a marginal or borderline manganese concentration in blood serum, and 0.6 to 3.0 ug/100 ml adequate.

The manganese content of most body tissues is remarkably resistant to change because of low intake. However, some reduction occurs in the liver, bone, and hair of deficient animals (Miller, 1974). Monitoring feed levels seems to be the best diagnostic aid for determining manganese status in cattle (Puls, 1981).

Selenium

The concentration of selenium in an animal's blood is a good indicator of either selenium deficiency or adequacy. Blood plasma levels of 1 to 5 ug/100 ml indicate selenium deficiency; selenium should be added to the diet. A blood level of about 10 ug/100 ml is desirable. Blood levels of about 20 ug/100 ml or higher indicate that the animal is receiving too much selenium and that a toxic situation may exist (Marczewski et al, 1982).

Analysis of glutathione peroxidase and measurement of the selenium content of the diet can also be used to establish selenium status and the adequacy of the diet for the the animal (Miller, 1974).

Iodine

Adequate iodine content in blood serum of cattle is considered to be 15 to 40 ug/100 ml, deficient to be 3 to 10 ug/100 ml, excessive to be 90 to 300, and chronically toxic to be 200 to 1500 ug/100 ml (Puls, 1981).

Feed iodine is not widely used in diagnosing a deficiency problem, especially when goitrogens are included in the diet. Probably the best diagnostic help is a knowledge of the area, since iodine deficiency is a problem in localized regions. Iodine deficient areas are known for most parts of the world, and are mapped with the help of clinical observations and statistics of goiter occurrence, especially in humans (NRC, 1970).

Blood Analysis

Blood is the most widely used tissue for studies in mineral nutrition. It reflects the mineral status of the animal, and can be obtained frequently and easily without harm to the animal (Underwood, 1981). The normal values or normal range of concentrations in the blood serum or plasma of healthy farm animals consuming satisfactory diets are known for most of the nutritionally important minerals for comparison with those in the blood of animals under study (Church, 1976; Puls, 1981; Underwood 1977 and 1981).

Most of the blood mineral analysis are made in plasma or serum, and the results are equivalent. Care must be taken to avoid hemolysis of red blood cells (Fick et al., 1979).

A variety of analytical techniques are used for the determination of minerals in blood. The most commonly used are flame atomic absorption for most of the minerals, colorimetry for phosphorus, and fluorimetry for selenium. Since manganese levels in plasma or serum are below the detection limits of flame atomic absorption, flameless atomic absorption is used in this case (Ullrey, 1977). Flameless atomic absorption can also be used to determine cobalt (Barfoot and Pritchard, 1980). Techniques that permit the determination of several elements at once are used in some laboratories. These include neutron activation (Ehmann and Janghorbani, 1979); plasma emission, and inductively coupled plasma discharge spectrophotometry (Barnes, 1979).

Gastrointestinal Parasitism in Dairy Cattle

A knowledge of the degree of parasite infestation is necessary to diagnose mineral or nutritional deficiencies in cattle, since symptoms of parasitism can often be confused with nutritional problems (Underwood, 1981). Parasitized animals, for example, are either more susceptible to copper deficiency, or copper deficient animals are more susceptible to parasitism (Puls, 1981). Anemia, emaciation, poor hair condition, and other symptoms due to parasitism can be confused with copper, iron or other mineral deficiencies or toxicities. The contrary can also be true: symptoms of mineral deficiencies can be attributed to parasitism.

The most common stomach worms of cattle are *Haemonchus placei*, *Ostertagia ostertagi* and *Trichostrongilus axei*. These species belong to the class of the nematodes. Among the trematodes, *Fasciola hepatica* is the most important parasite of domestic ruminants and the most common cause of liver fluke disease in the United States and other temperate areas of the world. The protozoans *Eimeria zuernii* and *Eimeria bovis* are the species of coccidia most often associated with clinical cases of coccidiosis in cattle (Merck, 1979).

Nematodes

In 1980, there were approximately 10.9 million dairy cows and 4.2 million dairy replacement heifers in the United States. Although surveys show a high prevalence of nematode infection nationwide in adult dairy cows, most show low worm burdens and egg counts of less than 10 epg. The question of whether low-level nematode infections reduce milk production in commercial dairy cows is controversial. The effects of parasitism in adult cows appear to depend partly on regional differences in pasture versus drylot management . There is more consistent agreement that both clinical and subclinical parasitism result in substantial economic losses in the raising of dairy replacement heifers. Heavy worm burdens and high egg count values can be found in pastured dairy calves and yearlings which may approach the levels found in heavily parasitized young beef animals. Anthelmintic control of this category of animals results in improved weight gain, and there is evidence that dairy heifers protected from subclinical parasitism may produce significantly more milk in their first lactation compared to untreated control animals (American Assoc. Vet. Pathologists, 1983).

Trematodes

In cattle, the liver flukes *Fasciola hepatica* and *Fascioloides magna* are responsible for the condemnation of 1 to 1.5 million livers annually at slaughter inspections. In addition to these losses, reports increasingly indicate that indirect losses due to fasciolasis during the animal's growth and production phases may be far greater. Indirect losses include reduction in average daily weight gain and lower feed conversion ratios in the feedlot, reduced milk production in dairy cattle, and reduced herd performance in cow-calf operations (American Assoc. Vet. Pathologists, 1983).

Protozoa

Coccidiosis due to *Eimeria sp.* is a common disease of the gastrointestinal tract of ruminants. Eimeria zurnii and E. bovis are the most pathogenic of the 14 species found in cattle. Virtually every animal becomes infected with one or more Eimeria species during its lifetime. The disease is insidious and is often diagnosed only after the animal show clinical signs of diarrhea, debilitation, or refusal of feed. Coccidiosis is most clinically important in feedlots, among young dairy animals, and in other situations where young, unexposed stock are placed in contaminated, confined areas (American Assoc. Vet. Pathologists, 1983).

Control

The most widely used measure of parasite control is chemotherapy. At present, 6 anthelmintics are approved for use in cattle: thiabendazole, levamisole, coumaphos, haloxon, phenothiazine and morantel. Thiabendazole (sold under the brand names of Thiaben, Bovizole, Polival, etc.) and levamisole (also known as Tetramisole, Ripercol, Levasole, Tramisol, etc.) have high degrees of efficacy against adult gastrointestinal nematodes and some larvae, and they are the most widely used. Morantel is comparable in efficacy. Levamisol is also active against lungworms. Milk from cows treated with coumaphos does not have to be withdrawn from sale; however, milk from cows treated with other anthelmintics must be withdrawn for a specified period after the cows are treated. New anthelmintics recently approved or in the process of approval by the FDA are the benzimidazole derivatives albendazole, fenbendazole, and oxfendazole, and ivermectin (American Assoc. Vet. Pathologists, 1983).

There is no flukicidal drug available in the United States that is fully approved for use in livestock by the Food and Drug Administration. At one time, hexachloroethane was widely used once or twice a year for control of fasciolasis in cattle and small ruminants. Declared a potential carcinogen, hexachloroethane was removed from the market in 1979. Albendazole, a broad-spectrum anthelmintic still being tested, was subsequently approved for emergency use against F. hepatica and F. magna in cattle and sheep. Restrictions on use, however, limit the potential effectiveness of this drug in reducing economic losses. It is not for use in lactating animals, the withdrawal period is 180 days, it is not for use in the first 45 days of gestation, and it can only be obtained from veterinarians who are responsible for maintaining pre- and posttreatment reports. Albendazole is efficacious against adult F. hepatica in cattle and sheep, but alike hexachloroethane has little effect on immature flukes (American Assoc. Vet. Pathologists, 1983). In other countries, however, there are several flukicides available for cattle including rafoxanide, brotianide and nitroxynil. These compounds can also kill immature flukes (Merck, 1979).

Coccidiosis can be prevented by maintaining sanitary conditions when animals, especially the young, are kept in confinement. The primary usefulness of anticoccidial drugs is to arrest further spread of infection among animals. Certain sulfa drugs and amprolium are the only drugs presently approved for use (American Assoc. Vet. Pathologists, 1983).

Chemotherapy kills adult worms and is effective in treating clinically affected animals, but it does not necessarily provide long-term benefits of preventing pasture contamination. Reinfection may occur in the interval between treatments. Optimum preventive control programs involve integration of several approaches: grazing management, strategic use of anthelmintics, and use of the host's ability to acquire immunity naturally. The strategy is (American Assoc. Vet. Pathologists, 1983):

1) to prevent the buildup of dangerous numbers of infective stages on pastures by reducing contamination with fecal eggs or larvae at critical periods;

2) to reduce acquisition of infections by anticipating periods during which large numbers of larvae are likely to occur; and

3) to remove susceptible animals from heavily contaminated pasture before these periods.

The essential requirement of integrated, preventive control is the provision of "safe" pasture for susceptible animals at appropriate times (American Assoc. Vet. Pathologists, 1983).

Diagnosis

The clinical signs associated with gastrointestinal parasitism are shared with many diseases and conditions; however, presumptive diagnosis based on history and sypmtoms is often justified and infection can usually be confirmed by the presence of eggs in fecal matter. In evaluating the clinical importance of fecal examination it is important to consider that the number of eggs per gram of feces is not an accurate indication of the number of adult worms. Negative counts can be found despite the presence of a large number of immature worms, due to suppression of egg production by immune reaction or previous anthelmintic treatment and variation in the egg-producing capacity of different worms. On the other hand, specific identification of eggs is difficult and impractical. Postmortem examinations are the most direct method of identifying and quantitizing gastrointestinal parasitisms (Merck, 1979).

At present there are no immunologic techniques available for practical use in antemortem assessment of the extent of nematode parasitism. Plasma pepsinogen tests for diagnosis of ostertagiasis have been used essentially as a survey monitoring tool, but such tests are most useful when animals are being tested repeatedly over an extended period. Recent experience indicates that serological procedures may have value for diagnosis of *F. hepatica* and *F. magna* infections, compared with time consuming fecal examinations. There are no reliable antemortem parasitologic diagnostic methods for cestodes or the important protozoans in animals (American Assoc. Vet. Pathologists, 1983).

MATERIALS AND METHODS

Samples were taken from three farms in each of five milk producing regions around Riobamba (altitude 2,754 m, 1^{o} 40' S, 78^{o} 39' W) the capital of the Chimborazo province in Ecuador. The regions sampled were the most important in milk production for the city, and ranged in altitude from around 3,000 m (9,840 ft) to 4000 m (13,120 ft). The regions chosen correspond to different geological formations on the slopes of the Andes. Average temperatures in the regions range from 6 to 11^{o} C (43 to 52^{o} F) throughout the year. Frost in the mornings is common at these altitudes. Precipitation ranges from 400 mm (16 i) to 1200 mm (40 i). The dry season lasts from July to September (Terán, 1979). Most of the farms had some form of irrigation at the time the samples were taken (July to September 1982). One dairy farm in the United States, located in Shiawasee county in the State of Michigan, was also sampled for comparison with the farms in Ecuador. Table 1 shows the names of the regions, their altitude above sea level, and their approximate geographical coordinates.

Blood serum samples were taken on each farm from the tail vein or artery of 10 adult milking cows and 10 animals under one year of age. Approximately 30 ml of blood were collected from each animal in test tubes without coagulant. Blood samples were left standing at room temperature from 4 to 10 hours prior to centrifugation. The test tubes with blood were then carried to the laboratory where they were centrifuged and the blood serum was separated. Blood serum was stored frozen in plastic

Table 1. Altitude above sea level and approximate geographical coordinates of five regions from the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

REGION		NAME	ALTITUDE ABOVE SEA LEVEL	LONGITUDE	LATITUDE
			m	degrees-min-sec	
1	ECUADOR	Chambo	2900	S 1°40'30''	W 78°30'33''
2	ECUADOR	San Juan	3200	S 1°30'26''	W 78°40'46''
3	ECUADOR	San Andrès	3600	S 1°29'57''	W 78°40'15''
4	ECUADOR	Guamote	3200	S 1°50'42''	W 78°40'16''
5	ECUADOR	Quimiac	3000	S 1°30'42''	W 78°30'16''
6	MICHIGAN	Lainsburg	240	N 42°57'33''	W 84°19'51''

(1) N,S: North, South longitute; W: West latitude; m: meters

containers. Serum was thawed at room temperature prior to analysis.

Five composite samples of pastures and soils were taken from each farm. Soil and pasture samples were collected from each field (2-5 hectares) by walking in zig-zag line. A total of 20 to 50 samples were collected from each field.

Soil samples were taken with a soil probe at a depth of 15 to 20 cm. Samples were air dried at room temperature. Dry soil samples were then crushed until a major portion of the sample passed a 10-mesh (U.S. No. 10) sieve.

Pasture samples were taken by hand at a height of approximately 20 cm from the ground. Half of each pasture sample was washed with distilled water to assess soil contamination. Pasture samples were dried in forced air ovens at 60^{o} C and ground to a particle size of aproximately 1 mm.

Grab samples of feces for parasite analysis were taken from each animal that was bled. Feces samples were kept in plastic bags and refrigerated until they were analyzed within 24 hours after collection.

A split plot design (Gill, 1978a, b and c) was used to analyze the results (Table 2), and the contrasts among all the means of the regions were tested with a Bonferroni t test (Gill, 1978a, Games, 1977). The SPSS (Statistical Package for the Social Sciences) program was used in the computer processing of the data (Nie et al., 1975; Hull and Nie, 1981).

Soil samples were taken, prepared and analyzed according to the procedures recommended for the North Central Region of the

Table 2. Statistical designs for the analysis of soil, pasture, and blood data (1)

SOIL

Source of variation	Degrees of freedom
REGION	5
FARMS/REGION	10
SAMPLES/FARM/REGION	72
TOTAL	87

Farms region is the error term for region, and samples/farm/region is the error term for farms/region

PASTURE AND BLOOD

Source of variation	Degrees of freedom	
	PASTURE	BLOOD
REGION	5	5
FARMS/REGION	10	10
TYPE OF SAMPLE	1	1
REGION X TYPE	5	5
FARMS/REGION X TYPE	10	10
SAMPLES/FARM/REGION/TYPE	130	288
TOTAL	161	319

Farms/region is the error term for region, and samples/farm/region/type plus farms/region X type is the error term for farms/region, type, and for the interaction region X type

(1) Gill, 1978a, b and c

United States (Bulletin No. 499, 1980). Phosphorus was extracted with Bray-1 solution (Knudsen, 1980). Calcium, magnesium, sodium and potassium were extracted with 1N ammonium acetate of pH 7.0 (Carson, 1980). Copper was extracted with 1N HCl. Iron, manganese, zinc and cobalt were extracted with 0.1 N HCl (Whitney, 1980). Molybdenum was extracted with Tamm's reagent: ammonium oxalate solution at pH 3.3 (Reisenauer, 1965). Sulfur was extracted with monocalcium phosphate solution (500 ppm P) (Eik, 1980). Nitrates were extracted with a saturated solution of calcium hydroxide (Carson, 1980). Total selenium in the soil was determined after wet digestion with nitric and perchloric acid (Whetter and Ullrey, 1978).

Pasture samples were taken, prepared and analyzed in accordance with the procedures of the University of Florida (Fick et al., 1979). Half of the fresh pasture sample from each field was washed with distilled water to assess soil contamination. Selenium content was determined after wet digestion with nitric and perchloric acid (Whetter and Ullrey, 1978). To measure the amounts of other metals in the pastures, samples were ashed overnight at 600^{o} C and the ash dissolved with hydrochloric acid (Fick et al., 1979).

Blood serum samples were deproteinized with trichloroacetic acid (Fick et al., 1979). Selenium content was determined after wet digestion of the whole serum sample with nitric and perchloric acid (Whetter and Ullrey, 1978). To determine manganese content, the serum samples were mixed 1:1 with water. Ten serum samples were pooled for cobalt analysis. Ten ml of serum were freeze dried and ashed at 600° C overnight. These ashes were dissolved with HCl, chelated with 1-nitroso-2-naphthol and extracted with chloroform. After evaporation to dryness, the samples were redissolved with 0.5 ml chloroform for cobalt analysis (Barfoot and Pritchard, 1980).

The pH of soils was determined by suspending 5 g of soil in 5 ml of water (McLean, 1980). Texture of soils was determined by the Bouyoucus method (Bouyoucos, 1951). Organic matter in soils was measured as carbon after oxidation with potassium dichromate by titration with ferroin indicator (Schulte, 1980). Nitrate content in soils was determined with the phenoldisulfonic acid method (Carson, 1980). The turbidimetric determination of barium sulfate content (Eik, 1980) was used for the analysis of sulfates. The ash, crude protein and crude fiber composition of the pastures was determined according to the A.O.A.C. (1975) procedures. Phosphorus in soils, pastures and blood serum was measured colorimetrically as phosphomolybdic acid at 600 nm (Harris and Popat, 1954). Selenium content in soils, pastures and blood serum was determined fluorimetrically (Whetter and Ullrey, 1978). Molybdenum content in soils and pastures, and cobalt and manganese content in soils, pastures and blood serum was determined by flameless atomic absorption spectrophotometry (Perkin, 1981). All other metal contents in soils, pastures and blood serum were determined using atomic absorption spectrophotometry with an air-acetylene flame (Perkin, 1982). Parasite egg counts were determined by the direct flotation method (Cox and Todd, 1962). Fasciola hepatica eggs were determined using a fluke ova sedimentation technique (Dennis et al.,1954).

RESULTS AND DISCUSSION

This chapter of results and discussion is divided into four parts: 1) minerals in soils; 2) nutrients in pastures; 3) minerals in blood; and 4) gastrointestinal parasites.

The levels of minerals found by soil analysis in the present investigation were compared with levels at which there is a possible response of a crop to fertilization, whenever there was information available on this in the literature. The implications for forage production of the level of minerals found in the soils, as well as the effect of soil pH, texture, and organic matter content, are discussed. Where appropiate, recommendations for fertilization are made.

The concentrations found in this study of nutrients in pastures are compared to the requirements of animals for these nutrients. Whenever the pastures do not provide adequate amounts of a given nutrient, recommendations for supplementation of the diet are made. When the crop is responsive to fertilization, or when the level of an element can be increased through addition of the element to the soil, suggestions for fertilization are also made.

The concentrations of minerals in blood found in this investigation are compared to values considered normal in the literature reviewed. When the mineral concentration in the animals tested in this study does not fall within the range considered typical, and/or the diet is inadequate, suggestions on how to prevent a deficiency are made.

Finally, fecal egg counts for gastrointestinal parasites are discussed because the detrimental effects of parasitism on animal production resemble the detrimental effects of mineral deficiencies. Suggestions for parasite control in the areas studied are made.

Minerals in Soils

Fertilization Practices in Ecuador

In Ecuador, particularly in the regions where the present investigation was carried out, pastures generally are not fertilized. However, crop rotation is a common practice. After a period of years, generally four to six, of dedicating the land to pasture, the soil is plowed, disinfected and fertilized, usually in preparation for potato cultivation. In this case around 136 kg of N, 400 kg of P2O5, and 136 kg of K2O are applied per hectare (120 lb of N, 360 lb P2O5, and 120 lb of K2O per acre). After one to four years of use for growing the alternate crop, the land is returned to pasture. A mixture of biannual rye-grass (*Lolium multiflorum*) and white clover (*Trifolium repens*) is the most commonly used pasture seed. Fescue (*Festuca sp.*), orchard grass (*Dactylis glomerata*), timothy (*Phleum pratense*), red clover (*Trifolium pratense*), and other species are used occasionally. Some farms grow alfalfa, and in some cases oats, rye or wheat are raised to be used for greenchop for the animals. In most of these situations no chemical fertilizer is applied to the soil, but the farmer takes advantage of the residual fertility from the previous crop. On some other farms, pastures are permanent. On these farms the soil is plowed and the mixture of grass and legume seed is planted every four to six years, generally without soil fertilization. Since the animals are grazing on the pasture, most of their manure reverts to the field. In Michigan, in contrast, fields used for growing corn and alfalfa, the main crops grown for animal forage, are fertilized every year with nitrogen, phosphorus and potassium, and occasionally microelements such as boron, molybdenum and copper.

Soil Analysis

Mineral analysis of pastures and soils is a very useful tool to diagnose deficiencies or excesses in forages for animals. In general, low levels of a particular element in the soil will result in the growth of vegetation low in that element. This in turn will produce a deficiency in animals fed with that plant material. The same principle applies to excesses of minerals. Mineral concentration in the soil does not always correlate well with the mineral content in the plant or with the mineral status of the animal. This is mainly due to the variation in the ability of different plant species, or even different varieties of the same species, in extracting mineral salts from soils, and to homeostatic mechanisms in the animals (Underwood, 1981). Plant tissue analysis, combined with soil analysis, is used by the soil scientists to diagnose the mineral status of the soils (Jones, 1972).

Soil pH

Soils from the regions of Ecuador and Michigan (Table 3, Figure 1), ranged from 5.78 to 6.71 pH. Out of a total of 88 samples from individual fields, 11% were in the range of 5.00-5.49 pH, 17% from 5.50 to 5.99, 26% from 6.00 to 6.49, 26% from 6.50 to 6.99, 9% from 7.00 to 7.49, 9% from 7.50 to 7.99, and 1% from 8.00 to 8.49. The difference among regions was not significant ($p > .05$), but the difference among farms within

Table 3. Soil pH, organic matter, and texture from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

		pH		ORGANIC MATTER %		TEXTURE: SAND %		TEXTURE: CLAY %		TEXTURE: SILT %	
REGION (2)	N	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)
1 ECUADOR	15	6.71	(0.33)	3.8	(1.61)	56	(3.47)	19^{ab}	(1.42)	25	(2.64)
2 ECUADOR	15	6.30	(0.33)	10.6	(1.61)	52	(3.47)	15^{abc}	(1.42)	33	(2.64)
3 ECUADOR	15	5.78	(0.33)	10.9	(1.61)	66	(3.47)	10^{c}	(1.42)	24	(2.64)
4 ECUADOR	15	7.17	(0.33)	4.9	(1.61)	60	(3.47)	14^{bc}	(1.42)	27	(2.64)
5 ECUADOR	15	6.58	(0.33)	8.1	(1.61)	65	(3.47)	11^{c}	(1.42)	24	(2.64)
6 MICHIGAN	13	5.97	(0.36)	2.3	(1.73)	55	(3.73)	22^{a}	(1.53)	23	(2.94)
Significance of F (3)											
Region		NS		*		NS		**		NS	
Farm/region		**		**		NS		*		NS	

(1) N, $\overline{X}$, SEM: number of observations, means and standard errors of means
(2) Region means within a column without a common superscript are different ($p < .05$)
(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

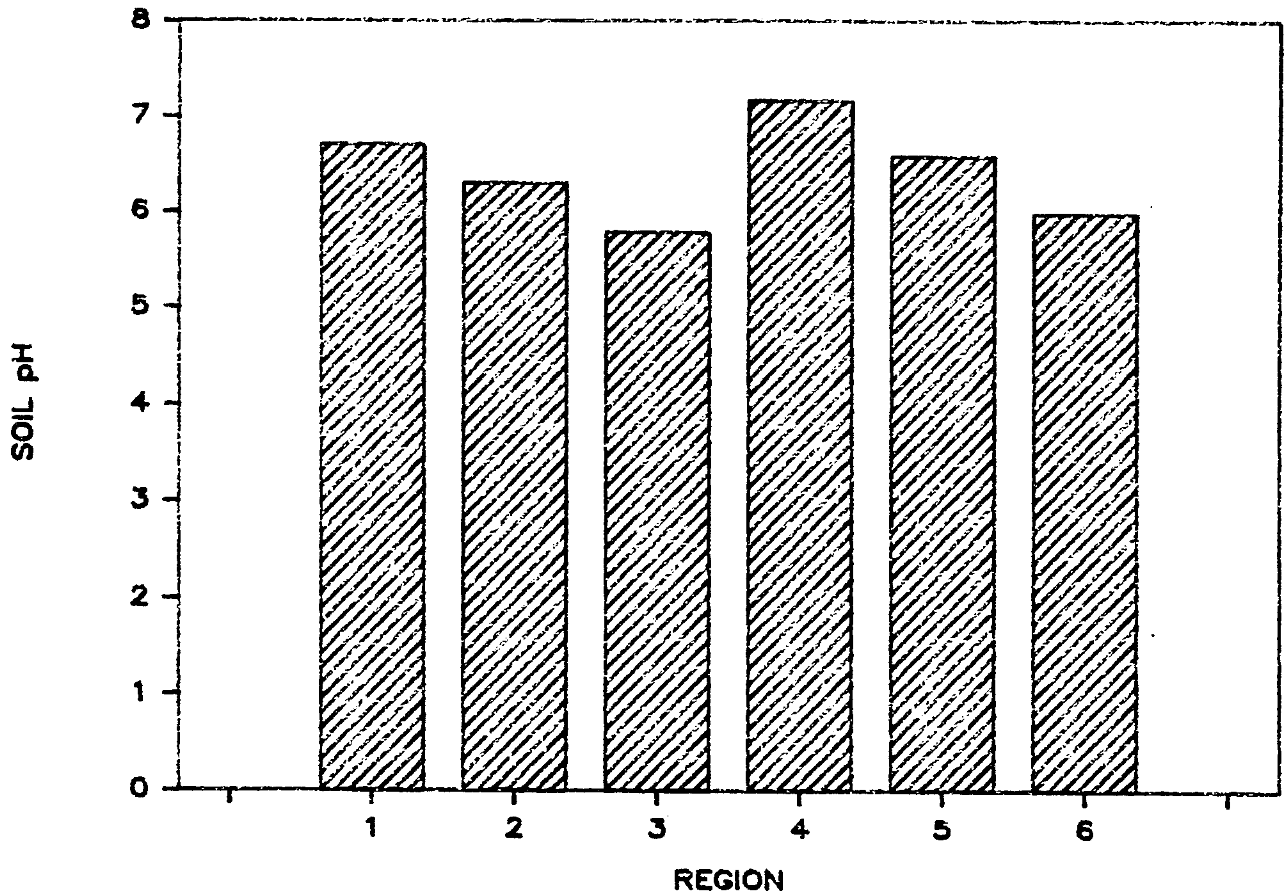

Figure 1. Soil pH in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

regions was highly significant ($p < .01$). The correlation coefficient among soil pH and calcium in the soils was 0.393.

Liming is not a common practice for pasture cultivation in Ecuador. From the fields tested, 26% had less than 6.0 pH and may need liming for better forage production. The recommended pH for alfalfa cultivation is 6.8 (Christenson et al., 1983). In the case of mixed pastures, a pH of 6.8 would favor the growth of legumes and improve the quality of the sward. Increased legume growth augments dry matter yield not only of the legume but also of the grasses, because more nitrogen is available to them. Table I.4 (Appendix I) shows the liming recommendations based on soil pH made by the Extension Service of Michigan State University. Soil pH is not, however, the best criterium for liming. Limestone requirements of the soil are best estimated by the Shoemaker, McLean and Pratt's method (McLean, 1980).

Organic Matter

Organic matter supplies nutrients to the soil, contributes to its ion exchange capacity and improves its structure (Schulte, 1980). A knowledge of the organic matter content is helpful in estimating the cation exchange capacity and the nitrogen-supplying power of the soil (Tisdale and Nelson, 1975). Organic matter content of Ecuador and Michigan soils (Table 3, Figure 2) ranged from 2.3% in region 6 in Michigan to 10.9% in region 3 in Ecuador, and the difference among regions ($p < .05$) and among farms within regions ($p < .10$) was significant.

It is possible that soils in Ecuador had a higher organic matter content than soils in Michigan because animals were

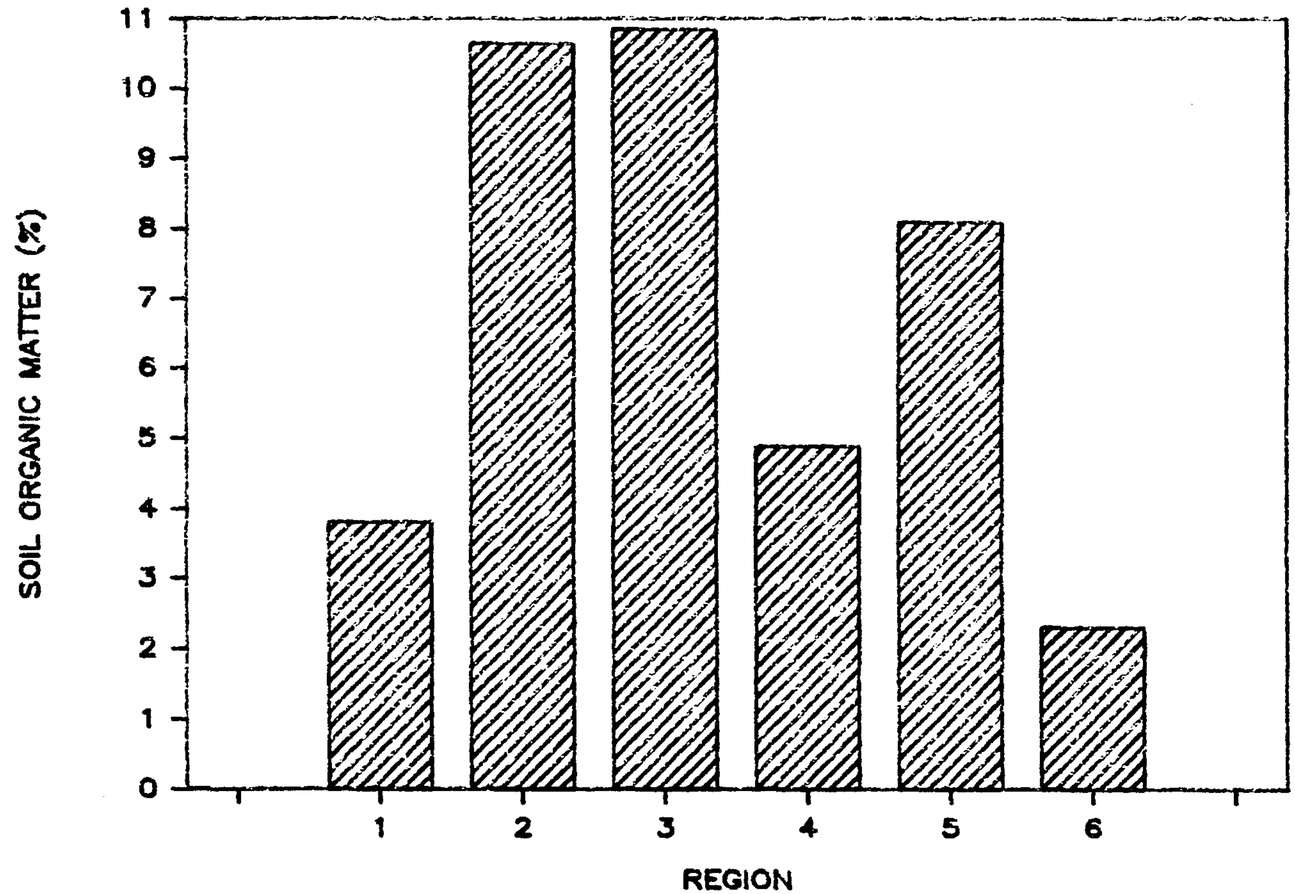

Figure 2. Soil organic matter in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

grazing on them all year and there was a greater accumulation of manure. Another possible explanation for the difference in organic matter content is that the Ecuadorean soil samples taken from grass-legume pastures may have contained more roots than the Michigan samples, which were taken from between the rows of crops in alfalfa and corn fields. Despite the higher values found, it is possible that organic matter in the Ecuadorean regions sampled had less chance of being metabolized by plants than the organic matter in the Michigan samples, because of the relatively low temperatures prevailing in these parts of Ecuador all year (6 to 11^{o} C). In Michigan, samples were taken in the month of September, when temperatures were relatively high.

Soils are considered organic when they have an organic matter content greater than 20% (Wrancke and Christenson, 1980), so the soils analyzed from Ecuador and Michigan fall in the category of mineral soils.

Texture

Soils from the regions sampled in Ecuador were mostly sandy loam, while the soils from Michigan ranged from sandy clay loam to sandy loam (Table 3). Sand and silt percentage did not differ significantly among regions or among farms within regions ($p > .05$). Clay percentage differed among regions ($p < .01$), ranging from 10% in region 3 of Ecuador to 22% in the soils from Michigan. The difference in clay percentage among farms within regions was also significant ($p < .05$).

Nitrogen

The nitrogen status of the soil depends on several factors.

Organic matter content is one. Organic soils generally contain more nitrogen than mineral soils. The type of crop previously grown on the soil also has an effect, since alfalfa and other legumes contribute nitrogen to the soil. Other important factors include previous nitrogen application, manure application, and environmental conditions under which the previous crop was raised (for example drought or pests will decrease the yield of a legume crop and therefore the nitrogen supply for the next crop. The rate of fertilization depends on the nitrogen requirements of the crop to produce the potential or desired yield, minus the nitrogen content of the soil (Vitosh et al., 1979). In the soils from Ecuador and Michigan (Table 4, Figure 3) the difference among soil nitrogen contents in the regions was significant ($p < .05$), and the difference among farms within region was not ($p > .05$).

Nitrogen fertilization is necessary for corn production and for pastures if the stands consist of only grass. For mixed pastures, or for alfalfa, nitrogen fertilizer is not needed when there is a good proportion of legumes in the association and manure is reverted to the fields. Indeed, heavy nitrogen application to grass-clover pastures results in a loss of clover from the association due to competition for light, moisture and nutrients, particularly potassium (Donald, 1958).

The Michigan State University Extension Service recommendations for nitrogen fertilization of corn are shown in Table I.5 (Appendix I).

Table 4. Nitrates, phosphorus, potassium, calcium, and magnesium concentrations in soils from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

		NITRATE-NITROGEN ppm		PHOSPHORUS ppm		POTASSIUM ppm		CALCIUM ppm		MAGNESIUM ppm	
REGION(2)	N	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)
1 ECUADOR	15	11.9	(2.11)	25.7	(10.9)	514	(94)	3303	(318)	804^{a}	(39)
2 ECUADOR	15	12.8	(2.11)	10.2	(10.9)	229	(94)	3045	(318)	814^{a}	(39)
3 ECUADOR	15	10.6	(2.11)	38.5	(10.9)	384	(94)	1938	(318)	586^{a}	(39)
4 ECUADOR	15	6.0	(2.11)	15.2	(10.9)	383	(94)	2774	(318)	635^{a}	(39)
5 ECUADOR	15	16.8	(2.11)	13.6	(10.9)	531	(94)	3230	(318)	691^{a}	(39)
6 MICHIGAN	13	15.9	(2.27)	61.6	(11.7)	175	(101)	1704	(342)	308^{b}	(42)
Significance of F (3)											
Region		*		NS		NS		NS		**	
Farm/region		NS		**		**		**		NS	

(1) N, $\overline{X}$, SEM: number of observations, means and standard errors of means
(2) Region means within a column without a common superscript are different ($p < .05$)
(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

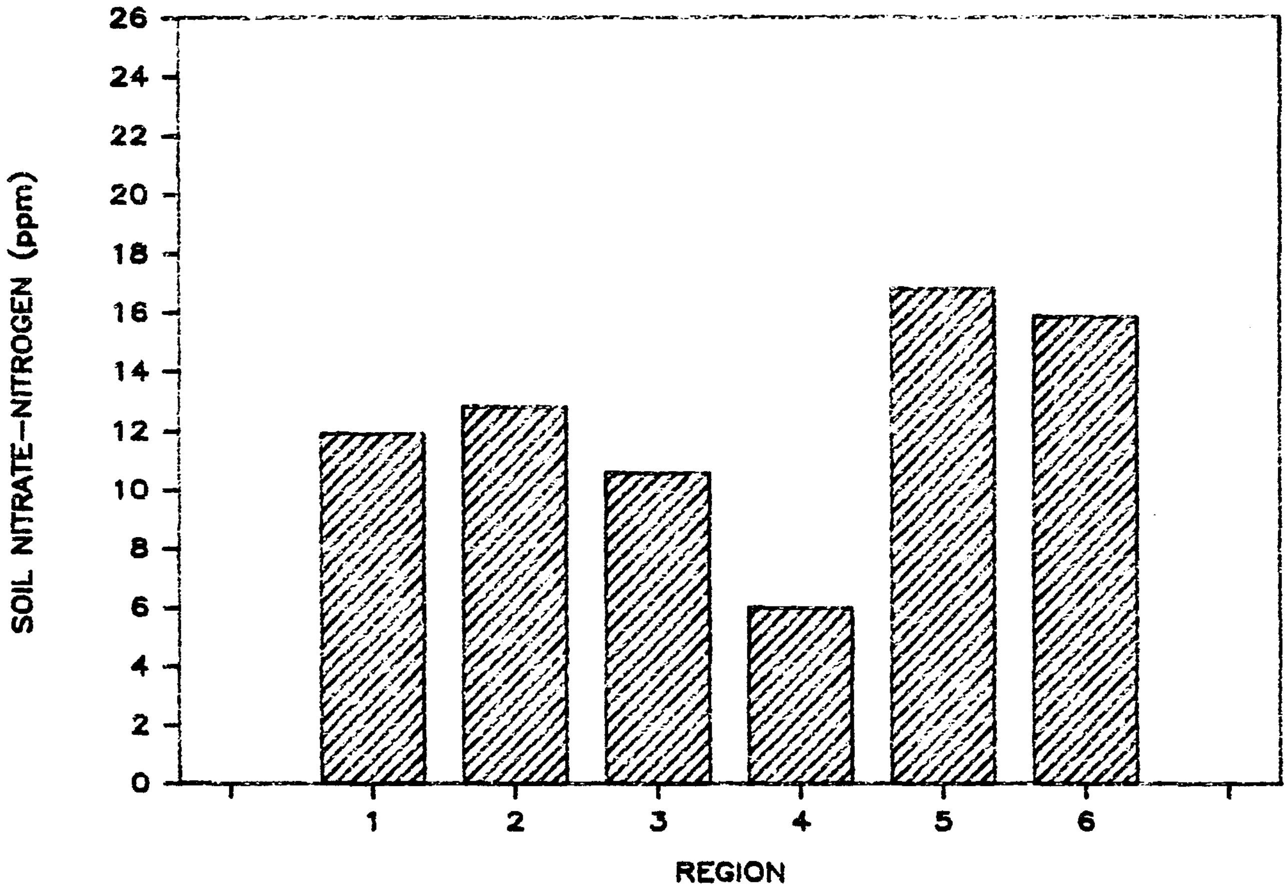

Figure 3. Soil nitrate-nitrogen in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Phosphorus

Different plant species have different requirements for phosphorus. A soil test of 10-20 ppm is considered low, 20-30 ppm medium and 30-50 ppm high for corn (Meints, 1982). Recommendations for fertilization are made on the basis of nutrient removal by the crop, expected crop yield, and, in the case of permanent crops such as alfalfa, maintenance of a good fertility level in the soil. The Michigan State University Extension Service recommendations for phosphorus fertilization for corn and alfalfa are shown in table I.6 and I.7 (Appendix I), respectively.

Soils from regions 2, 4 and 5 from Ecuador (Table 4, Figure 4), had a low phosphorus content for corn cultivation, region 1 had a medium content, and region 5 had a high content. Region 6, in Michigan, had a very high phosphorus content, probably due to recent fertilization. There was no significant difference among the regions ($p > .05$), but the difference among farms within region was significant ($p < .01$).

Potassium

For corn cultivation, a soil potassium test of 0-25 ppm is considered very low, 25 to 75 low, 75-125 medium, 125-175 high, and above 175, very high (Meints, 1982). Region 6 in Michigan had an average of 175 ppm of potassium in the soil. Soils from regions 1 to 5 in Ecuador all contained above 175 ppm of potassium (Table 4, Figure 5), probably due to their volcanic origin. There was no significant difference in potassium content of soils among regions ($p > .05$), but the difference among farms

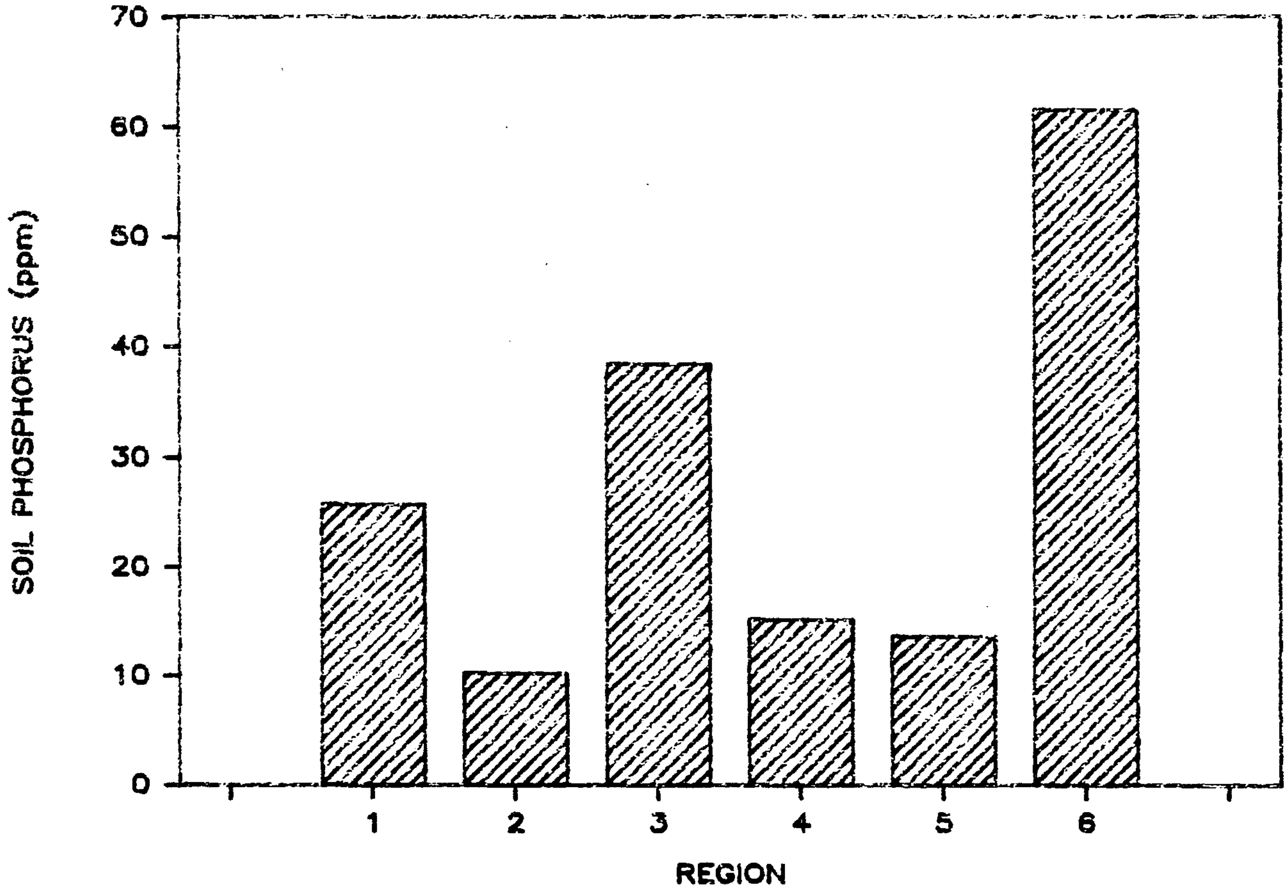

Figure 4. Soil phosphorus in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

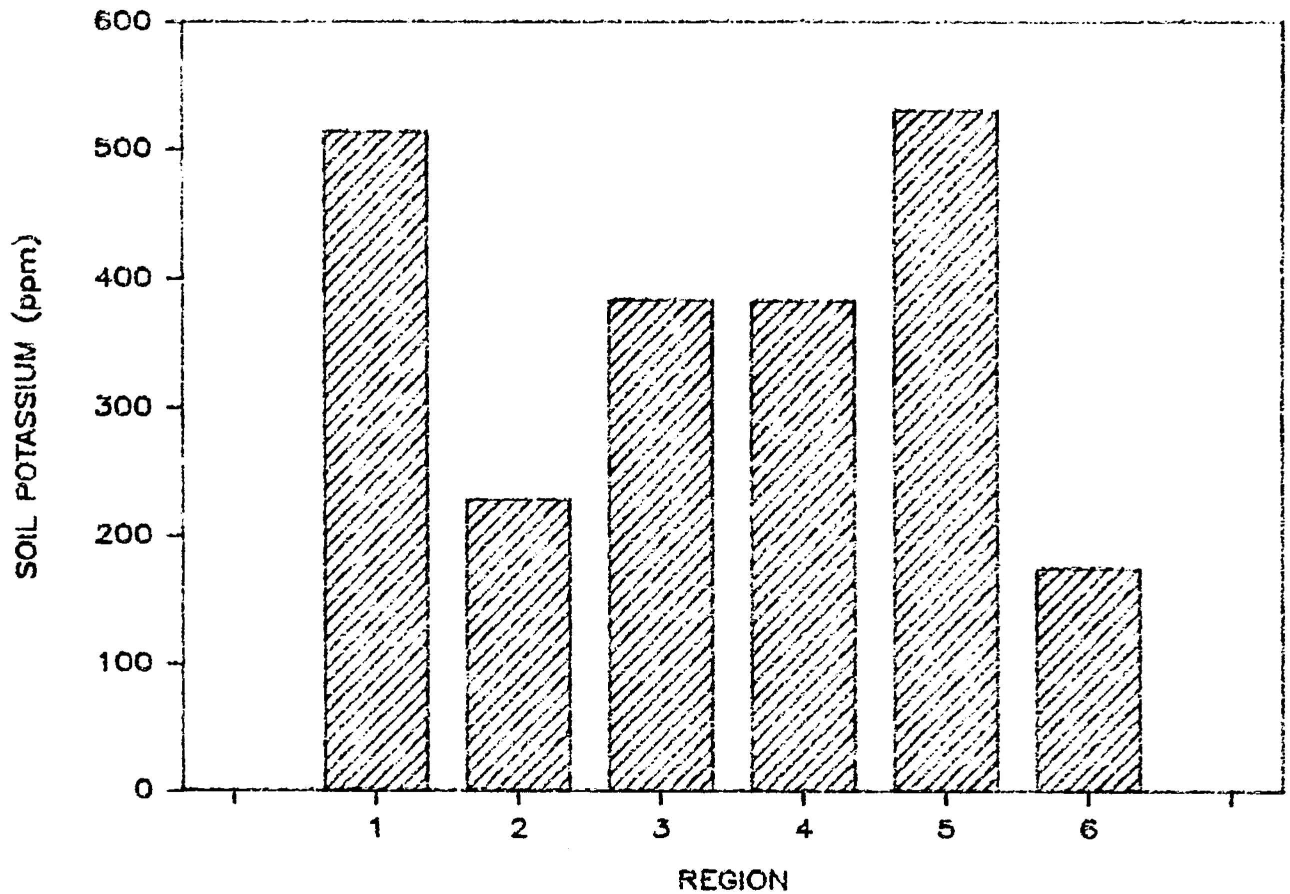

Figure 5. Soil potassium in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

within regions was significant ($p < .01$).

Phosphorus and potassium fertilization are necessary for optimal pasture production. The recommendations for alfalfa (Warncke and Christenson, 1980) can be followed for the fertilization of mixed pastures to favor the growth of legumes. The recommendations for annual phosphorus and potassium fertilization for alfalfa are shown in table I.7 (Appendix I). Recommendations for phosphorus and potassium fertilization for corn are shown in table I.6 (Appendix I).

Calcium

Calcium, although essential for plants and animals, is seldom inadequate in the soil for crop requirements. Testing for calcium content in soils is useful to assess magnesium status in the soil (Robertson et al., 1976a). When the pH of the soil is adequate for plant growth, the calcium content of the soil is likely to be sufficient due to the low requirements of the crops (Robertson et al., 1976a).

In the present investigation, calcium content in soils ranged from around 1700 and 1900 ppm in regions 6 in Michigan and 3 in Ecuador to 2700 to 3300 in the other regions of Ecuador (Table 4, Figure 6). The difference among the means of regions was not significant ($p > .05$), but the difference among means of farms within regions was highly significant ($p < .01$).

Magnesium

According to Vitosh et al. (1981), criteria for recommending magnesium fertilization in Michigan are: 1) the exchangeable magnesium level is less than 37.5 ppm (75 lb/acre); or 2) the

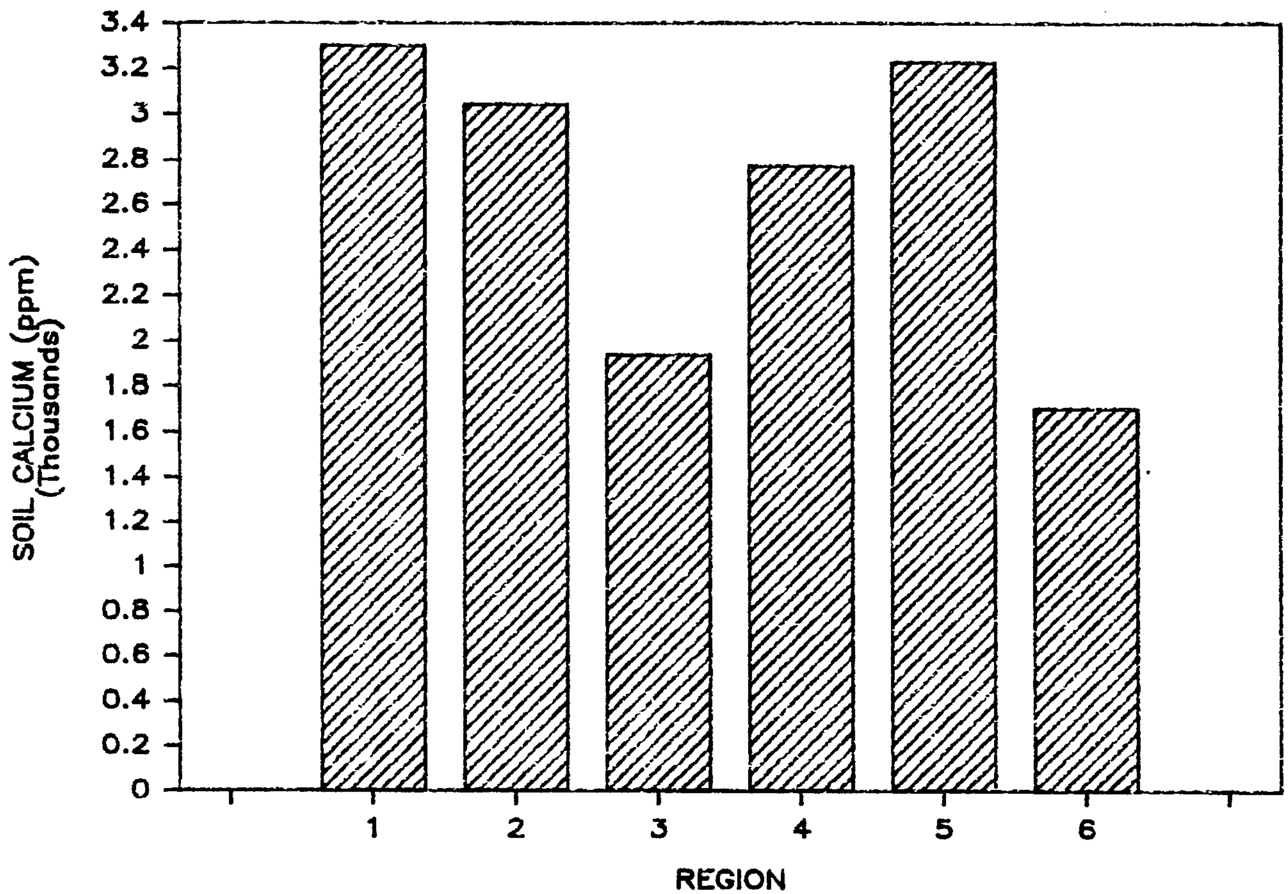

Figure 6. Soil calcium in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

equivalents of potassium exceed magnesium; or 3) the soil magnesium as a percent of total bases (calcium + magnesium + potassium) is less than 3 percent. None of these criteria are met in the samples taken in Ecuador. Magnesium as a percent of total bases was slightly below 3.0 in region 6 (Figure 8). It is possible that responsive crops such as corn will benefit from magnesium fertilization in the area studied in Michigan. Magnesium content in the soils ranged from 308 ppm in region 6 in Michigan to 814 ppm in region 2 in Ecuador (Table 4, Figure 7). The difference among regions was significant ($p < .01$), but the difference among farms within regions was not ($p > .05$).

<u>Sodium</u>

Under most practical conditions animals benefit from sodium supplementation to the diet. Some plant species also benefit from sodium fertilization, depending on the adequacy of potassium in the soil, but forage species are not likely to suffer from sodium deficiency. Sodium becomes important when nitrates are used as a nitrogen fertilizer, because sodium nitrate helps to maintain the soil pH, while continuous use of the ammonium salt lowers the pH in the soil. In this experiment, sodium in soils (Table 5, Figure 9) ranged from 131 ppm in region 5 in Ecuador to 252 ppm in region 4 in Ecuador. Soils from Michigan, region 6, had an average of 166 ppm sodium. The difference in sodium concentration among regions was significant ($p < .05$), but the difference among farms within regions was not ($p > .05$).

<u>Cobalt</u>

Cobalt is needed by the legume root nodule bacteria system

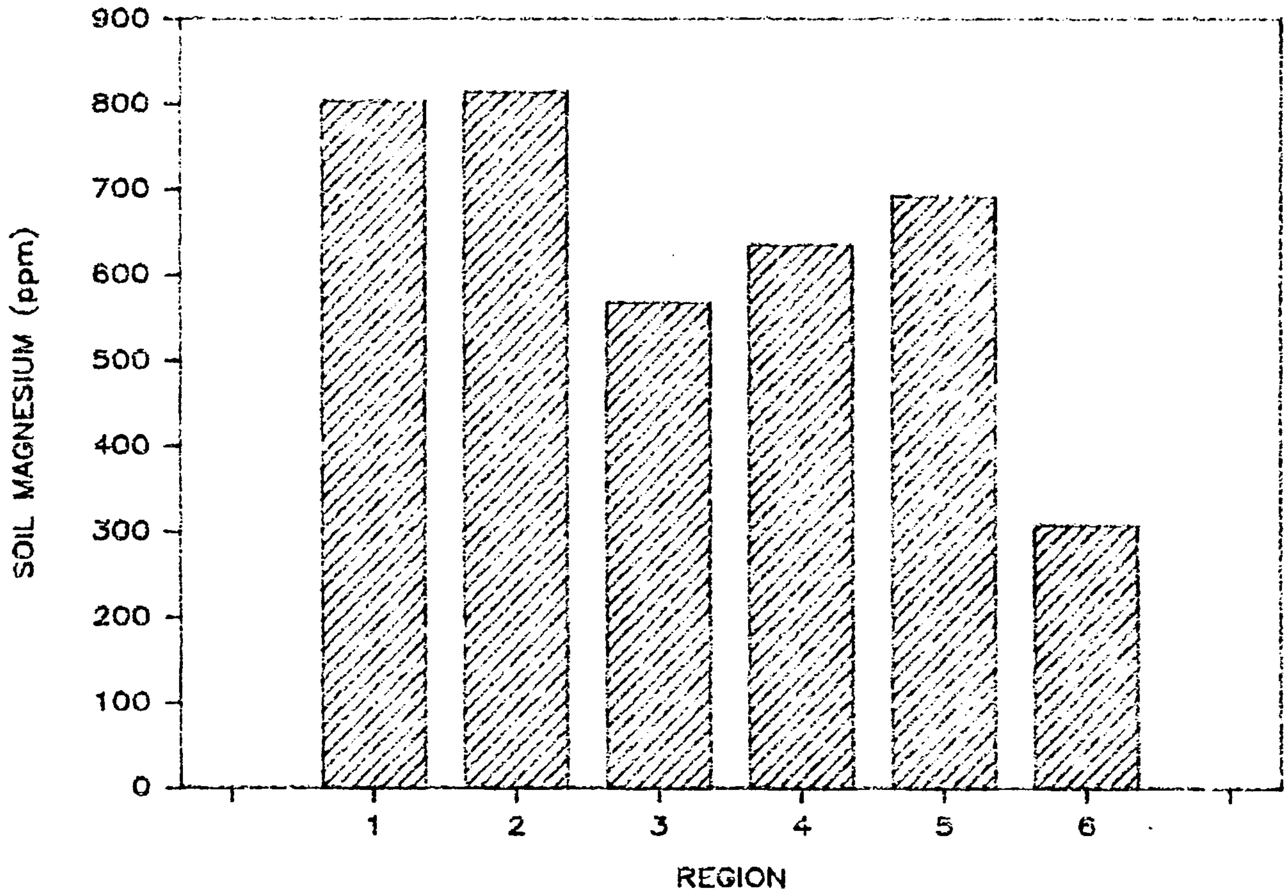

Figure 7. Soil magnesium in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

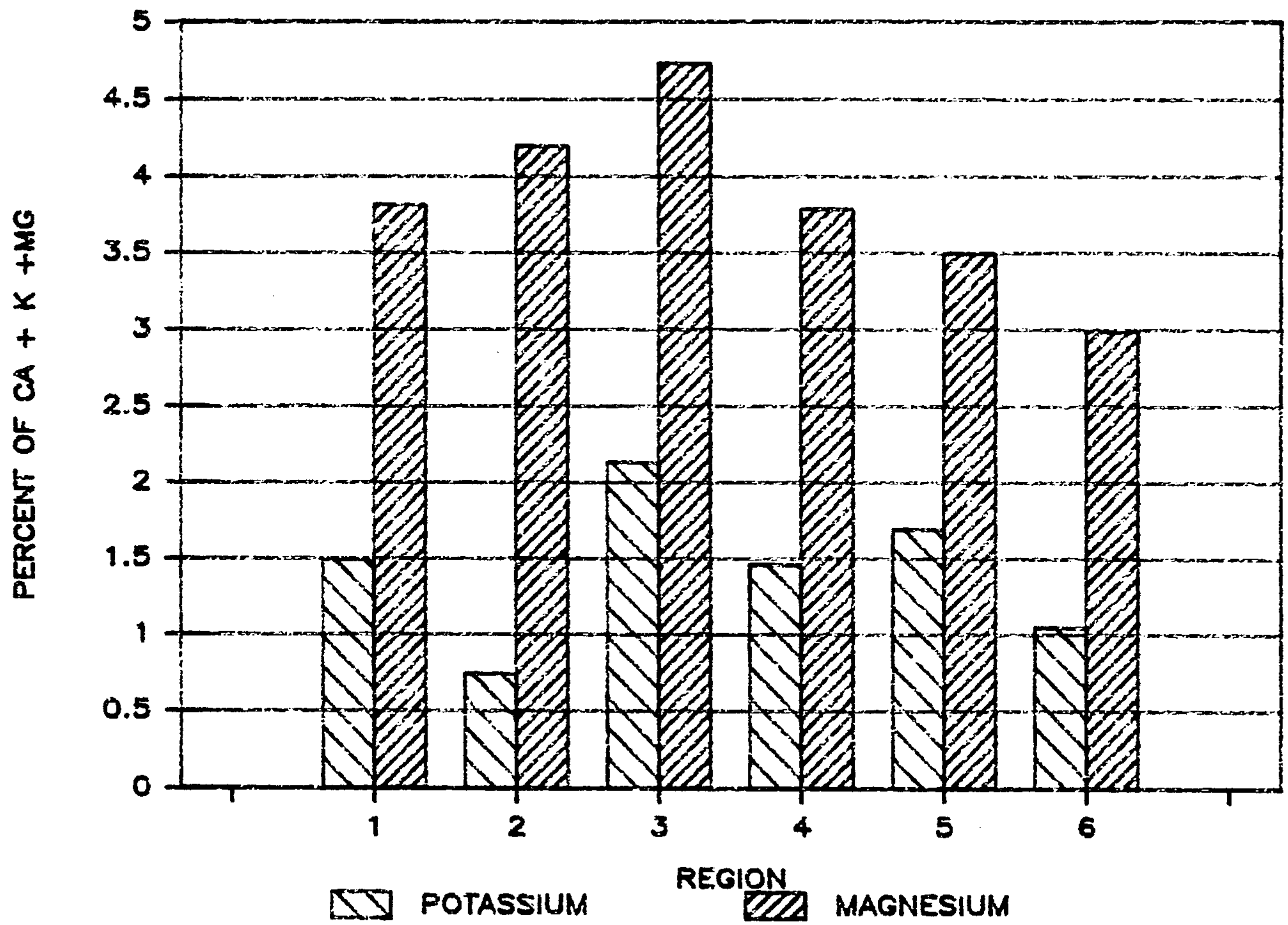

Figure 8. Soil potassium and magnesium as a percent of total bases in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

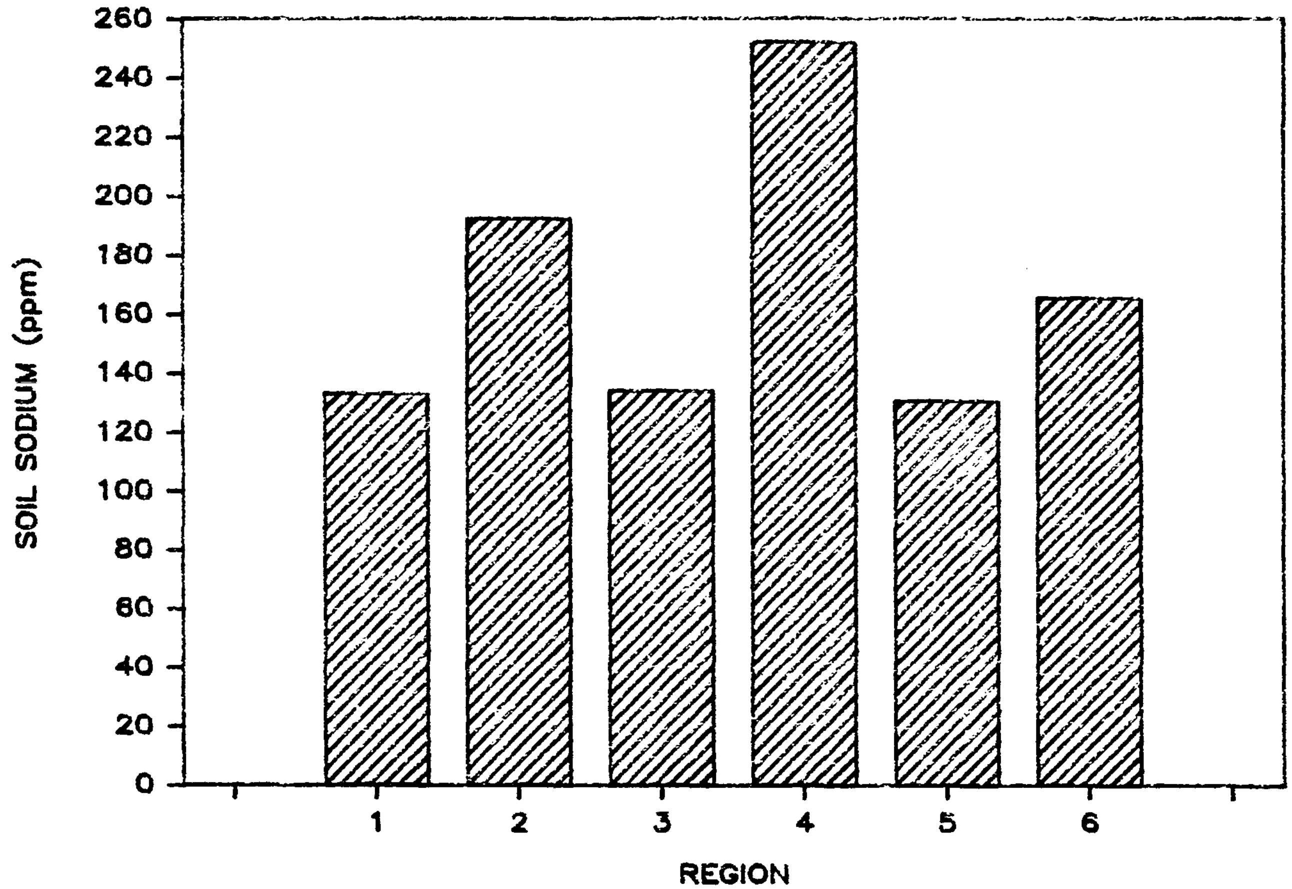

Figure 9. Soil sodium in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

for the fixation of atmospheric nitrogen. Soils are suspected to be cobalt deficient when they have less than 5 ppm of total cobalt content or when legumes grown on them have less than 0.07 ppm cobalt (Kubota and Allaway, 1972). The minimum cobalt requirement of dairy cattle is about 0.10 ppm (NRC, 1978). Cobalt content in the sample soils (Table 5, Figure 10), extracted with 0.1 N HCl, ranged from 0.67 ppm in region 6 in Michigan to 2.53 ppm in region 1 in Ecuador. The difference among regions ($p < .05$) and among farms within region ($p < .01$) was significant.

Iron

The amount of extractable iron in soil depends on the texture, profile and drainage characteristics of the soil. In Michigan (Mokma et al., 1979), the plow layer of well-drained loam and sandy loam soils had 54 ppm iron, and the plow layer of well-drained loamy sand and sand soils had 48 ppm iron. Poorly drained soils of the same textures had higher extractable iron: 119, 145 and 150 ppm respectively. Soil iron is less available for plants at high soil pH values (Robertson et al., 1981a).

In the present study (Table 5, Figure 11), soils from region 6, in Michigan, had an average iron content of 89 ppm. The highest value found was in region 2 of Ecuador: 269 ppm. All the samples were taken from the plow layer. Drainage characteristics ranged from well drained to somewhat poorly drained in the fields sampled. The difference among regions ($p < .05$) and among farms within regions ($p < .01$) was significant.

Table 5. Sodium, cobalt, iron, manganese, and molybdenum concentrations in soils from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

		SODIUM ppm		COBALT ppm		IRON ppm		MANGANESE ppm		MOLYBDENUM ppm	
REGION (2)	N	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)
1 ECUADOR	15	133	(16)	2.53[a]	(0.32)	182[ab]	(29)	114	(13)	0.05[b]	(0.04)
2 ECUADOR	15	193	(16)	2.00[ab]	(0.32)	269[a]	(29)	65	(13)	0.26[a]	(0.04)
3 ECUADOR	15	134	(16)	1.29[ab]	(0.32)	225[ab]	(29)	66	(13)	0.28[a]	(0.04)
4 ECUADOR	15	252	(16)	2.18[ab]	(0.32)	139[ab]	(29)	78	(13)	0.16[b]	(0.04)
5 ECUADOR	15	131	(16)	1.48[ab]	(0.32)	109[b]	(29)	54	(13)	0.23[a]	(0.04)
6 MICHIGAN	13	166	(17)	0.67[b]	(0.34)	89[b]	(31)	60	(14)	0.52[a]	(0.05)
Significance of F (3)											
Region		*		*		*		NS		**	
Farm/region		NS		**		**		**		**	

(1) N, $\overline{X}$, SEM: number of observations, means and standard errors of means
(2) Region means within a column without a common superscript are different ($p < .05$)
(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

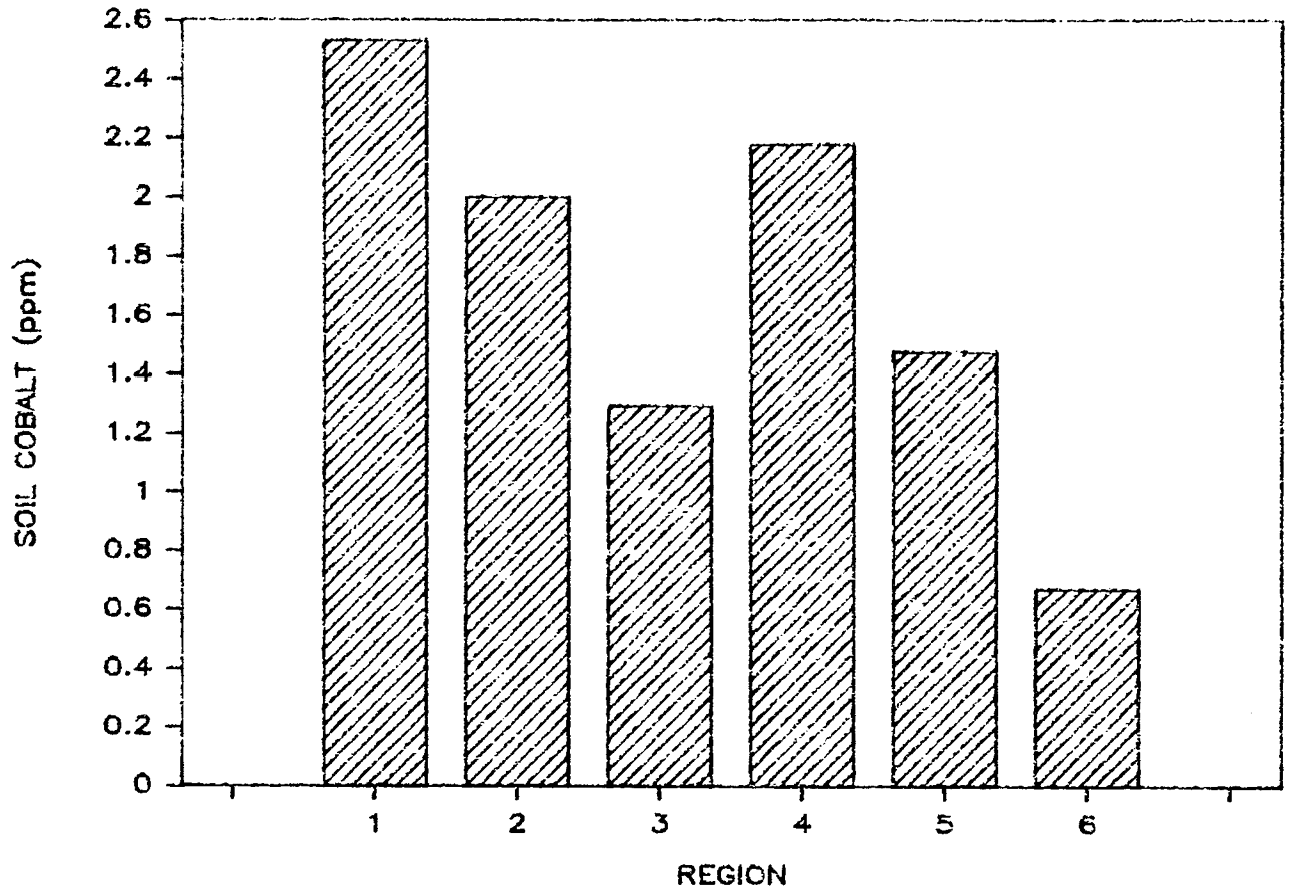

Figure 10. Soil cobalt in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

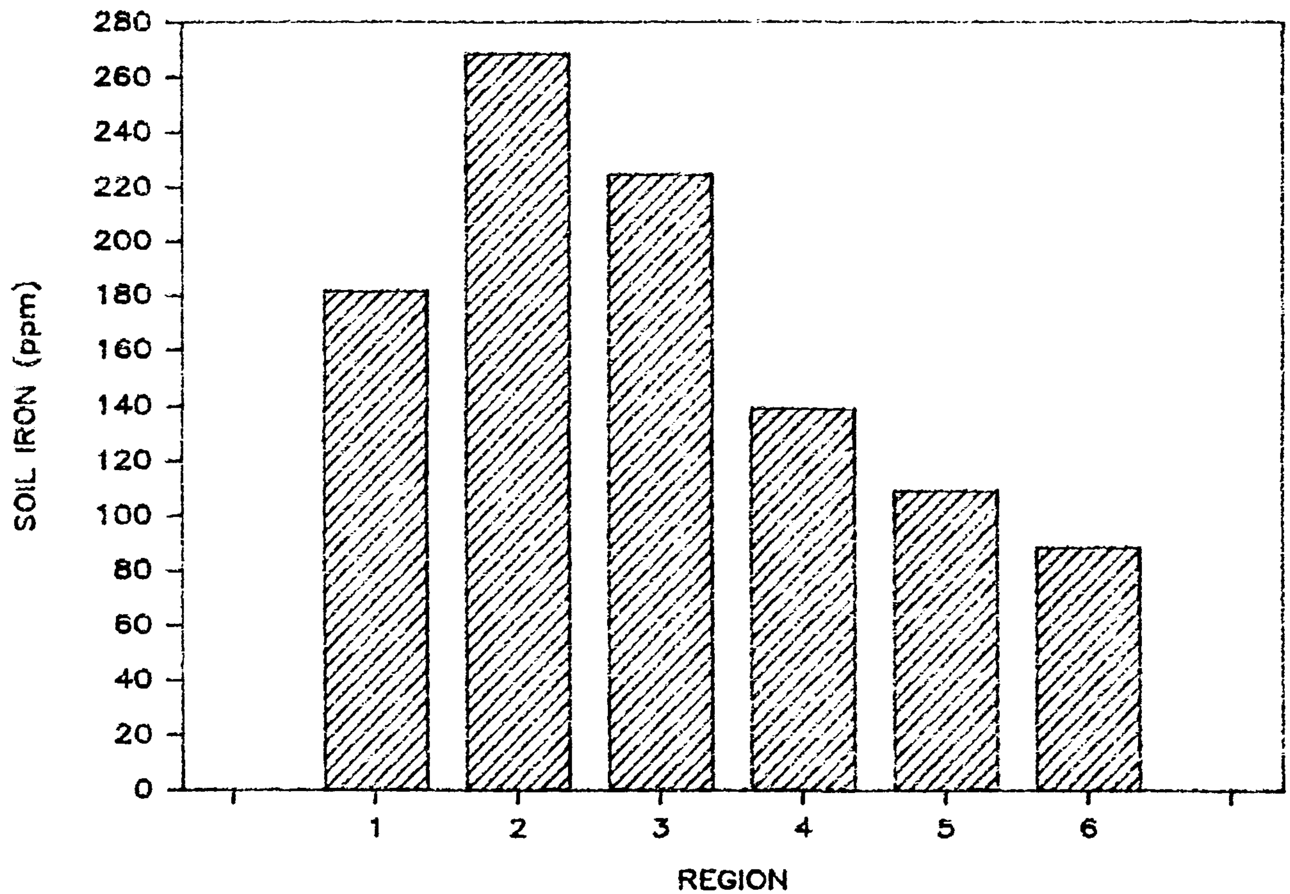

Figure 11. Soil iron in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Manganese

Soil manganese availability in soils decreases when the soils are not well drained or when they have a high pH (Robertson and Lucas, 1981a). Manganese content in soils tested in this investigation (Table 5, Figure 12) ranged from 54 ppm in region 5 to 114 ppm in region 1 in Ecuador. Soils from region 6, in Michigan, had an average of 60 ppm manganese. There was no significant difference among regions ($p > .05$), but farms within regions differed ($p < .01$).

Manganese fertilization is recommended for responsive crops when the soil test (0.1 N HCl extractable manganese) gives values below 20 ppm; the pH of the soil also must be considered when fertilization is recommended. It is probable that the soils tested in this study do not need manganese fertilization.

Alfalfa, grasses and corn are medium responsive crops to manganese fertilization (Vitosh et al., 1981). Manganese fertilization recommendations made by the Michigan State University Extension Service (Vitosh et al., 1981) are shown in table I.8 (Appendix I).

Molybdenum

Molybdenum is essential to plants. Among its other functions, it has a part in the enzyme nitrate reductase of Rhizobia for fixation of nitrogen. Although essential for animals, molybdenum is of interest in nutritional studies mainly because of its interaction with sulfur and copper. Molybdenum availability increases at higher soil pH values (Robertson et al., 1981b). The critical level (Table I.2, Appendix I) of

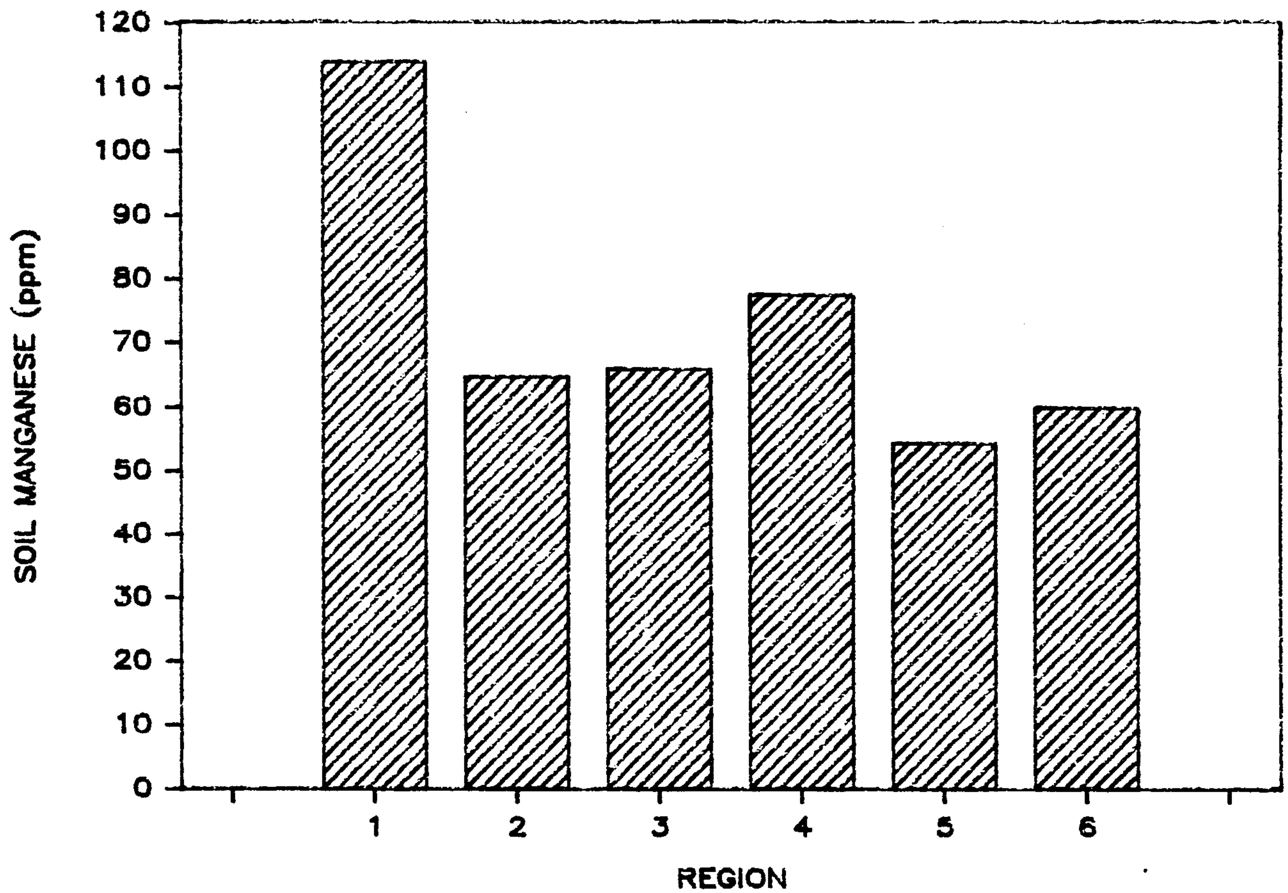

Figure 12. Soil manganese in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

molybdenum in the soil (extracted with ammonium oxalate at pH 3.3) is 0.04-0.20 ppm (Cox and Kamprath, 1972).

Molybdenum in sampled soils (Table 5, Figure 13) ranged from 0.05 ppm in region 1 in Ecuador to 0.52 ppm in region 6 in Michigan. Soils from region 4 in Ecuador had a molybdenum content of 0.16 ppm. Soils from the other regions studied in this study had a molybdenum content above 0.20 ppm, which is the critical level. Alfalfa is a crop highly responsive to molybdenum fertilization and benefits from treating seed with molybdenum in soils deficient in this element. It is possible that alfalfa and legumes in general grown on soils with a molybdenum content below or within the critical level, such as those from region 1 and 4 in Ecuador, will respond to molybdenum fertilization. It is also possible that molybdenum in the soil will become more available to the plant after liming in the fields that need pH ammendment.

For molybdenum in soils, there was a significant difference among regions ($p < .01$), as well as among farms within regions ($p < .01$). The correlation coefficient between soil pH and molybdenum in soils was -0.443.

Selenium

The selenium content of most soils lies between 0.1 and 2 ppm. The maximum concentration of selenium found in several thousand soil samples in the United States was under 100 ppm, and the majority of the seleniferous soils analyzed contained an average of less than 2 ppm selenium (NRC, 1983). Selenium is more available to plants when the pH of the soil is high (Tisdale et al., 1985). Based on feed analysis, the soils of the State of

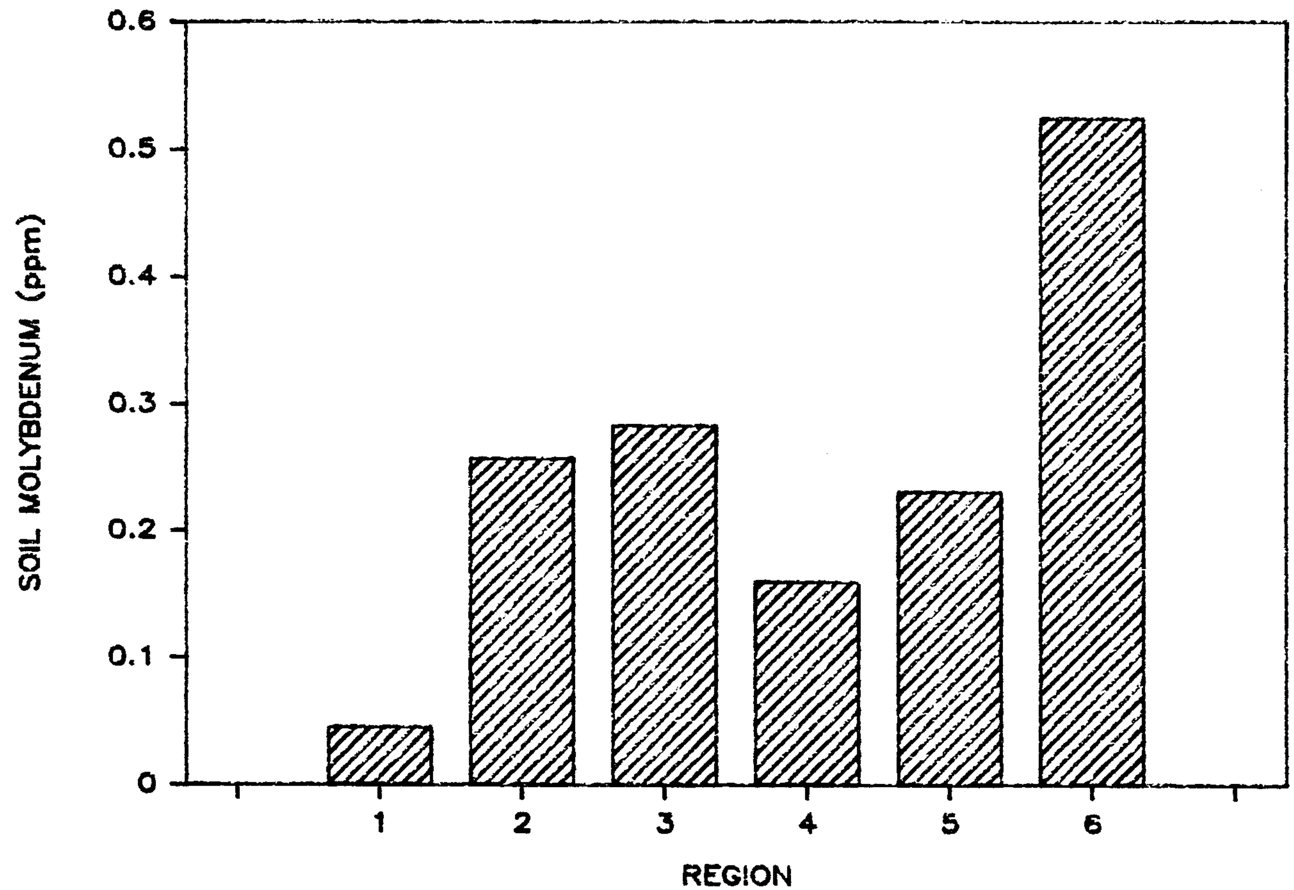

Figure 13. Soil molybdenum in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Michigan are classified as selenium deficient. Approximately 80% of all forage and grain from Michigan contained less than 0.05 ppm selenium (Kubota and Allaway, 1972).

Soil samples (Table 6, Figure 14) from region 4 in Ecuador had an average selenium content of 0.09 ppm. Samples from region 3 in Ecuador had an average selenium content of 3.41 ppm. Soils from region 6 in Michigan contained 0.41 ppm of selenium. There was no significant difference among regions ($p > .05$), but farms within regions differed in selenium content ($p < .01$).

Zinc

The critical level for zinc in soils ranges from 1.0 to 7.5 ppm (Table I.2, Appendix I). Zinc is more likely to be deficient for plants in soils with calcareous surface horizons or in leached, acid, sandy soils. Zinc deficiency may also be prevalent where the soil is high in available phosphorus. Interactions involving zinc, phosphorus and iron result in poor utilization of zinc by plants (Kubota and Allaway, 1972). Zinc deficiencies have been identified in Michigan in navy beans, especially the Sanilac variety. Corn is a crop highly responsive to zinc fertilization, while grasses and alfalfa show low response (Robertson and Lucas, 1981b). Recommendations for zinc fertilization are shown in table I.9 (Appendix I).

Zinc in soils sampled ranged from 3.7 ppm in region 6 in Michigan to 12 ppm in region 2 in Ecuador (Table 6, Figure 15). The average zinc content in soils from region 1 in Ecuador was 6.5 ppm, and in region 4 in Ecuador 5.1 ppm. The average pH of soils from region 4 in Ecuador was 7.2, thus it is possible that

Table 6. Selenium, zinc, sulfates, and copper concentrations in soils from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

REGION(2)		N	SELENIUM ppm $\overline{X}$	SELENIUM ppm (SEM)	ZINC ppm $\overline{X}$	ZINC ppm (SEM)	SULFATE-SULFUR ppm $\overline{X}$	SULFATE-SULFUR ppm (SEM)	COPPER ppm $\overline{X}$	COPPER ppm (SEM)
1	ECUADOR	15	0.64	(0. 74)	6.5	(1.92)	8^{c}	(5. 06)	312^{a}	(1.60)
2	ECUADOR	15	0.32	(0. 74)	12.0	(1.92)	46^{a}	(5. 06)	138^{c}	(1.60)
3	ECUADOR	15	3.41	(0. 74)	9.0	(1.92)	63^{a}	(5. 06)	130^{c}	(1.60)
4	ECUADOR	15	0.09	(0. 74)	5.1	(1.92)	18^{c}	(5. 06)	231^{ab}	(1.60)
5	ECUADOR	15	0.18	(0. 74)	9.5	(1.92)	29^{b}	(5. 06)	170^{bc}	(1.60)
6	MICHIGAN	13	0.41	(0. 79)	3.7	(2.07)	7^{c}	(5. 44)	27^{d}	(1.72)
Significance of F (3)										
Region			NS		NS		**		**	
Farm/region			**		**		**		*	

(1) N, $\overline{X}$, SEM: number of observations, means and standard errors of means
(2) Region means within a column without a common superscript are different ($p < .05$)
(3) NS: non-significant; **: $p < .01$; *: $p < .05$

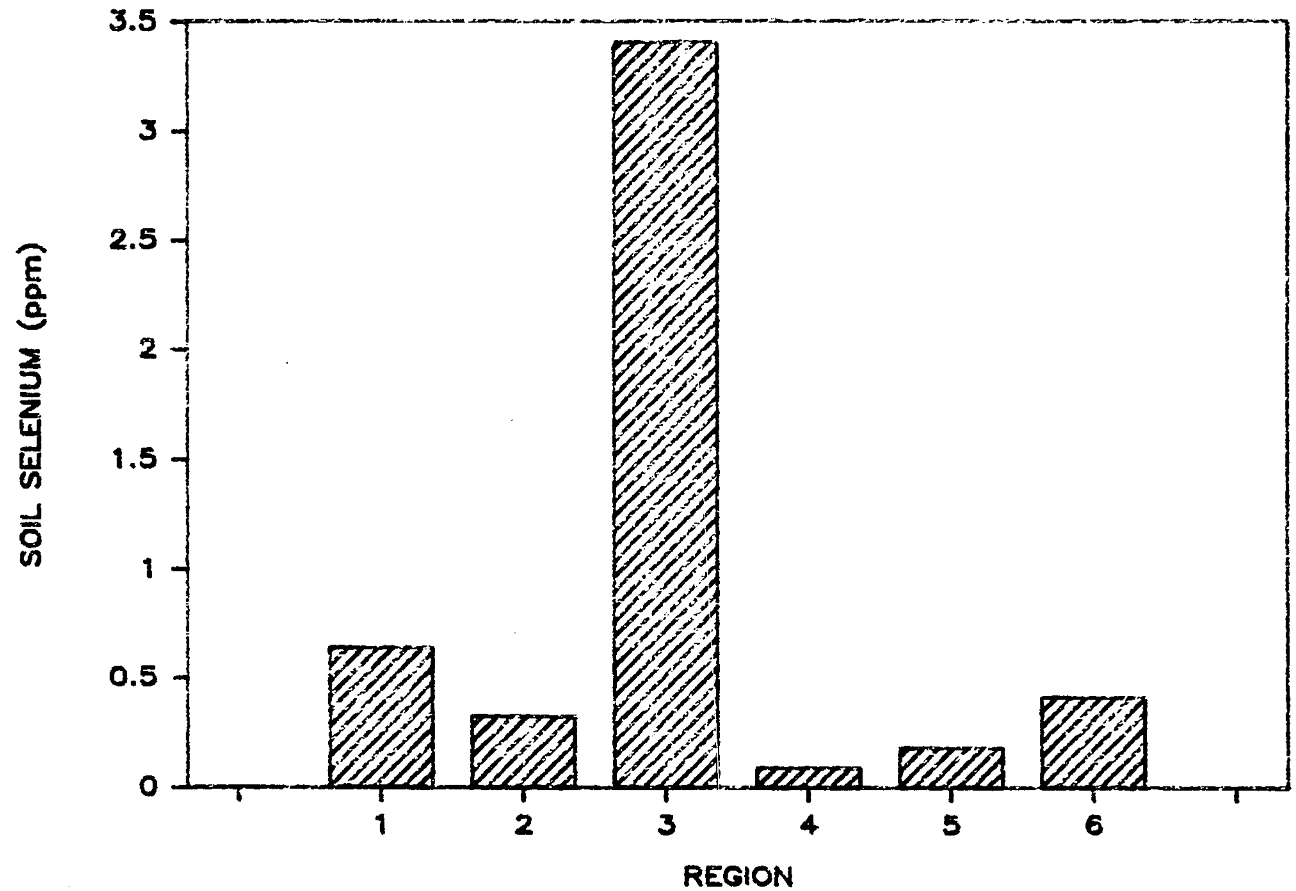

Figure 14. Soil selenium in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

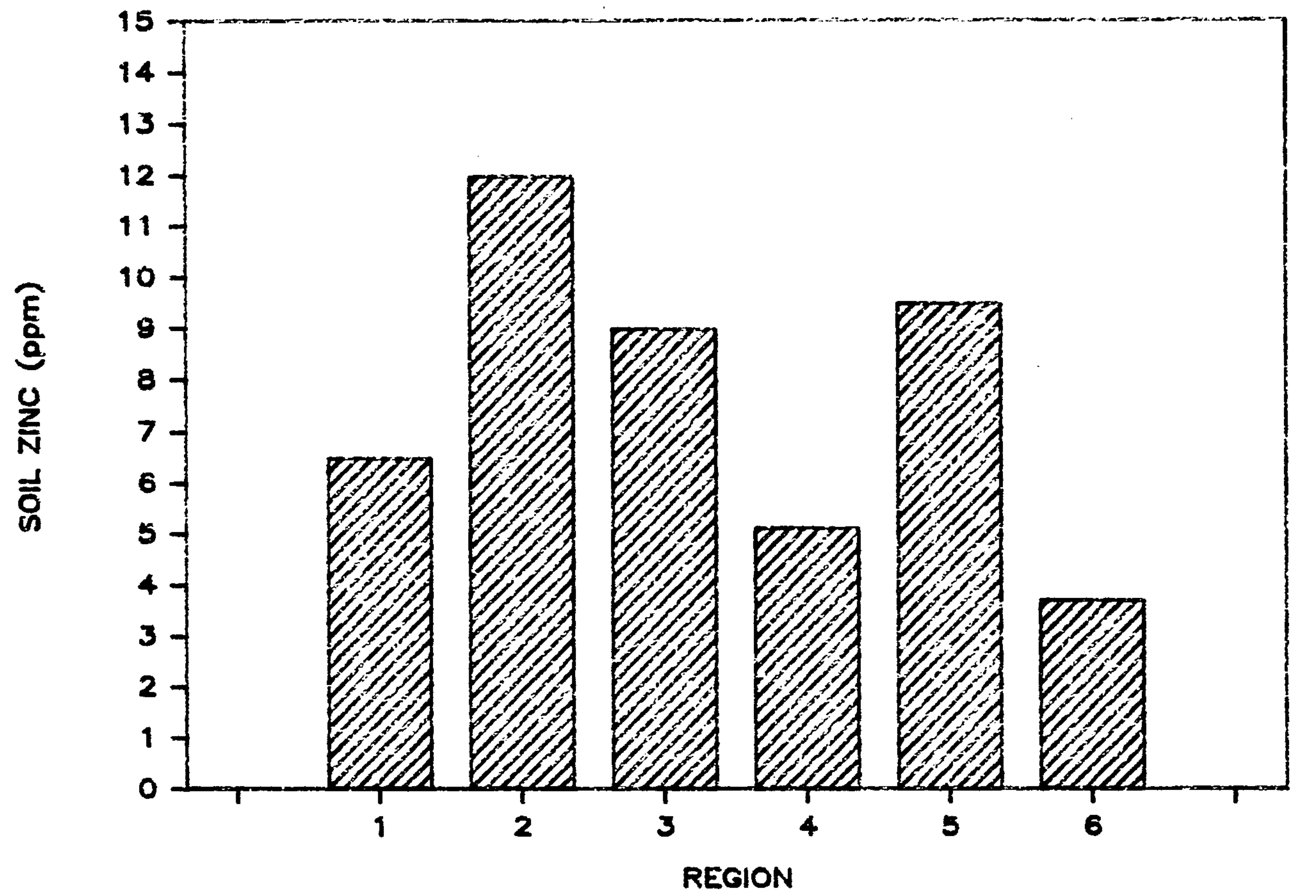

Figure 15. Soil zinc in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

zinc fertilization will increase the yield of responsive crops such as corn in this region. There was no significant difference among regions ($p > .05$), but the difference among farms within region were significant ($p < .01$).

Soil Sulfates

The threshold levels below which sulfur fertilization is frequently recommended in the Great Lakes area is between 6 to 7 ppm (12 to 14 lb/acre) of sulfate-sulfur in the soil. Several fields in Michigan had been found to have sulfur concentrations below the levels mentioned, but sulfur fertilization failed to cause an increase in crop yields. Legumes are more responsive to sulfur fertilization than other crops (Robertson et al., 1976b).

Sulfur content of the soil was 7 ppm in region 6 in Michigan and 8 ppm in region 1 in Ecuador. The other regions in Ecuador had average sulfur values above 18 ppm (Table 6, Figure 16). It is possible that some sulfur fertilization is needed in region 1 and 6. The procedure recommended by the Extension Service of Michigan State University (Robertson et al., 1976b) is to fertilize test strips across the field at a rate of 22 to 44 kg/hectare (20 to 40 lb/acre). If there is an increase in yield of the crop in the strips tested, then all the crop should be fertilized with sulfur.

The differences of soil sulfate content among regions and farms within regions were significant ($p < .01$). The correlation coefficient of soil pH and soil sulfur was -0.295.

Copper

The critical level (Table I.2 Appendix I) for copper

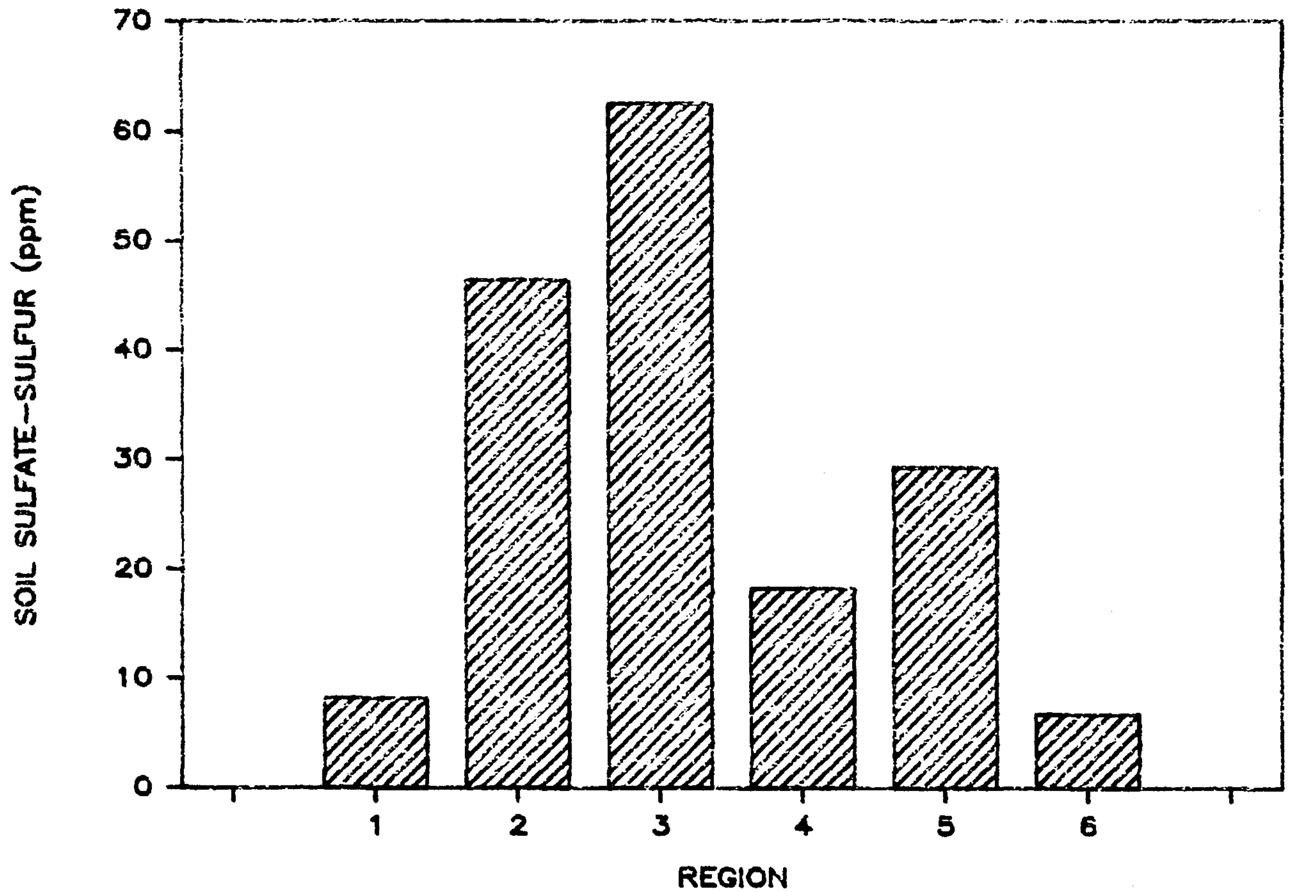

Figure 16. Soil sulfate-sulfur in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

concentration in organic soils measured after extraction with 1.0 N HCl ranges from 9-20 ppm (Whitney, 1980). Soils in region 6 in Michigan (Table 6, Figure 17) had the lowest copper content of the six regions sampled for this investigation (2.7 ppm). Region 1 in Ecuador had the highest copper concentration (31.2 ppm). Copper content in region 6 in Michigan is below critical level range. Soils from regions 2 and 3 in Ecuador had 13.8 and 13.0 ppm copper, and therefore were also low in copper. These values are within the range of critical level, where a response to fertilization is possible. The difference among regions (p .01) and among farms within regions (p .01) was significant.

Crops, especially legumes, grown in soils from regions 2, 3 and 6 may benefit from copper fertilization.

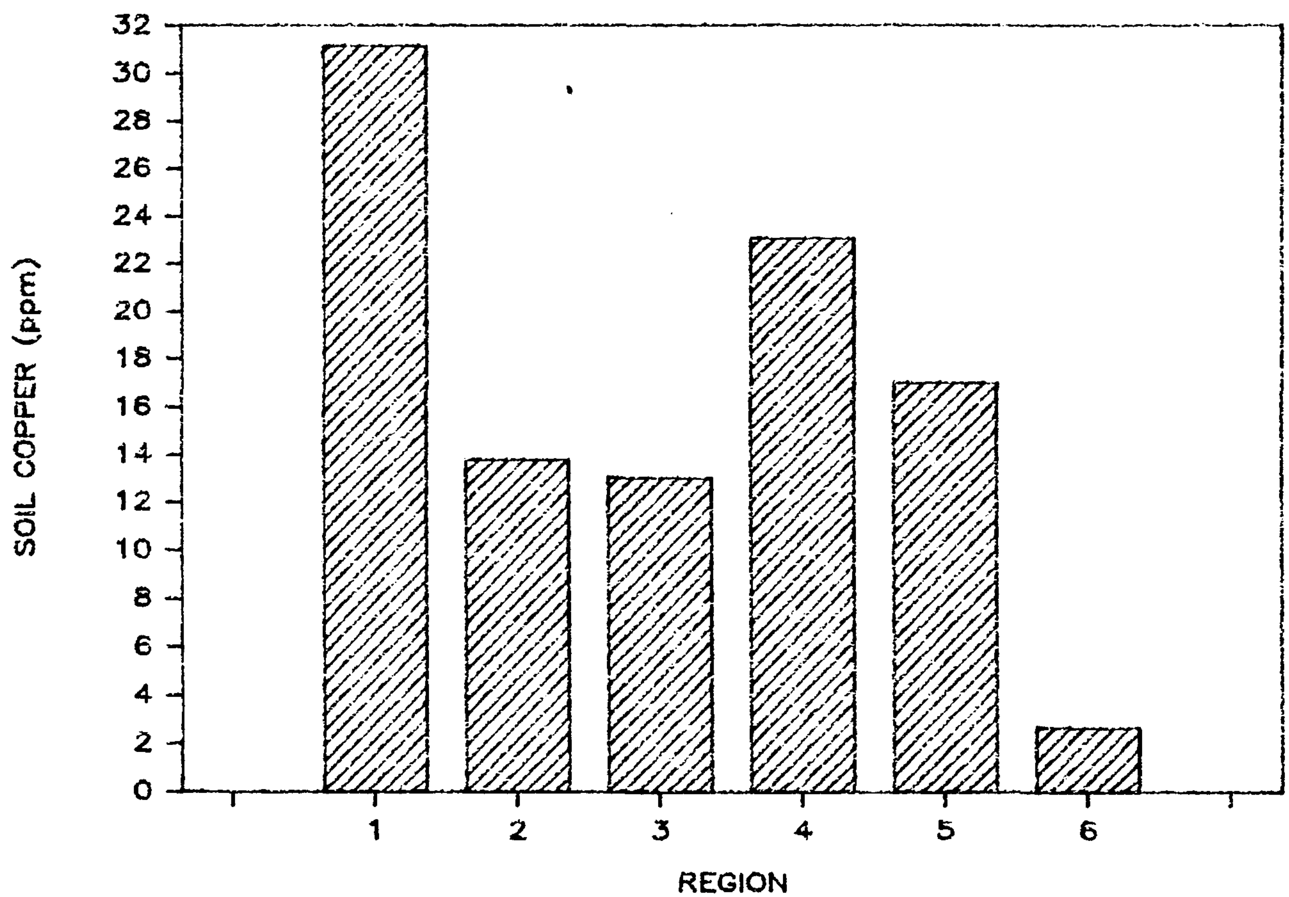

Figure 17. Soil copper in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Nutrients in Pastures

Pastures Management in Ecuador

Pastures studied in Ecuador are generally associations of grasses and legumes. Preferred species for pasture are ryegrass (Lolium multiflorum) and white clover (Trifolium repens). Other less frequently cultivated species include orchard grass (Dactylis glomerata), fescues (Festuca sp.), timothy (Phleum pratense) and red clover (T. pratense). Some farms grow alfalfa (Medicago sativa), and in some cases oats (Avena sativa), rye (Secale cereale), or wheat (Triticum sp.) for greenchop. Some of the weeds commonly found among the cultivated species are dandelion (Taraxacum oficinale), chicory (Chicorium intibus), thistles (Cirsium sp.), docks (Rumex sp.), plantains (Plantago sp.), grama (Paspalum sp.), sweet vernal grass (Anthoxantum odoratum) and velvet grass (Holcus lanatus).

Dairy cattle are kept permanently on pasture. The rotation of the herd from pasture to pasture is practiced on all farms. The size of the lots where the animals are kept from 1 to 5 days depends on the size of the herd, is from 1 to 5 hectares (2.5 to 12 acres). Grazing lots are fenced with barbed wire. Depending on the altitude of the farm, rotations are completed in 45 to 90 days. Average temperatures at higher altitudes are lower, the pasture grows more slowly, and rotations therefore take longer. At 3000 m (9800 ft) the average temperature is about 12^{o} C, and the rotations are completed in about 60 days. For each 200 m (650 ft) increase in altitude, a 1^{o} C decrease in temperature is expected (Terán, 1979).

Almost all dairy cattle in the regions studied are either Holstein Friesians or crosses of Holsteins with native breeds. Indeed, almost all the dairy cattle are black and white. Few farms have Brown Swiss, Jersey, or other breeds.

Dairy animals are maintained almost exclusively on pasture. Very few farms give the animals grain at the time of milking. Salt is provided to all animals, but trace mineral salt is seldom used. Some farmers ocassionally give bone ash to animals as a source of phosphorus; dicalcium phosphate or other phosphorus sources are seldom used. Several mineral mixtures can be found in the farm stores, but farmers do not use them on a regular basis. Since several of the areas studied are deficient in iodine, this mineral is provided to the animals in iodized salt or mixed with molasses.

Dairy farmers are conscious of the need for mineral supplementation for the cattle, but either the proper mineral mixtures or ingredients are not available, or the market price is too high. Specific requirements for, or problems with, microminerals are not well understood. The common dairy farmer lacks a good guide on mineral nutrition for dairy cattle.

Ash

The amount of mineral elements as a group in feed or animal tissue is determined by burning off the organic matter and weighing the residue, which is called ash. The figure arrived at by ash determination of a specific feed is used in the conventional feed analysis as one variable in computing the nitrogen free extract value for that feed. The ash from a feed may also be used as a starting point for determining the concentrations of the specific elements present (Maynard and Loosli, 1969).

Mean ash content in pastures (Table 7, Figure 18) ranged from around 11 to 14% in the five regions studied in Ecuador. Mean ash content in pastures from Michigan was 5.6%. Mean ash concentration differed among regions ($p < .05$), type of sample ($p < .01$), and farms within region ($p < .01$). The interaction of type of sample and region was not significant ($p > .05$).

Mean ash content of all samples was 11.5% when the pastures were washed with distilled water, and 12.6% when they were not washed. This difference in ash content is an indication of soil contamination. Grazing animals ingest soil along with herbage and this ingested soil can be a source of elements for the animals. Soil type, stocking rate, earthworm population, and management all affect the amount of soil ingested (Healy, 1974). Soil ingested can be a substantial part of the dry matter intake. Measurements in Southwest England indicate soil intakes from 3 to 6% of the total dry matter intake (Thornton, 1974). Using titanium as an indicator, Fries et al. (1982) found that the soil ingestion of dry cows and yearling heifers from Maryland and Michigan was around 2.4% of the dry matter intake, when the animals were kept on pasture. Addition of soil to the diet of nonpregnant, nonlactating cows apparently did not have any effect on the absorption of other nutrients from the diet (Miller, 1977).

Table 7. Pasture ash, crude protein, and crude fiber from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

		ASH % DM		CRUDE PROTEIN % DM		CRUDE FIBER % DM	
REGION (2)	N	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)
1 ECUADOR	30	13.7^{a}	(1.02)	14.0	(1.33)	35.4	(1.38)
2 ECUADOR	30	12.7^{ab}	(1.02)	15.4	(1.33)	29.2	(1.38)
3 ECUADOR	30	11.5^{ab}	(1.02)	10.4	(1.33)	35.1	(1.38)
4 ECUADOR	30	14.5^{a}	(1.02)	13.6	(1.33)	32.9	(1.38)
5 ECUADOR	30	11.2^{ab}	(1.02)	14.7	(1.33)	35.0	(1.38)
6 MICHIGAN	12	5.6^{bc}	(1.33)	14.0	(2.11)	30.0	(2.18)
WASHED	81	11.5	(0.26)	13.2	(0.48)	34.0	(0.35)
NON-WASHED	81	12.8	(0.26)	14.1	(0.48)	32.6	(0.35)
Significance of F (3)							
Region		*		NS		*	
Farm/region		**		**		**	
Type of sample		**		NS		**	
Type X region		NS		NS		NS	

(1) N, $\overline{X}$, SEM: number of observations, means and standard errors of means

(2) Region means within a column without a common superscript are different ($p < .05$)

(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

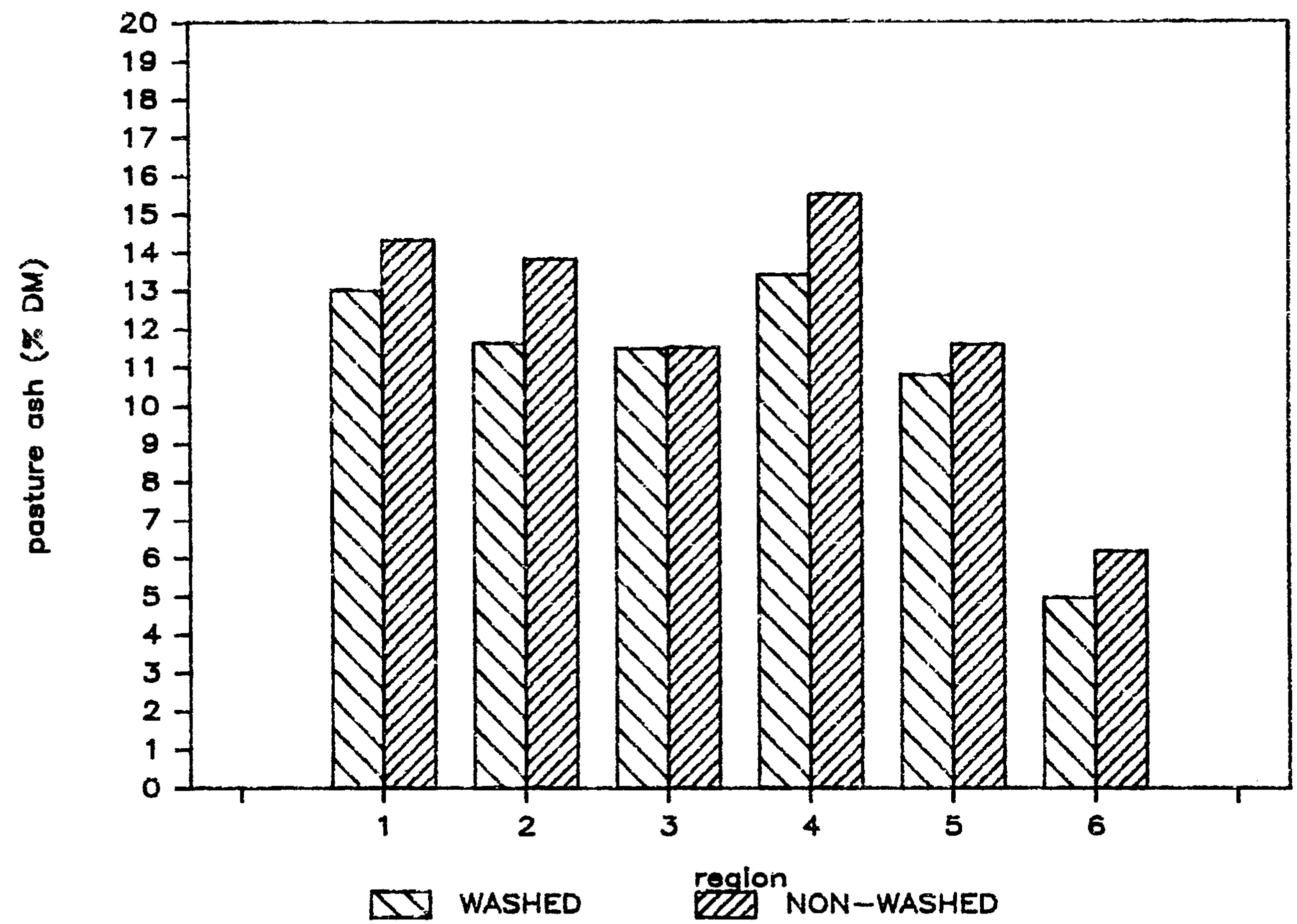

Figure 18. Ash in washed and non-washed pasture samples in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Crude Fiber

Crude fiber in the diet of ruminants is necessary for proper digestion. A minimum crude fiber content of 17.3% of the diet is suggested by the NRC (1978) to maintain a normal milk fat percentage. In this investigation pastures had a crude fiber content ranging from 29.2% in region 2 in Ecuador to 35.4% in region 1 in Ecuador (Table 7, Figure 19). Region 6 in Michigan had an average of 30.0% crude fiber in the pastures. There was a significant difference among regions ($p < .05$), farms within regions ($p < .01$), and type of sample ($p < .01$). Washed samples had an average of 34.0% fiber and non-washed samples 32.6%, probably because some soil contamination.

Nitrogen

Nitrogen in pastures, expressed as percent protein, ranged from an average of 10.4 in region 3 in Ecuador to 15.4 in region 2 in Ecuador (Table 7, Figure 20). The average in region 6 in Michigan for corn silage and alfalfa samples was 14.0% protein. The differences among regions, types of sample, and the interaction were not significant ($p > .05$). There was a significant difference among farms within regions (p .01). The amount of nitrogen in soils was poorly correlated with the amount of nitrogen in pastures ($r = -0.043$). The correlation coefficient between crude fiber and protein in pastures was -0.261.

Lactating cows, depending on their level of milk production, require from 13 to 16% protein in the diet. Growing heifers and bulls require 12% protein in the ration, and dry pregnant cows

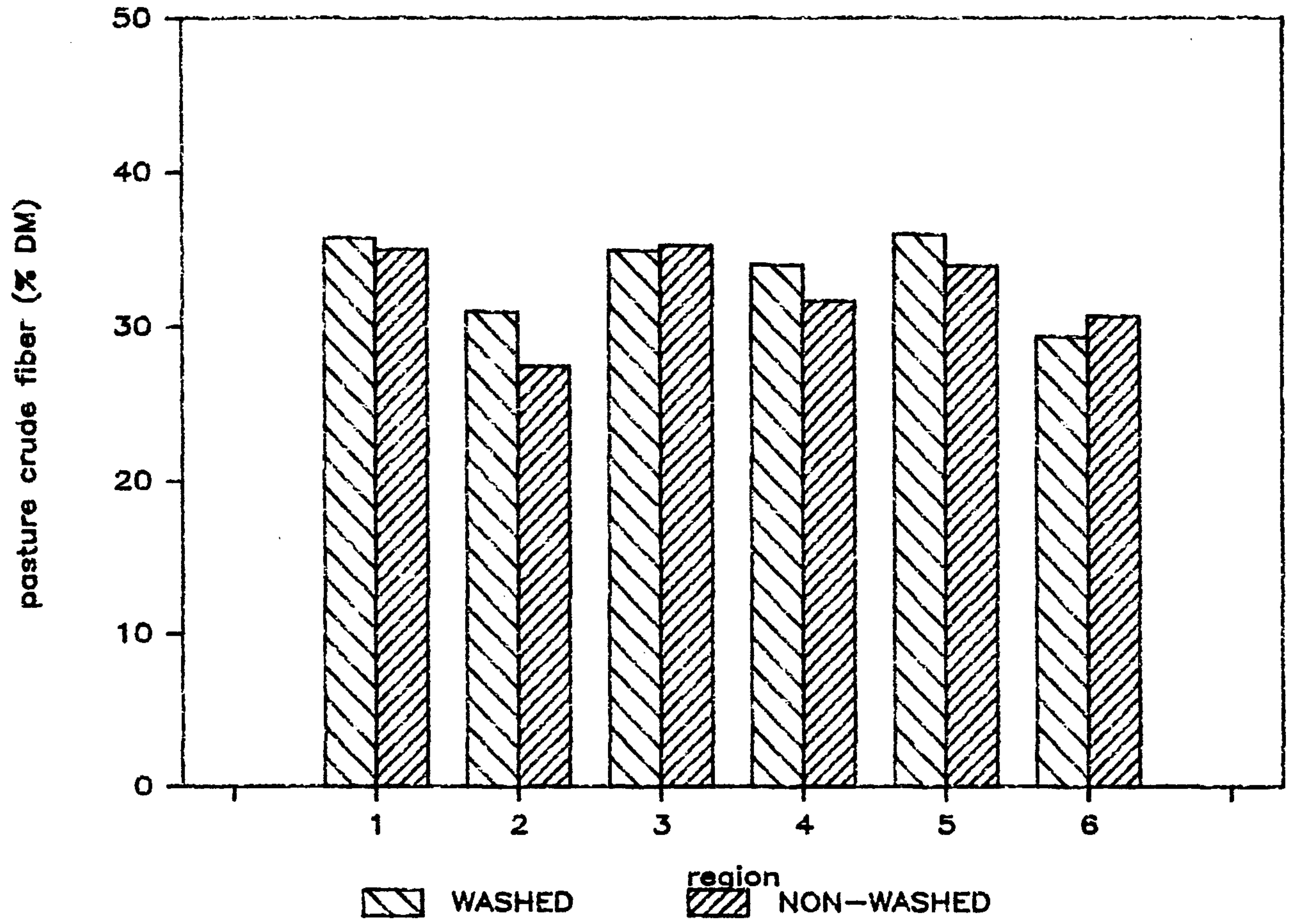

Figure 19. Crude fiber in washed and non-washed pasture samples in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

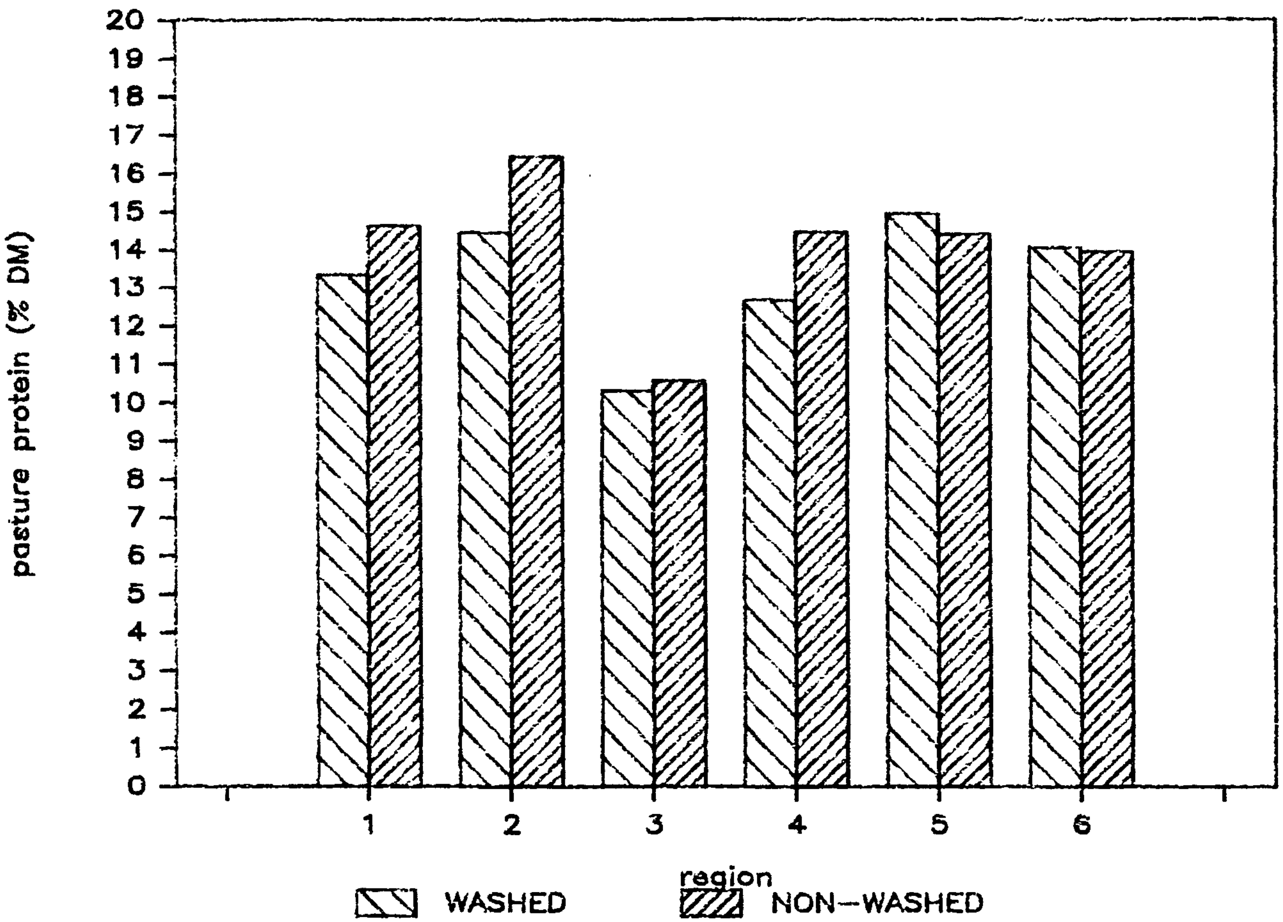

Figure 20. Crude protein in washed and non-washed pasture samples in five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

11% (NRC, 1978). Pastures from region 3 in Ecuador may not have enough protein to sustain adequate growth or milk production of dairy animals. High producing cows in all the areas studied may need protein supplementation.

Calcium

Calcium content of the pasture samples ranged from 0.40% in region 2 to 0.76% in region 1 in Ecuador. Average calcium content in region 6 in Michigan was 0.66% of the dry matter (Table 8, Figure 21). There was not a significant difference ($p > .05$) among regions, type of sample, or in the interaction between the two, but the difference among farms within region was significant ($p < .01$). The correlation coefficient between calcium in pastures and calcium in soils was 0.026.

Calcium requirements are calculated by multiplying the phosphorus requirement by a factor that can range from 1 to 7. The best absorption of both elements has been achieved when the relation of calcium to phosphorus is around 2:1 (NRC, 1978). Calcium-to-phosphorus relation in region 1 to 6 was in this order, 2.5, 1.7, 2.0, 1.8, 2.8 and 2.8. Lactating cows have a high phosphorus requirement, so phosphorus supplements are often added the diet. When such supplementation occurs, it is possible that calcium also needs to be added to the diet to maintain a proper calcium-to-phosphorus relationship.

Phosphorus

Mean phosphorus content in pastures ranged from 0.21% in regions 3 and 5 to 0.30% in region 1 of Ecuador. Mean phosphorus content of pastures in region 6 in Michigan was 0.24% (Table 8,

Table 8. Calcium, phosphorus, sodium, potassium, and magnesium concentrations in the dry matter of washed and non-washed pasture samples from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

		CALCIUM % DM		PHOSPHORUS % DM		SODIUM % DM		POTASSIUM % DM		MAGNESIUM % DM	
REGION(2)	N	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)
1 ECUADOR	30	0.76	(0.12)	0.30	(0.03)	0.018^{b}	(0.003)	3.07	(0.25)	0.26	(0.03)
2 ECUADOR	30	0.40	(0.12)	0.24	(0.03)	0.018^{b}	(0.003)	2.22	(0.25)	0.24	(0.03)
3 ECUADOR	30	0.42	(0.12)	0.21	(0.03)	0.020^{ab}	(0.003)	2.03	(0.25)	0.20	(0.03)
4 ECUADOR	30	0.50	(0.12)	0.27	(0.03)	0.033^{a}	(0.003)	2.68	(0.25)	0.29	(0.03)
5 ECUADOR	30	0.58	(0.12)	0.21	(0.03)	0.021^{ab}	(0.003)	2.68	(0.25)	0.21	(0.03)
6 MICHIGAN	12	0.66	(0.09)	0.24	(0.05)	0.018^{b}	(0.004)	1.70	(0.38)	0.24	(0.05)
WASHED	81	0.56	(0.04)	0.24	(0.01)	0.021	(0.001)	2.30	(0.10)	0.30	(0.01)
NON-WASHED	81	0.52	(0.04)	0.25	(0.01)	0.022	(0.001)	2.63	(0.10))	0.32	(0.01)
Significance of F (3)											
Region		NS		NS		*		NS		NS	
Farm/region		*		**		**		**		**	
Type of sample		NS		NS		NS		*		NS	
Type X region		NS		NS		NS		NS		NS	

(1) N, $\overline{X}$, SEM: number of observations, means and standard errors of means
(2) Region means within a column without a common superscript are different ($p < .05$)
(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

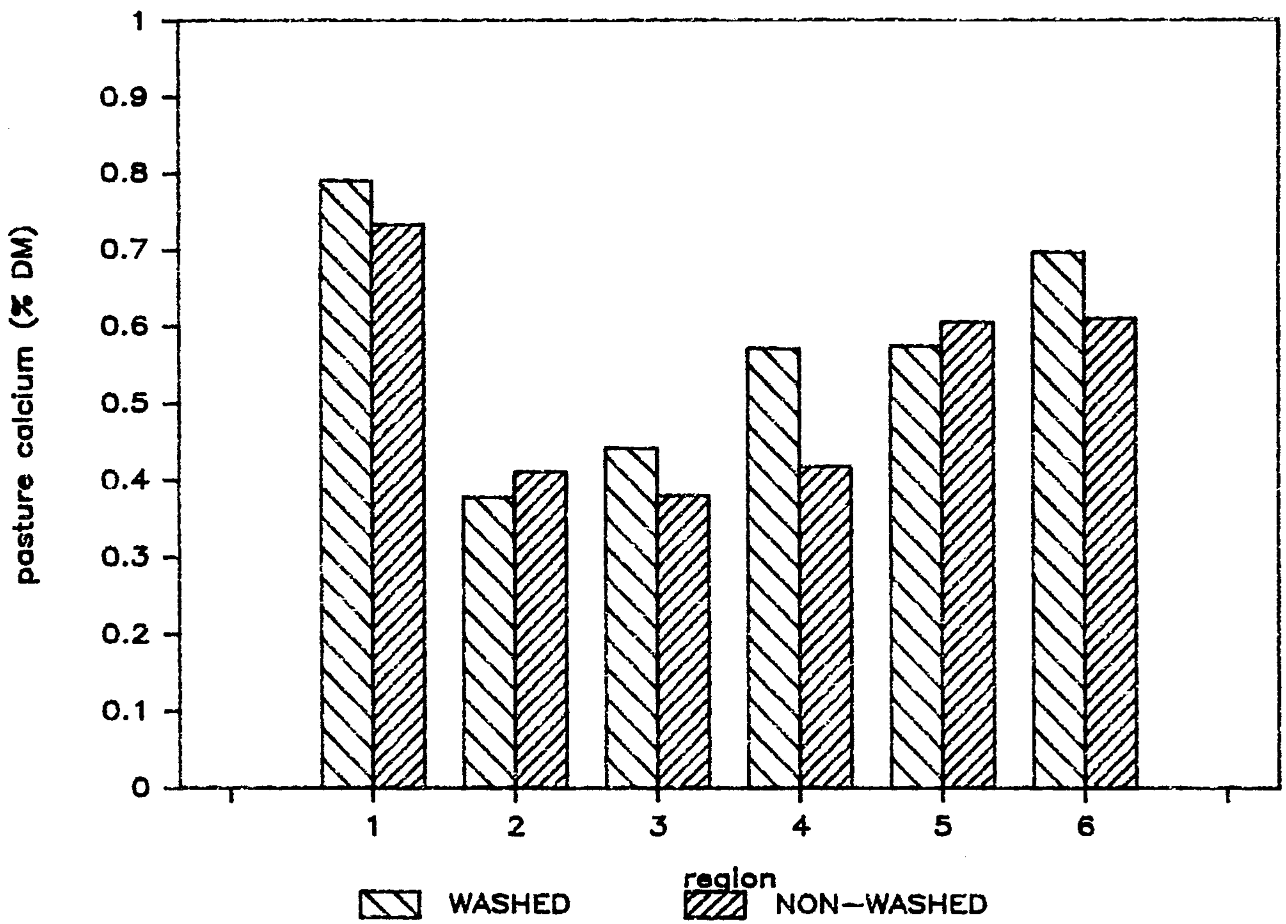

Figure 21. Calcium in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Figure 22). The difference among regional means was not significant ($p > .05$). The difference between means of washed and nonwashed samples was not significant ($p > .05$), nor was the interaction of type of sample with region ($p > .05$). The difference among farms within regions was highly significant (p .01). The correlation coefficient between phosphorus in pastures and soils was 0.317.

Lactating cows, depending on their level of milk production, require from 0.31 to 0.40% phosphorus in the ration. Growing heifers and bulls, and dry pregnant cows require 0.26% phosphorus in the diet (NRC, 1978). Phosphorus supplementation is often necessary for high producing cows, and even for dry cows and growing animals if they are consuming forages low in phosphorus sush as those in regions 2, 3 and 5 of Ecuador, and in region 6 in Michigan.

Calcium and phosphorus are usually supplied to the animals as part of the grain mix. Grazing animals that do not receive concentrate should be provided with minerals in a mineral feeder. Calcium and phosphorus sources may be mixed with the trace mineral salt in a proportion calculated to meet the requirements, based on the salt consumption of the animals.

Magnesium

The suggested magnesium requirement of dry preganant cows, and growing heifers and bulls is 0.16 percent of the diet; it increases to 0.20-0.25% percent of the diet of lactating cows fed substantial amounts of preserved forages and/or concentrates (NRC, 1978). Magnesium content in the pasture samples tested in

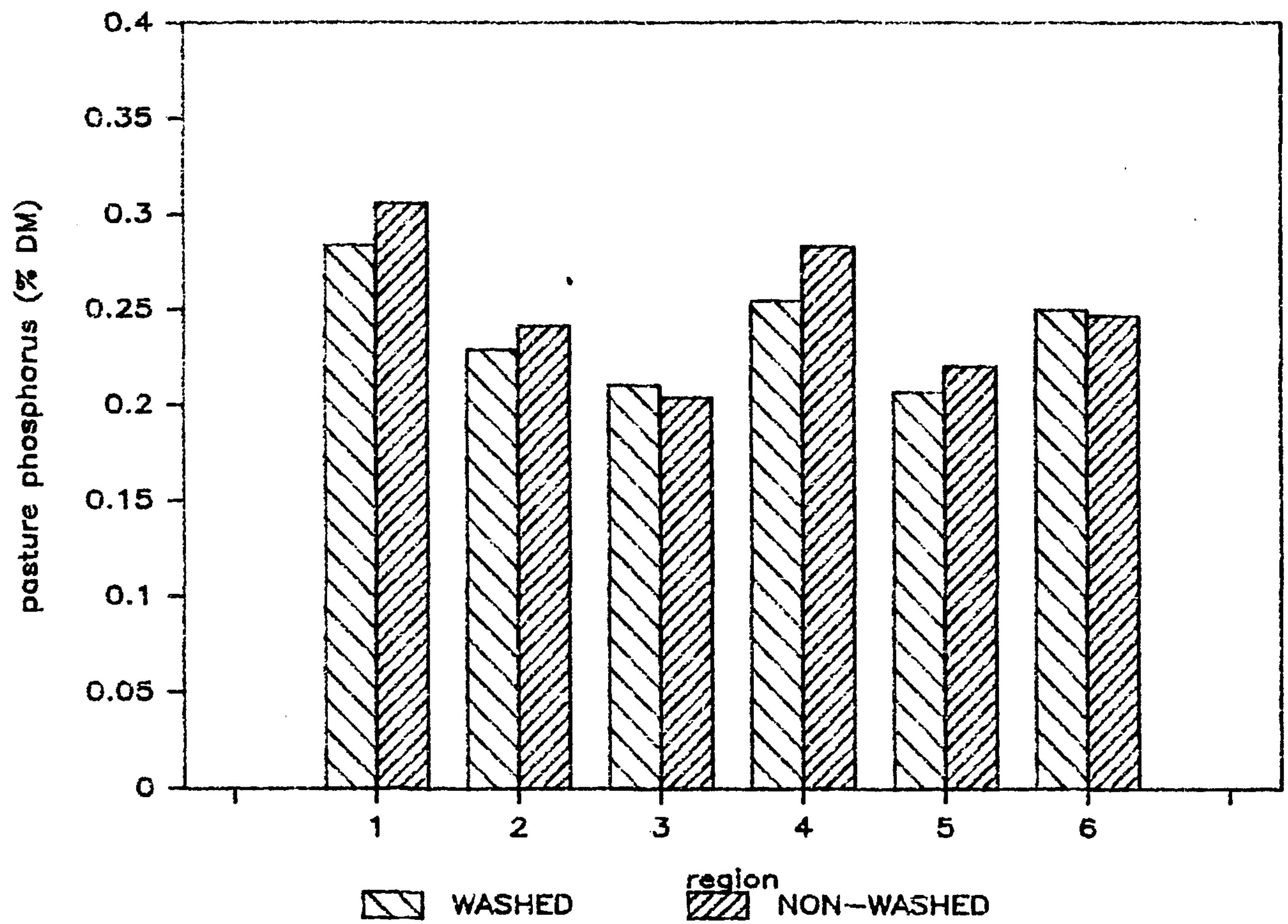

Figure 22. Phosphorus in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

the present experiment ranged from 0.20% in region 3 to 0.26% in region 1 of Ecuador. Average magnesium content in pastures in region 6 in Michigan was 0.24% (Table 8, Figure 23). Differences among regions, types of samples, and the interaction between the two were not significant ($p > .05$). The difference among farms within regions was significant ($p < .01$). The correlation coefficient between magnesium in pastures and soils was 0.228.

Magnesium supplementation to the diet of cattle in the regions studied seems unnecessary, except when lactating cows are consuming a high amount of concentrates, since magnesium content in corn grain is lower than in forages (Adams, 1975). It is worth noting, however, that magnesium oxide in the diet helps to prevent low milk fat syndrome in dairy cows (Emery et al., 1965).

Sodium

In pastures , sodium content ranged from 0.018% in regions 1 and 2 of Ecuador and region 6 in Michigan, to 0.33% in region 3 in Ecuador (Table 8, Figure 24). The difference in sodium content in pastures among regions was significant ($p < .05$), as was the difference among farms within regions ($p < .01$). The difference among types of samples and the interaction of types with regions were not significant ($p > .05$). The correlation coefficient between sodium in soils and in pastures was 0.288.

The NRC (1978) estimate of the sodium requirements of cattle is 0.18 percent of the ration dry matter for lactating cows, and 0.10% for other types of dairy cattle. This requirement is obviously not met by the sodium content of pastures alone, so the animals' diets need supplementation. When the animals recieve

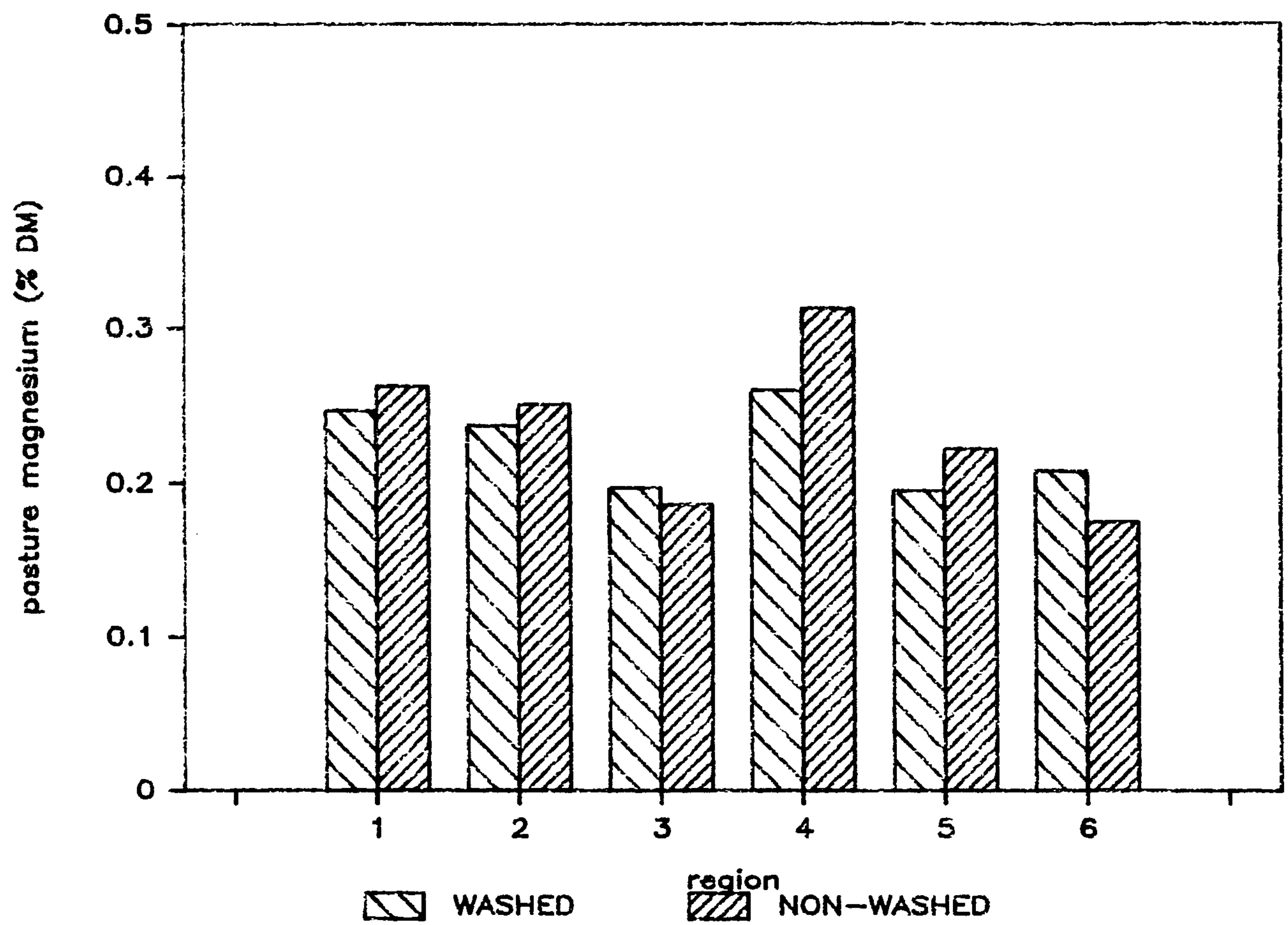

Figure 23. Magnesium in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

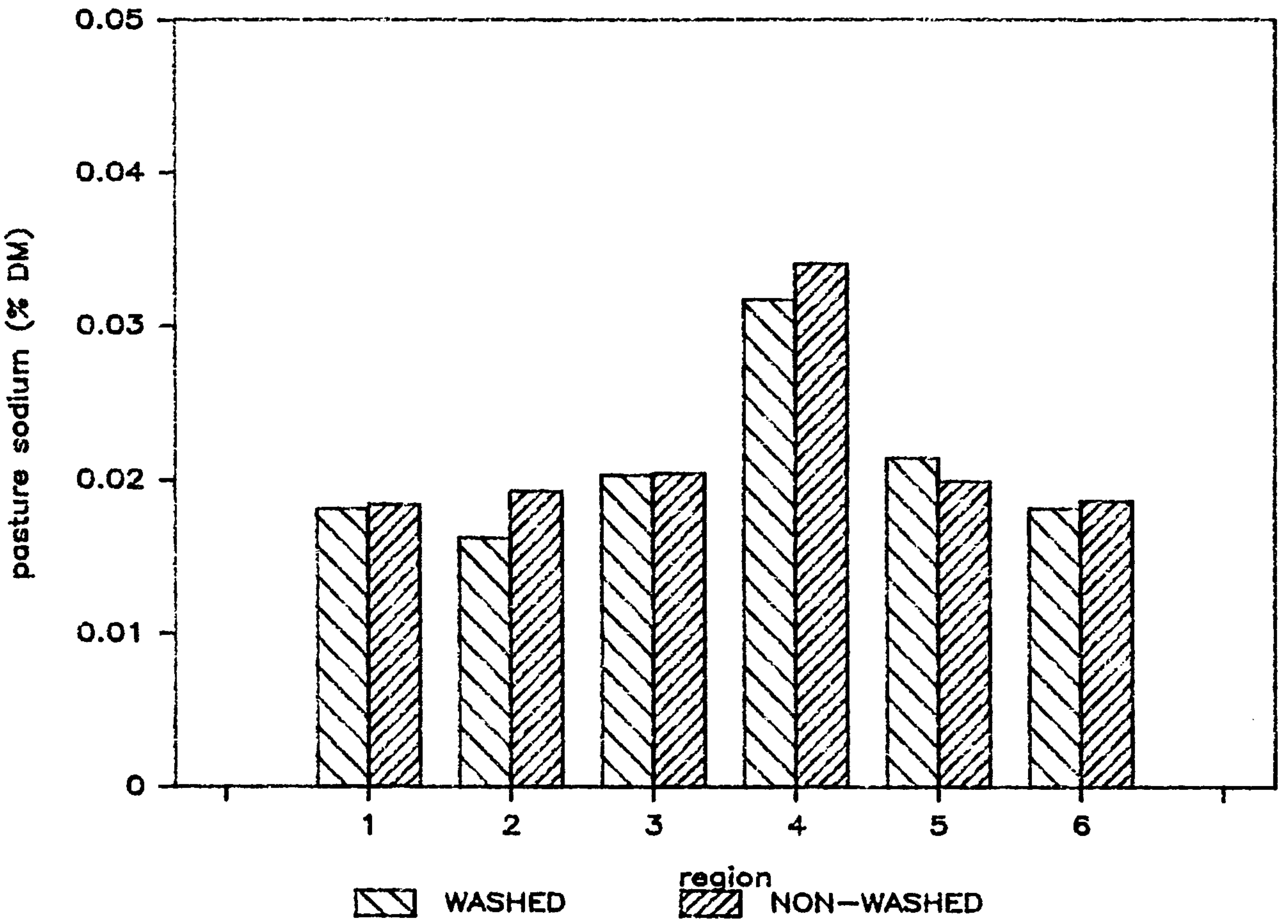

Figure 24. Sodium in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

concentrate, sodium chloride is included in the grain mixture, usually at a rate of 1% of the grain mixture. Grazing animals that do not receive concentrate need to be offered salt, along with other minerals, in mineral feeders in the field. Voluntary salt intake by cattle is variable, but lactating dairy cows consume on the average 45 g per day. Dry cows and heifers consume from 15 to 30 g of salt per day (Crampton and Harris, 1969). This intake should be considered when determining the percentage of each mineral to be included in the mineral mix.

Potassium

Potassium concentration in pastures ranged from 1.70% in region 6, in Michigan, to 3.07% in region 1 in Ecuador (Table 8, Figure 25). In pastures, the differences among regions and the interaction of region with type of sample were not significant ($p > .05$). The difference among farms within region was significant ($p < .01$), as was the difference between the average potassium content of washed and non-washed pasture samples ($p < .05$). The correlation coefficient between potassium in pastures and in soils was 0.268.

The potassium requirement of dairy cattle is 0.8 to 1.0% of the diet's dry matter (NRC, 1978; Underwood, 1981). The forages analyzed in this study have enough potassium to meet the animals' requirements, but if grain is supplemented to the ration total potassium in the diet may be below their requirements. Corn grain has around 0.35% potassium (NRC, 1978).

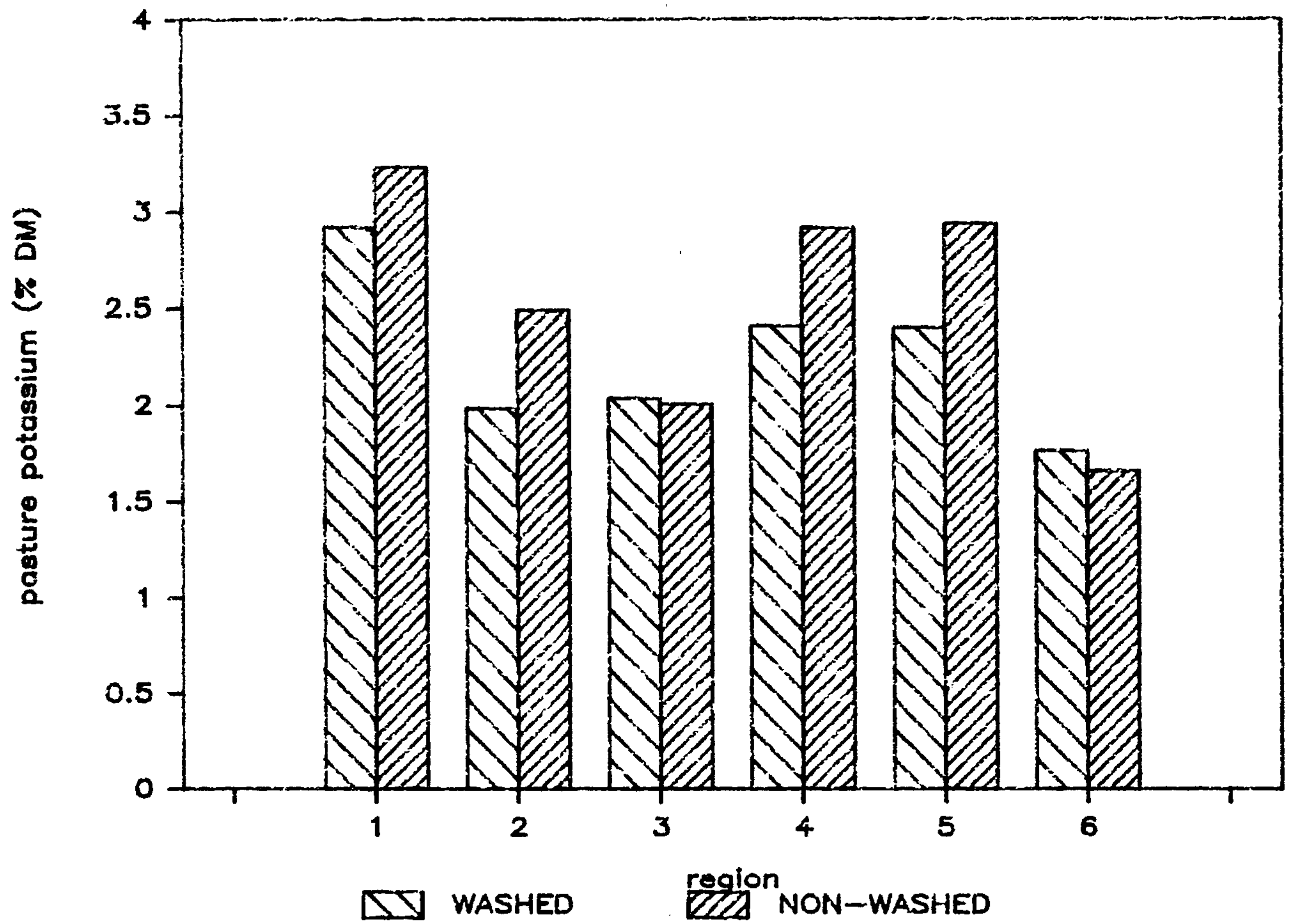

Figure 25. Potassium in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Copper

The minimum estimated copper requirement for dairy cattle is 10 ppm (NRC, 1978). Copper requirements must be calculated in relation to the molybdenum content of the feed, to insure a minimum 2:1 ratio of copper to molybdenum.

Pastures in regions 2 and 3 in Ecuador and region 6 in Michigan had 4.6, 4.7 and 5.5 ppm of copper (Table 9, Figure 26). Copper in pastures from regions 1, 4 and 5 in Ecuador was 9.3, 7.8 and 6.8 ppm. All these values are below the minimum requirement of 10 ppm, although the copper to molybdenum ratio was in all the cases greater than 2:1.

The difference among regions ($p < .05$), and among farms within regions ($p < .01$), was significant. The differences among types of samples and the interaction between type and region were not significant ($p > .05$). The correlation coefficient between copper in pastures and in soils was 0.322.

To prevent copper deficiency in cattle, 0.5 to 1.0% copper sulfate (0.125 to 0.250% copper) may be added to the salt in copper deficient areas (NRC, 1978; Underwood, 1981). The trace mineral salt used in region 6 in Michigan at the time of sampling had only 0.03% copper. This percentage is not enough to raise the total copper concentration in the diet to 10 ppm, as suggested by the NRC (1978). It is possible that animals from all the six regions studyed could benefit from copper supplementation via the trace mineral salt.

The sufficiency range of copper concentration is 6 to 20 ppm for corn, and 11 to 30 ppm for alfalfa (Table I.2, Appendix 1).

Table 9. Copper, iron, zinc, cobalt, and manganese concentrations in the dry matter of washed and non-washed pasture samples from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

		COPPER ppm		IRON ppm		ZINC ppm		COBALT ppm		MANGANESE ppm	
REGION(2)	N	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)
1 ECUADOR	30	9.3	(0.9)	221	(55)	41	(6)	0.25	(0.02)	35	(7)
2 ECUADOR	30	4.6	(0.9)	138	(55)	40	(6)	0.15	(0.02)	36	(7)
3 ECUADOR	30	4.7	(0.9)	106	(55)	31	(6)	0.20	(0.02)	48	(7)
4 ECUADOR	30	7.8	(0.9)	357	(55)	38	(6)	0.18	(0.02)	42	(7)
5 ECUADOR	30	6.8	(0.9)	108	(55)	41	(6)	0.26	(0.02)	27	(7)
6 MICHIGAN	12	5.5	(1.5)	44	(80)	28	(9)	0.15	(0.03)	46	(12)
WASHED	81	6.5	(0.3)	145	(15)	39	(2)	0.19	(0.01)	37	(2)
NON-WASHED	81	6.6	(0.3)	205	(15)	34	(2)	0.22	(0.01)	40	(2)
Significance of F (3)											
Region		*		*		NS		*		*	
Farm/region		**		**		**		**		**	
Type of sample		NS		**		*		NS		NS	
Type X region		NS		NS		NS		NS		**	

(1) N, $\overline{X}$, SEM: number of observations, means and standard errors of means
(2) Region means within a column without a common superscript are different ($p < .05$)
(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

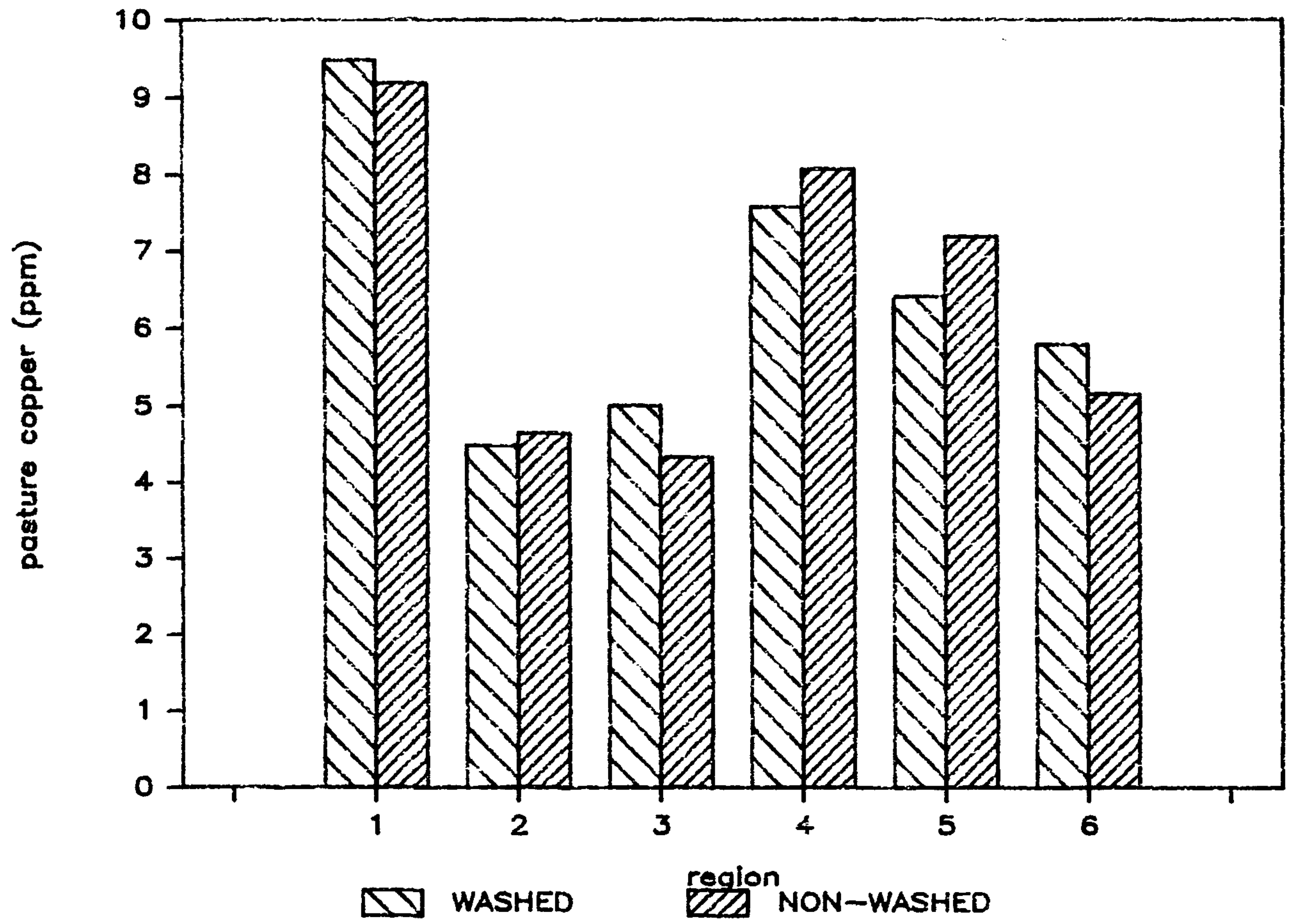

Figure 26. Copper in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Even though the samples for this investigation represent entire plants that are likely to have a lower element concentration than the plant's parts suggested in the table, their low copper content may be an indication of low copper availability in the soil. Also, the copper content in the soil (Table 6), as discussed above is low. Copper fertilization may increase the copper content in the pasture, and possibly improve the crop yield, especially of alfalfa and legumes that are highly responsive to copper fertilization.

The recommendation of the Extension Service of Michigan State University to correct possible copper deficiencies is a band application of 6.7 kg of copper per hectare (6 lb/acre) per year, until 18 kg (40 lb) of copper has been applied or until the soil test is over 20 ppm copper (Robertson et al., 1981c).

Iron

According to the NRC (1978), an iron level of 100 ppm in the dry matter of the diet should be adequate for all needs of calves to 3 months of age, and 50 ppm sufficient for all other dairy cattle. In pastures, the iron concentration ranged from 45 ppm in region 6 in Michigan to 357 ppm in region 4 in Ecuador (Table 9, Figure 27). All regions in Ecuador had an iron content above 100 ppm. The difference among regions ($p < .05$) and among farms within regions ($p < .01$) was significant. Non-washed samples had significantly more iron, 205 ppm, than washed samples, which contained 145 ppm ($p < .01$), indicating soil contamination. The effect of interaction of type of sample with region was not significant ($p > .05$). The correlation of iron in soils

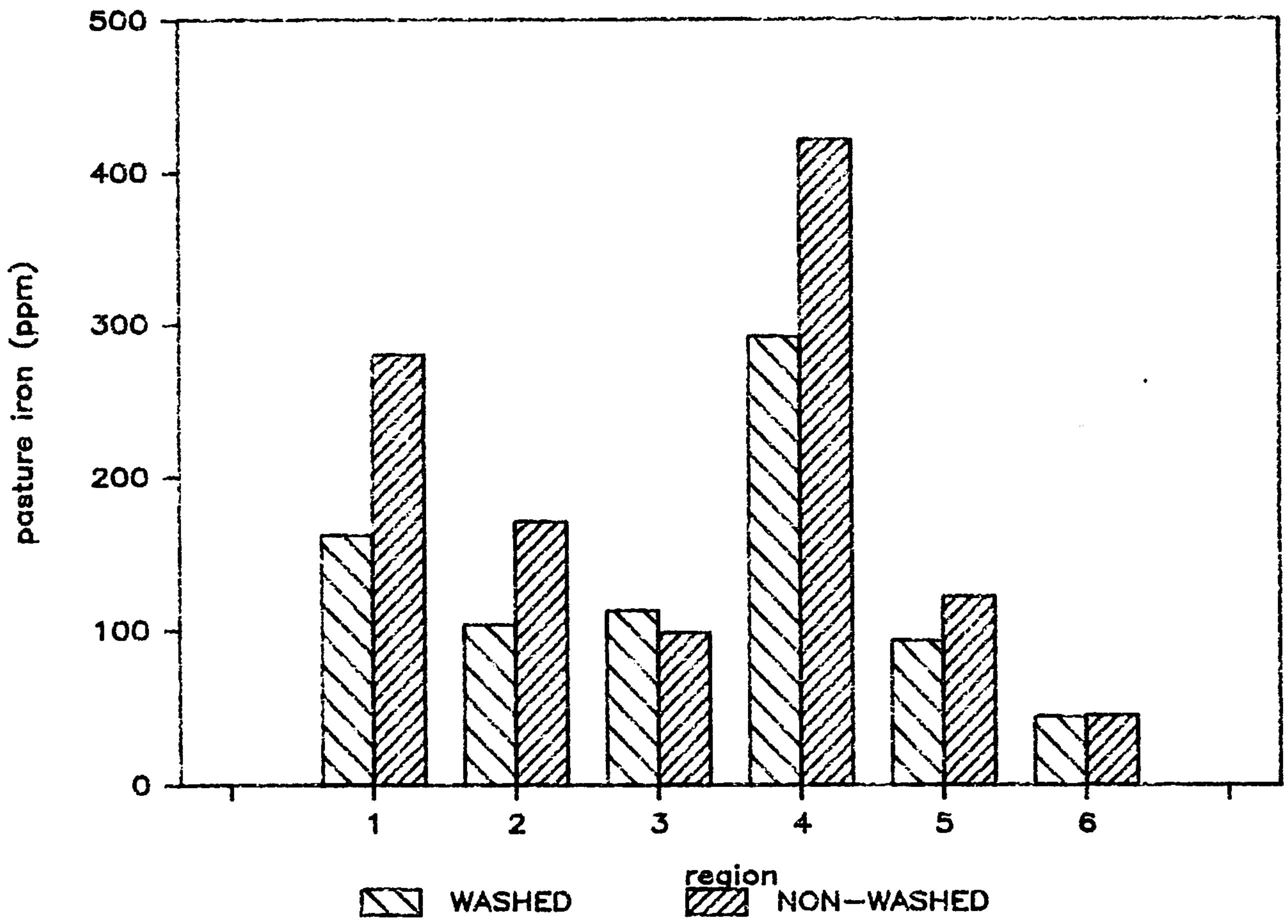

Figure 27. Iron in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

(extracted with 0.1 N HCl) to that in pastures was -0.02. The correlation of iron in soils to pH in soils was -0.153.

An iron concentration of 45 ppm in the forages of region 6 is not enough to meet the animals' requirements. However, a trace mineral salt was fed that provided sufficient iron for the animals. Trace mineral salts have around 0.2 % iron (Table I.10, Appendix I).

Zinc

The estimated zinc requirement of dairy cattle is 40 ppm (NRC, 1978). Zinc in pastures (Table 9, Figure 28) ranged from 28 ppm in region 6 in Michigan to 41 ppm in regions 1 and 5 in Ecuador. Animals from region 6 in Michigan and region 3 in Ecuador may benefit from zinc supplementation via the trace mineral salt.

There was no significant difference among regions ($p > .05$), but the difference among farms within regions ($p < .01$) and among types of samples ($p < .05$) was significant. The interaction between type of sample and region was not significant ($p > .05$). Correlation coefficients were as follows: 0.024 between zinc in soils and in pastures, 0.004 between zinc in pastures and pH in soils, -0.086 between zinc in pastures and phosphorus in soils, and 0.066 between zinc in pastures and iron in soils.

The sufficiency range of zinc for corn is 20-70 ppm for corn and 21-70 ppm for alfalfa. Average zinc content in corn samples in region 6 was 23 ppm, it was 31 in alfalfa. The extractable zinc level in the soils in this region was also low, as discussed above. Corn is a crop highly responsive to zinc (Robertson and

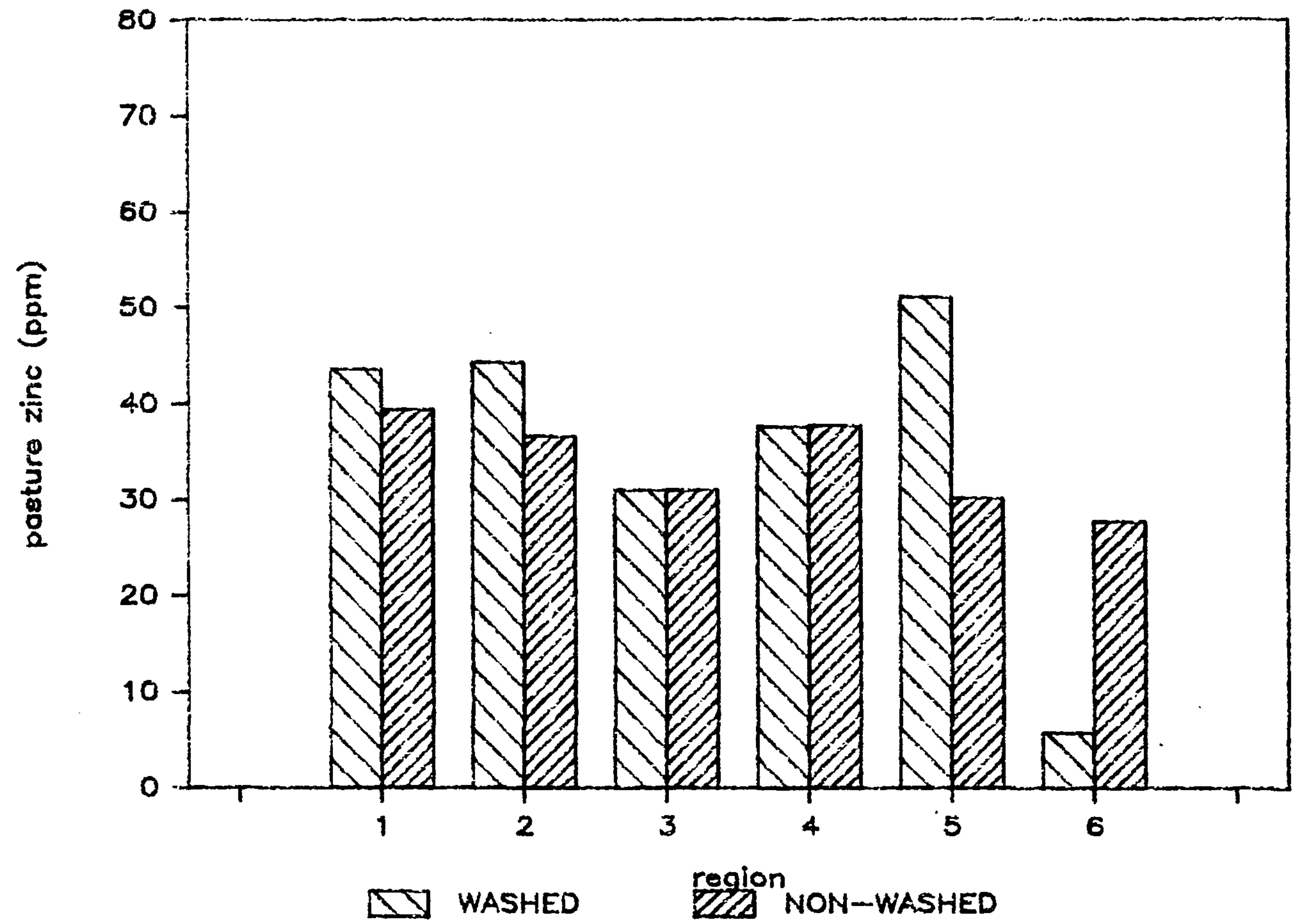

Figure 28. Zinc in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Lucas, 1981b), so it is possible that zinc fertilization would improve the yields in this region.

To treat a deficient soil, a band application at planting time of 3.4 to 4.5 kg of inorganic zinc or 0.6 to 0.9 kg of organic zinc (chelate) per hectare (3 to 4 lb/acre or 0.5 to 0.8 lb/acre) is recommended. Where zinc is broadcast, rates should be increased. For highly responsive crops, 28 kg/hectare (25 lb/acre) of zinc showed good availability for seven years. Also, after several years of banding zinc, when a total of 28 kg/hectare (25 lb/acre) has been used, rates can be greatly reduced, and in some instances even eliminated (Robertson and Lucas, 1981b).

Cobalt

In pastures cobalt content ranged from 0.15 ppm in region 6 in Michigan to 0.26 ppm in region 5 in Ecuador (Table 9, Figure 29). Regional means of cobalt content in pastures ($p < .05$) and means in farms within regions ($p < .01$) were significantly different. The difference among means of type of sample and the interaction were not significant ($p > .05$). The correlation coefficient between cobalt in soils and in pastures was 0.052.

The cobalt requirement of dairy cattle is 0.10 ppm of the diet's dry matter (NRC, 1978). This requirement seems to be met by the forages analyzed in the present investigation. Trace mineral salts, however, almost always include cobalt in their formulas, usually at a rate of 0.003 to 0.005% of the mixture, in order to prevent possible deficiencies.

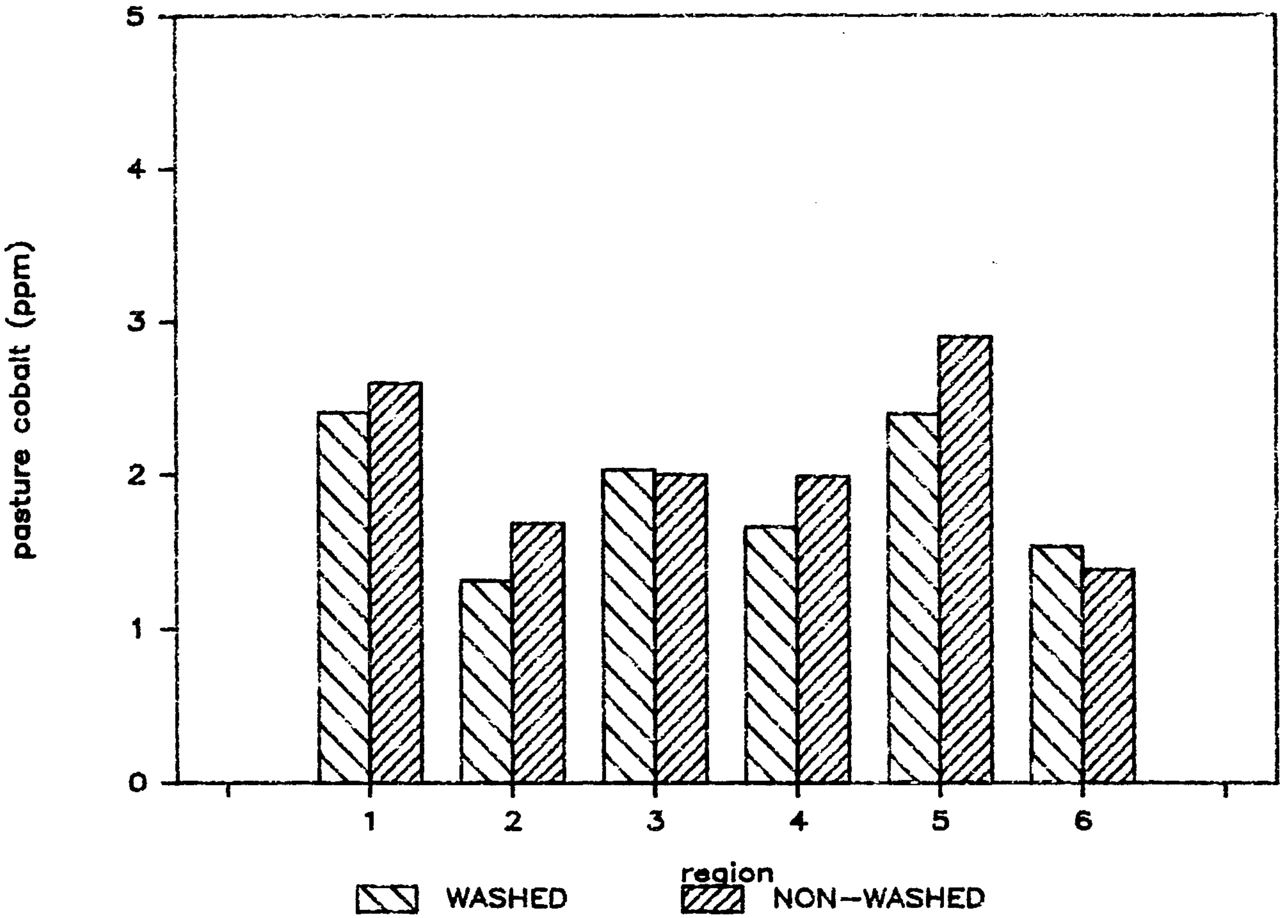

Figure 29. Cobalt in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Manganese

The manganese requirement of cattle has not been well defined but the suggested manganese dietary requirement is 40 ppm (NRC, 1978). Manganese content in pastures in regions 1, 2 and 5 in Ecuador was 35, 36 and 27 ppm. In regions 3 and 4 in Ecuador, and region 6 in Michigan, average manganese content in pastures was 48, 42 and 46 ppm (Table 9, Figure 30). These facts indicate a possible manganese deficiency in regions 1, 2 and 5. The use of a manganese containing trace mineral salt should prevent a deficiency of this element in the animals. A typical trace mineral salt (Table I.10, Appendix I) contains around 0.2% manganese, which is enough to meet the requirements of dairy animals under most practical conditions.

There was a significant difference among regions ($p < .05$) and among farms within regions (p .01). The interaction among regions with type of sample was also significant ($p < .01$). The difference among types of samples was not significant ($p > .05$). The correlation coefficent between manganese in pastures and soils was 0.065. The correlation coefficient among manganese in pastures and pH value in soils was -0.323.

Molybdenum

Molybdenum is important in animal nutrition because of its interaction with copper and sulfur. Different authors suggest copper-to-molybdenum ratios ranging from 4:1 to 2:1 in the diet of ruminants to avoid molybdenum-induced copper deficiency in ruminants (Underwood, 1981).

In plants, molybdenum is essential for nitrogen fixation and

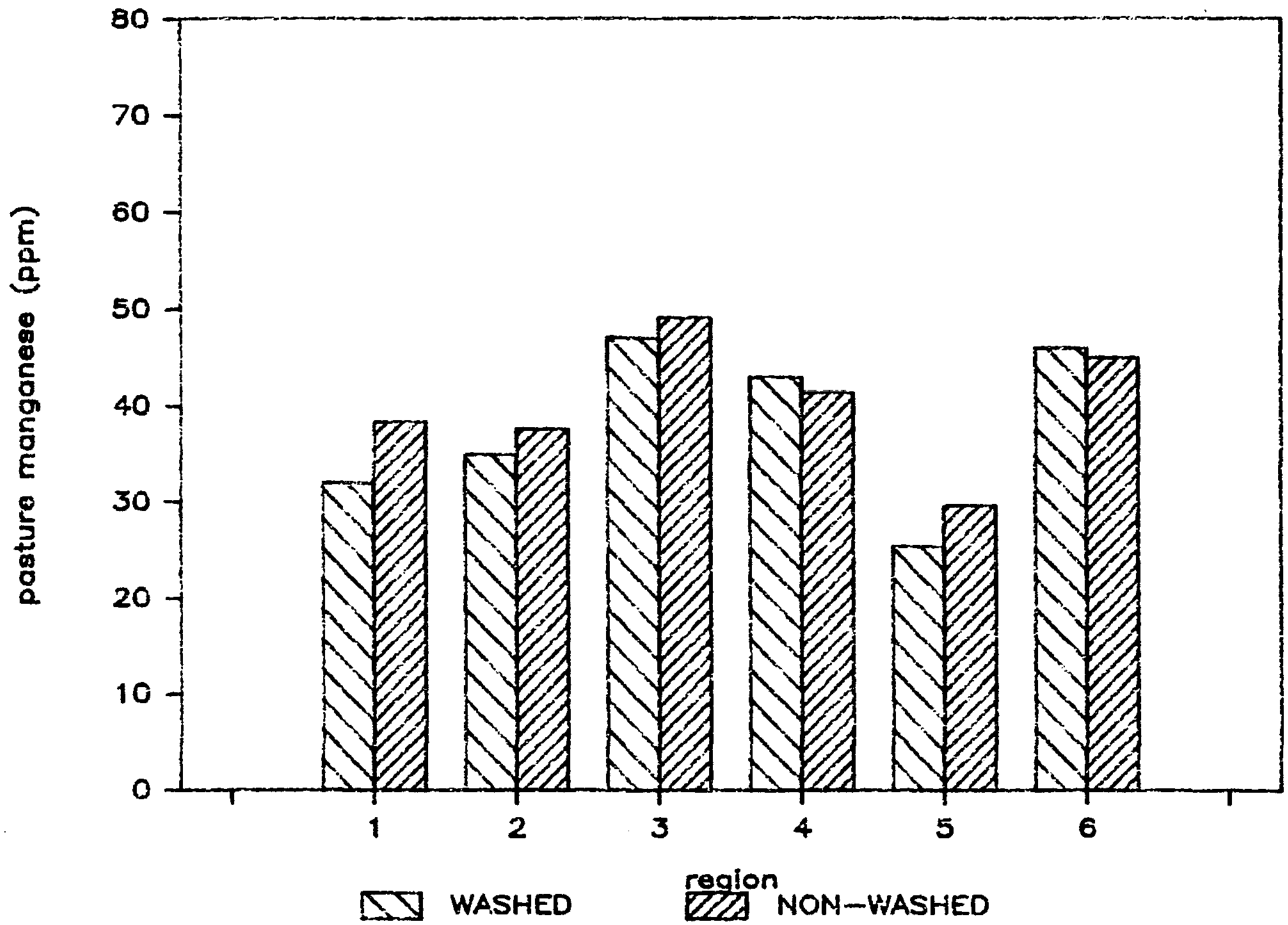

Figure 30. Manganese in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

nitrate reduction. The presence of 0.1 to 2.0 ppm of molybdenum in the ear leaf of initial silk in the corn plant and 1.0 to 5.0 ppm in the top six inches of the alfalfa plant prior to initial flowering is an indication of sufficient amounts of molybdenum in the soil (Cox and Kamprath, 1972).

In the present experiment, values ranging from 0.18 ppm (region 6 in Michigan) to 1.93 ppm (region 3 in Ecuador) were found for molybdenum in pastures (Table10, Figure 31). The molybdenum content in pastures from the other regions in Ecuador ranged from 0.54 (region 1) to 1.74 ppm (region 5). Molybdenum in soil of region 1 was also low. It is possible that pastures can benefit from molybdenum fertilization in regions where soil molybdenum is low. In regions where soil molybdenum is relatively high, such as in region 6, liming would probably make soil molybdenum more available to the plants. The Extension Service of Michigan State University has published a practical guides on molybdenum and other minerals fertilization (Robertson et al., 1981b).

The differences among regions, types of sample, and the interaction were not significnt ($p > .05$). Mean molybdenum content in pastures from farms within region differed significantly ($p < .01$). The correlation coefficient between molybdenum in soils and pastures was 0.86. The correlation coefficient between soil pH and molybdenum content in pastures was -0.106. coefficient between soil pH and molybdenum in soils was -0.443. The correlation coefficient between soil pH and molybdenum in pastures was -0.106.

Table 10. Molybdenum and selenium concentrations in the dry matter of washed and non-washed pasture samples from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

		MOLYBDENUM ppm		SELENIUM ppm	
REGION (2)	N	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)
1 ECUADOR	30	0.54	(0.37)	0.46	(0.06)
2 ECUADOR	30	1.10	(0.37)	0.55	(0.06)
3 ECUADOR	30	1.93	(0.37)	0.41	(0.06)
4 ECUADOR	30	1.09	(0.37)	0.51	(0.06)
5 ECUADOR	30	1.74	(0.37)	0.53	(0.06)
6 MICHIGAN	12	0.18	(0.58)	0.19	(0.10)
WASHED	81	1.12	(0.09)	0.46	(0.02)
NON-WASHED	81	1.27	(0.09)	0.48	(0.02)
Significance of F (3)					
Region		NS		NS	
Farm/region		**		**	
Type of sample		NS		NS	
Type X region		NS		NS	

(1) N, $\overline{X}$, SEM: number of observations, means and standard errors of means
(2) Region means within a column without a common superscript are different ($p < .05$)
(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

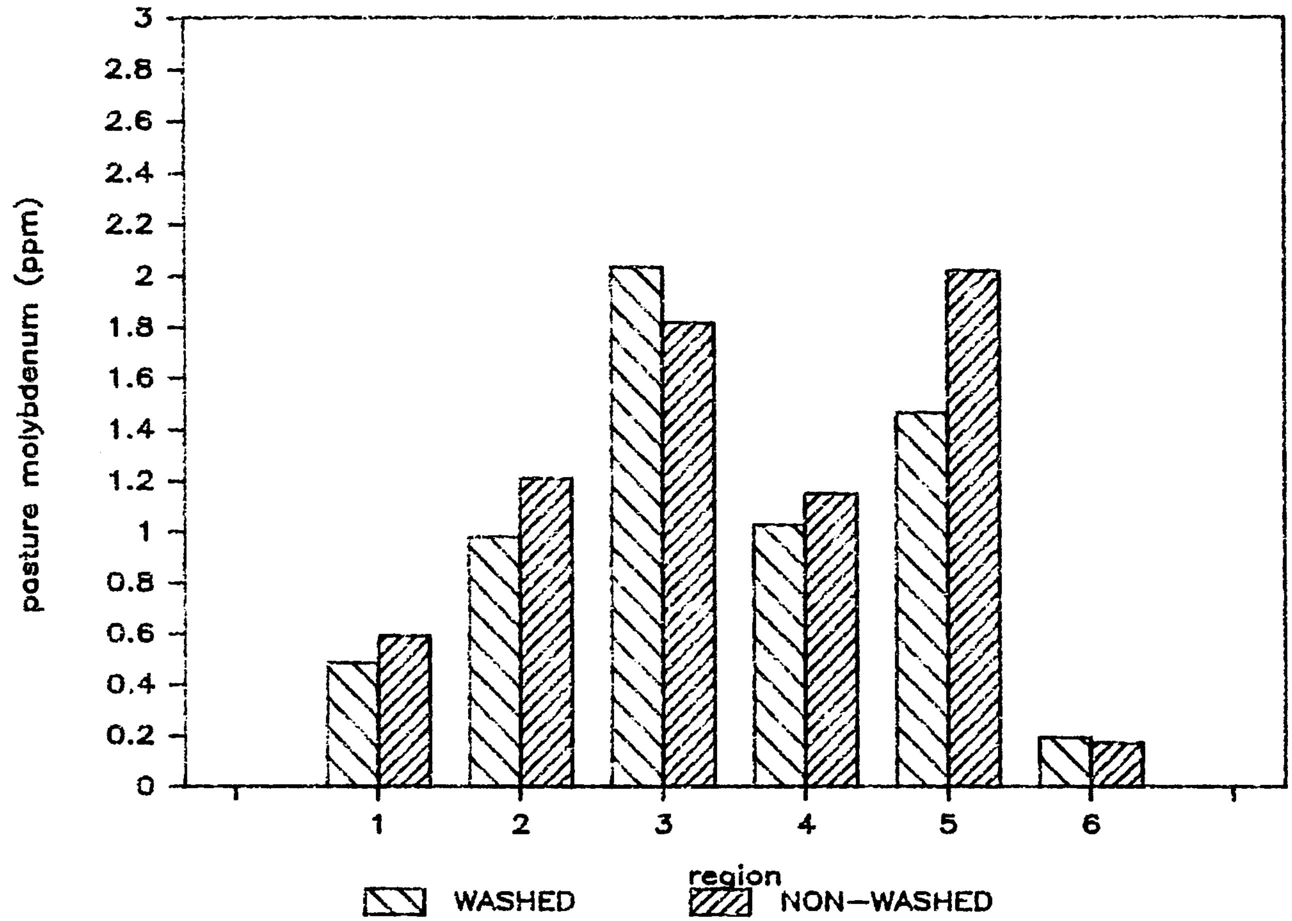

Figure 31. Molybdenum in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Selenium

Selenium requirement of ruminants is not well defined, but the NRC (1978) suggests 0.10 ppm. The amount required depends on the chemical form of selenium and the levels of interfering or enhancing factors in the diet, including vitamin E, sulfur, lipids, proteins, amino acids, and several microelements.

The critical level at which ruminants start showing signs of selenium deficiency seems to be around 0.05 ppm in the diet (Kubota and Allaway, 1972). The level of selenium toxic to animals may be as low as 3 to 5 ppm. depending on several factors. The chemical form fed has an effect on the level of toxicity: the naturally occurring organic selenium found in plants is apparently much more toxic than the inorganic form (NRC, 1978). Toxicity can also be affected by composition of the diet, particularly protein, sulfur, and arsenic. These nutrients reduce selenium toxicity (NRC, 1978).

In the present study (Table 10, Figure 32) the lowest selenium concentration in pastures was found in region 6 in Michigan (0.19 ppm) and the highest in region 2 of Ecuador (0.55 ppm). Selenium concentration in pastures in the other regions in Ecuador ranged from 0.41 to 0.53 ppm. All these values are within the range of minimum requirements (0.10 ppm) and less than toxicity levels (3 to 5 ppm) given by the NRC (1978).

The differences among regions, types of sample, and the interaction were not significant ($p > .05$). Mean selenium content in pastures from farms within region differed significantly ($p < .01$). The correlation coefficient between

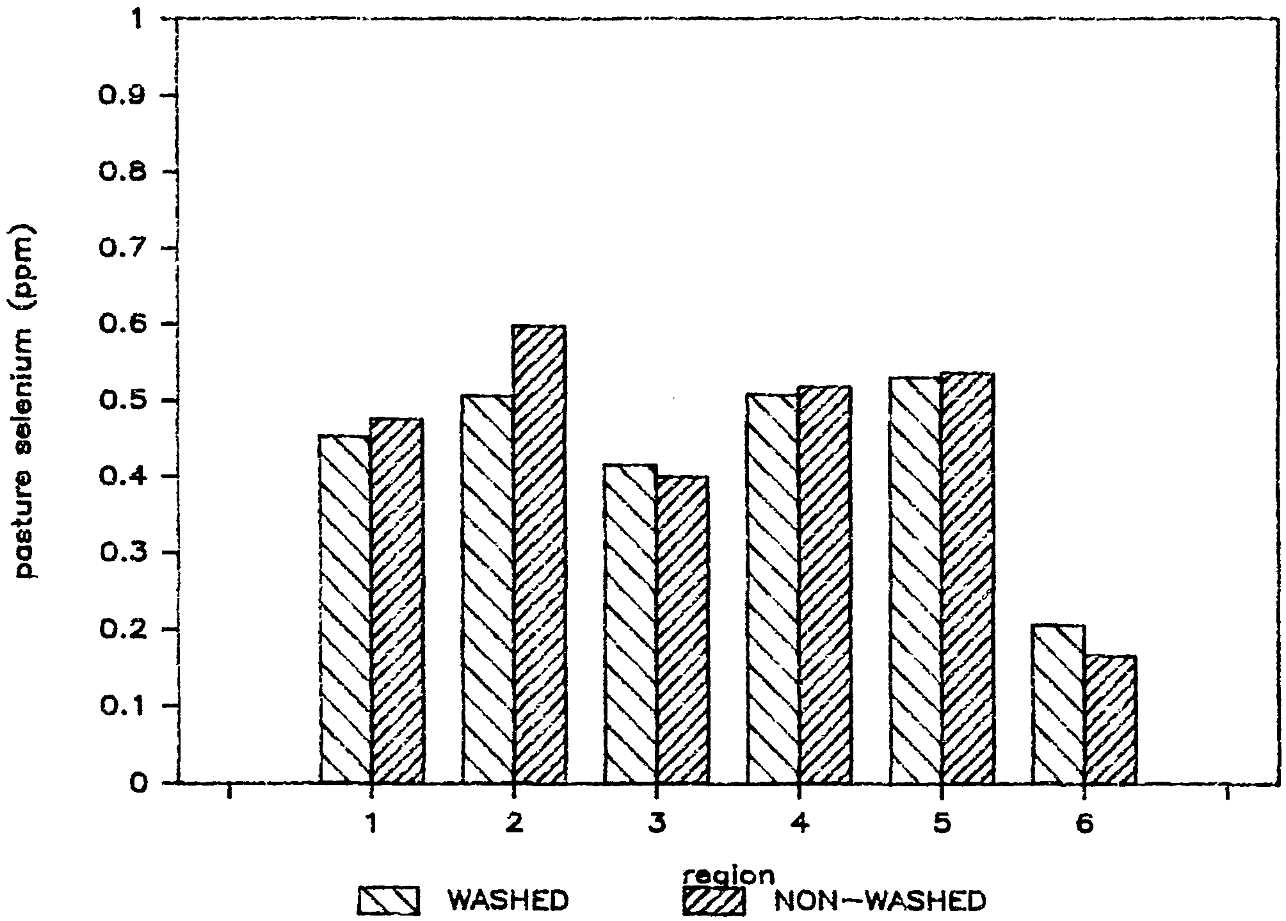

Figure 32. Selenium in washed and non-washed pasture samples from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

selenium in soils and in pastures was -0.128. The correlation coefficient between selenium in pastures and pH in soils was 0.237.

Minerals in Blood

Mineral concentration in blood is in general regulated by homeostatic mechanisms (Miller, 1975). Metabolic profiles of dairy cows used to assess nutritional status have shown little relation between calcium and phosphorus intake and concentration of the same minerals in blood (Parker et al., 1970; Payne et al., 1970, Blowey et al., 1975; Allen et al., 1976; Rowlands and Pocock, 1976; Adams et al., 1978; Lee et al., 1978; Kronfeld et al., 1982; Roussel et al., 1982). Nevertheless, blood analysis is a favored method to diagnose mineral nutrition problems because of its accesibility and ease of handling. More important, since blood is the main system for transport of nutrients in the body, deficiencies or excesses of a particular nutrient may be reflected in its concentration in the blood.

Calcium

Animals consuming diets low in calcium, or diets with a calcium-to-phosphorus ratio of less than 1:1 will develop signs of calcium deficiency such as depressed feed intake, reduced rate of gain, reduced milk production and osteomalacia before the calcium concentration in blood is reduced (Underwood, 1981).

Table 11 shows the concentration of calcium, phosphorus, sodium, potassium and magnesium in the blood serum of dairy animals tested in the present experiment. Table I.3 (Appendix I) shows typical mineral concentration in blood plasma or serum of ruminants.

The typical range of serum calcium concentration in ruminants is 9.0 to 12.0 mg/100 ml (Church, 1976). Except for

Table 11. Calcium, phosphorus, sodium, potassium and magnesium concentrations in the blood serum of calves and dairy cows from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

		CALCIUM mg/100 ml		PHOSPHORUS mg/100 ml		SODIUM mg/100 ml		POTASSIUM mg/100 ml		MAGNESIUM mg/100 ml	
REGION(2)	N	$\bar{X}$	(SEM)	$\bar{X}$	(SEM)	$\bar{X}$	(SEM)	$\bar{X}$	(SEM)	$\bar{X}$	(SEM)
1 ECUADOR	60	9.47	(0.40)	7.55	(0.74)	477	(22)	25	(1.36)	3.04	(0.20)
2 ECUADOR	60	8.76	(0.40)	6.90	(0.74)	443	(22)	23	(1.36)	3.00	(0.20)
3 ECUADOR	60	8.57	(0.40)	6.25	(0.74)	526	(22)	26	(1.36)	2.96	(0.20)
4 ECUADOR	60	8.64	(0.40)	6.47	(0.74)	432	(22)	26	(1.36)	2.44	(0.20)
5 ECUADOR	60	9.96	(0.40)	6.57	(0.74)	485	(22)	23	(1.36)	3.47	(0.20)
6 MICHIGAN	20	8.14	(0.69)	5.52	(1.29)	380	(39)	20	(2.35)	2.13	(0.35)
COWS	160	8.88	(0.12)	4.62	(0.34)	474	(5)	24	(0.28)	2.93	(0.05)
CALVES	160	9.16	(0.12)	7.35	(0.34)	460	(5)	24	(0.28)	2.92	(0.05)
Significance of F (3)											
Region		NS		NS		NS		NS		*	
Farm/region		**		**		**		**		NS	
Type of animal		NS		**		*		NS		NS	
Type X region		NS		*		**		**		NS	

(1) N, $\bar{X}$, SEM: number of observations, means and standard errors of means
(2) Region means within a column without a common superscript are different ($p < .05$)
(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

regions 1 and 5 in Ecuador (Table 11, Figure 33), average serum calcium levels in the regions studied in Ecuador and in Michigan, were below 9.0 mg/100. All average values were, nevertheless, above 8.0 mg/100 ml. There was no significant difference among regions ($p > .05$). The difference among types of animals ($p > .05$) and the interaction of type with region ($p > .05$) were not significnt either, but the difference between farms within region was highly significant ($p < .01$).

The correlation coefficient between serum calcium and serum phosphorus was 0.332; between serum calcium and calcium in pastures it was 0.509; between serum calcium and phosphorus in pastures it was 0.074.

Phosphorus

Serum phosphorus levels ranged from 5.52 mg/100 ml in region 6 in Michigan to 7.55 mg/100 ml in region 1 in Ecuador (Table 11, Figure 34), but the difference among regional means was not significant ($p > .05$). All the values found are within the range considered normal for ruminants, which is 4-9 mg/100 ml (Church, 1976). Serum phosphorus in calves (7.35 mg/100 ml) was significantly higher ($p < .01$) than in cows (4.62 mg/100 ml). Phosphorus values of 4-6 mg/100 ml in cows, and 6-8 mg/100 ml in young animals, have been observed in blood plasma (Underwood, 1981). The difference among farms within regions was significant ($p < .01$), as was the interaction of type of animal with region ($p < .05$). The correlation coefficient between serum phosphorus and pasture phosphorus was 0.210.

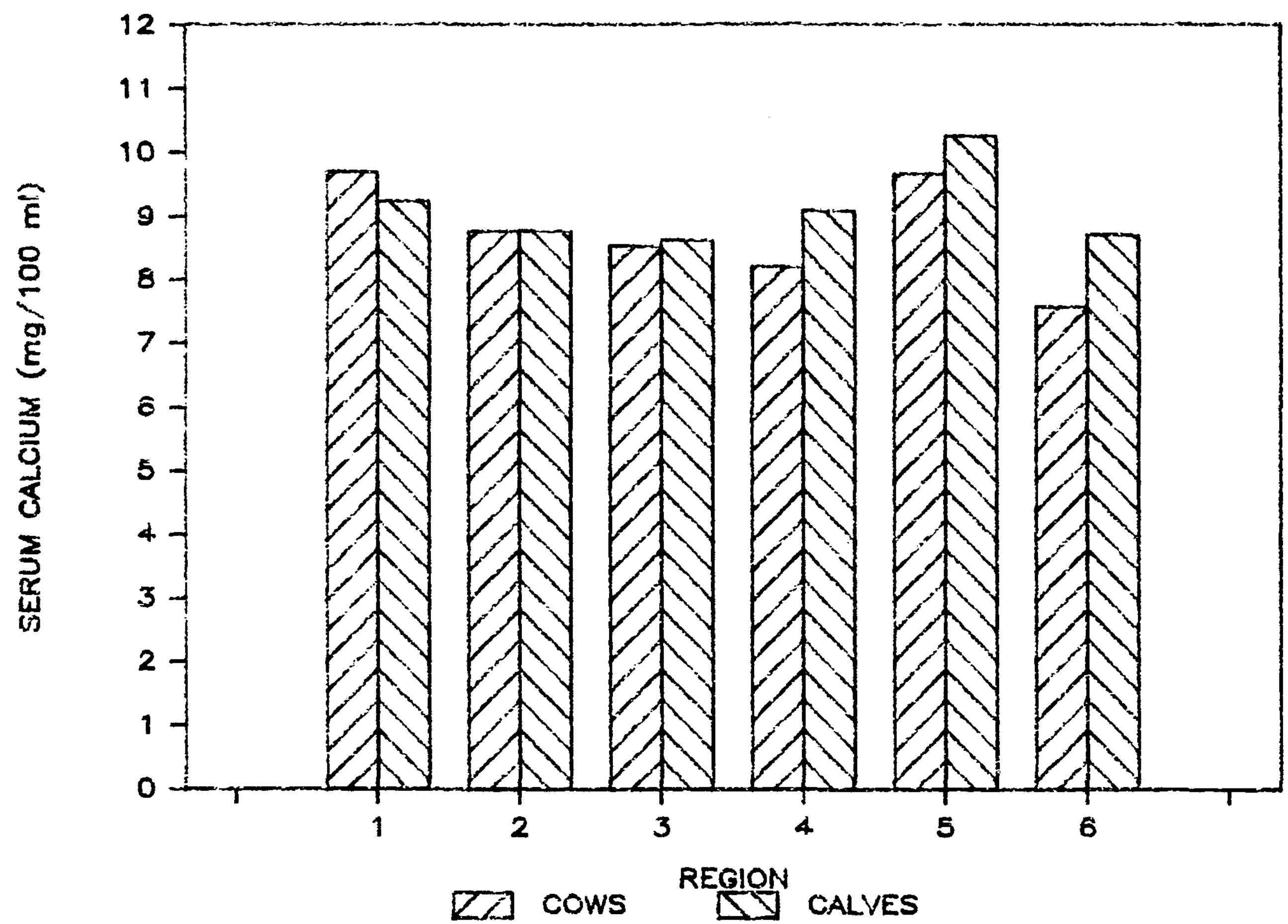

Figure 33. Calcium in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

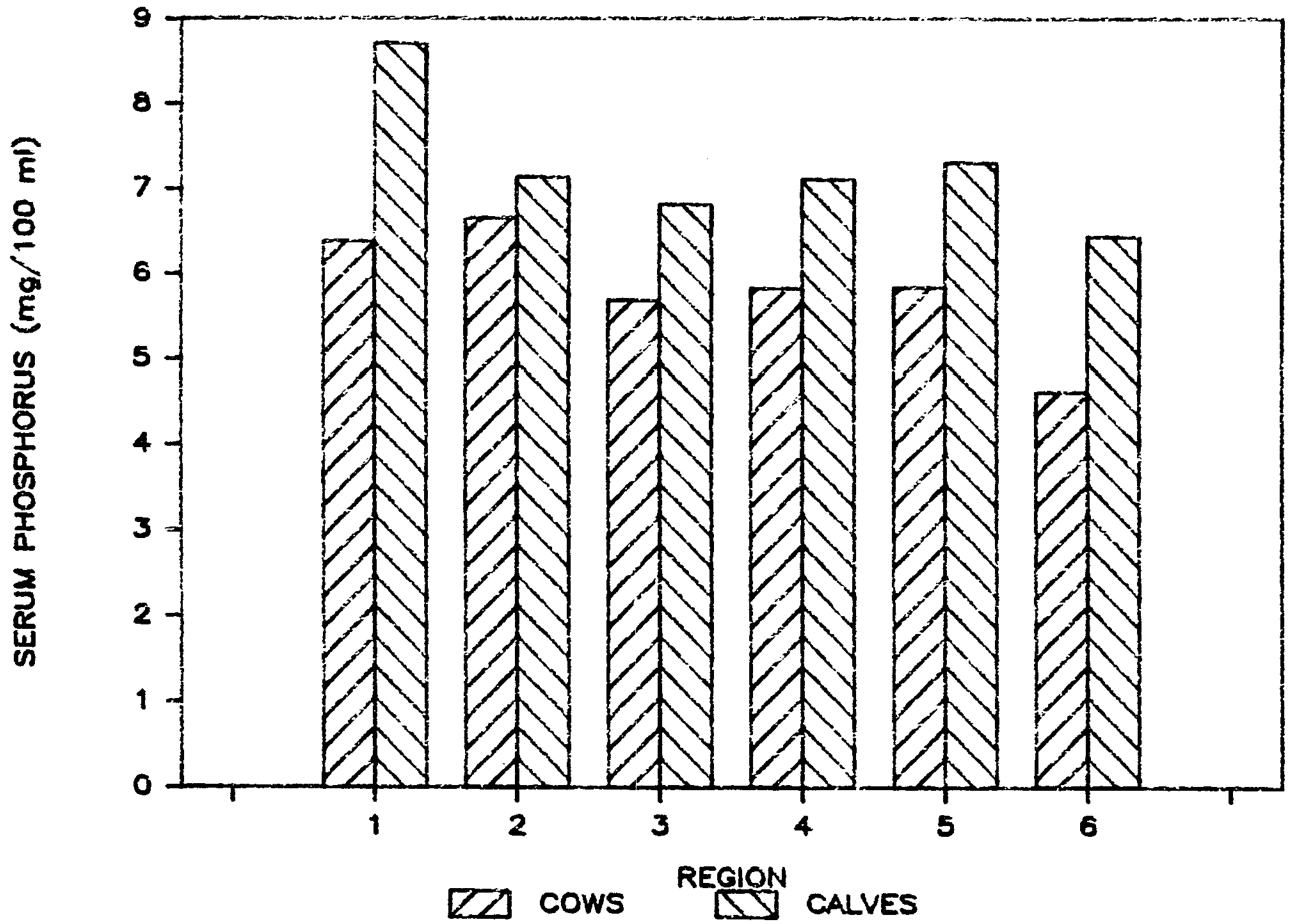

Figure 34. Phosphorus in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Magnesium

The normal concentration of magnesium in the blood serum of cattle is around 1.8 to 3.0 mg/100 ml (Church, 1976). In the present investigation all values were within or slightly above the concentrations considered normal (Table 11, Figure 35). The means of regions differed significantly ($p < .05$), but multiple comparisons of all regional means (Bonferroni's t test) showed nonsignificant differences ($p > .10$). There was no significant difference of serum magnesium among farms within region nor among types of animals ($p > .05$). The interaction of region with type was not significant either ($p > .05$).

No signs or history of magnesium tetany were observed in any of the farms studied. Cows in region 6 were provided with magnesium oxide in the concentrate to prevent low milk-fat syndrome.

Sodium and Potassium

Normal concentrations in the blood plasma of cattle are around 300 mg/100 ml for sodium, and 14 to 18 mg/100 ml for potassium (Church, 1976). In the present investigation, sodium and potassium levels in blood plasma were higher than what is considered normal (Table 11, Figures 36 and 37). It is possible that at high altitude the concentration of these two elements is increased, as reported by Wilson (1975). Animals in the regions studied looked healthy, so it is possible that these higher than normal sodium and potassium concentrations in serum are not pathological.

There was not a significant difference among regional means

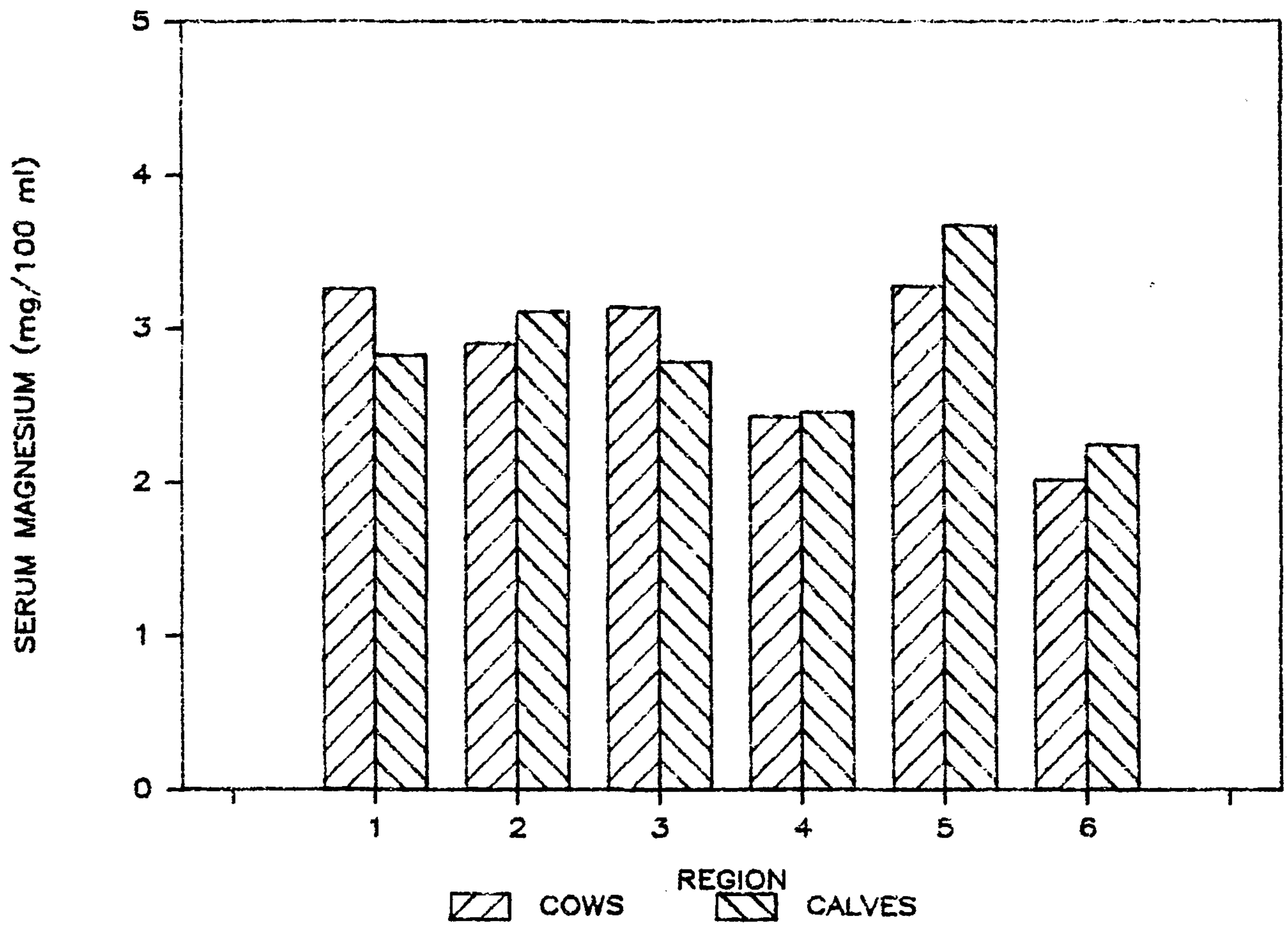

Figure 35. Magnesium in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

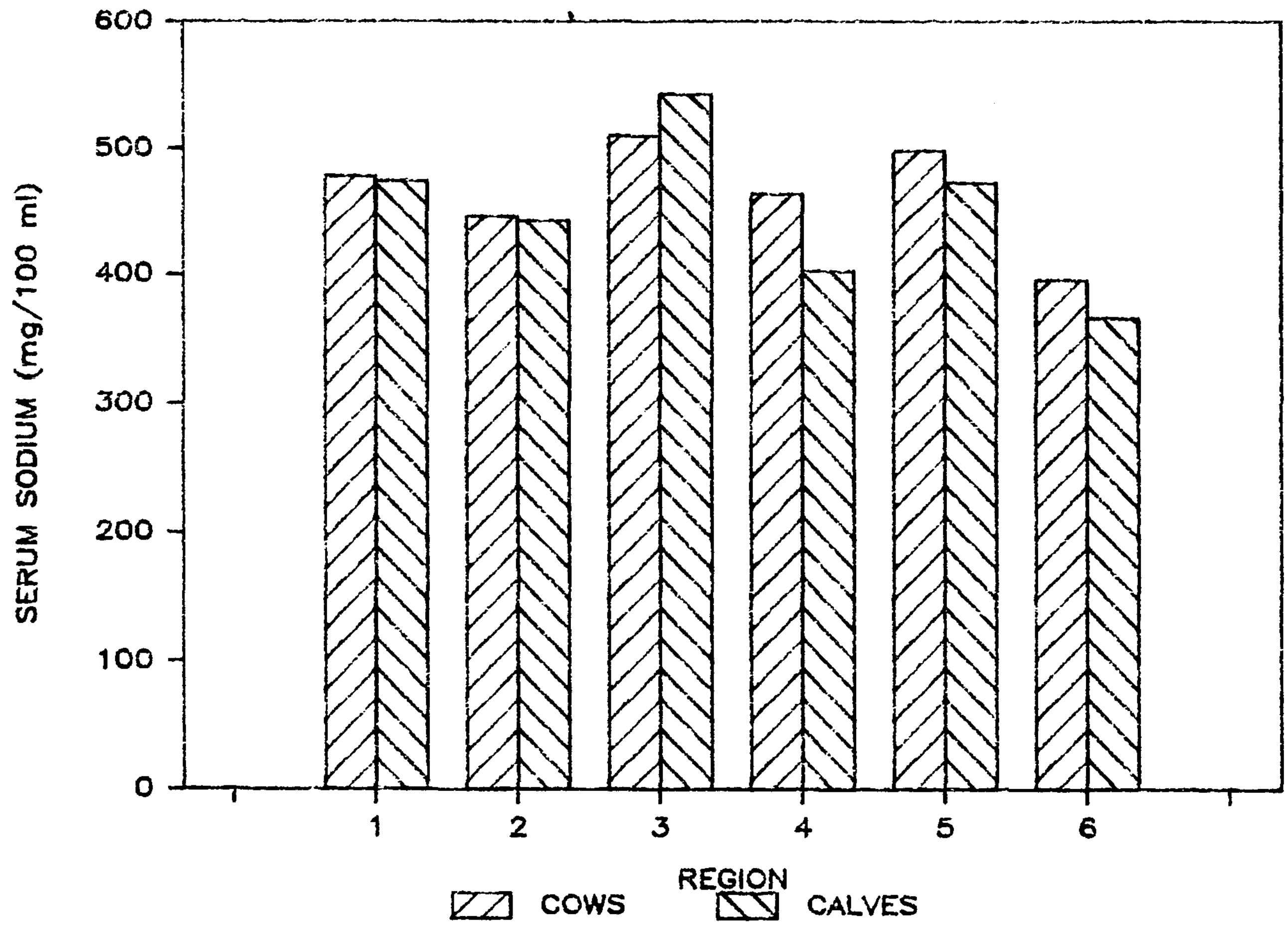

Figure 36. Sodium in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

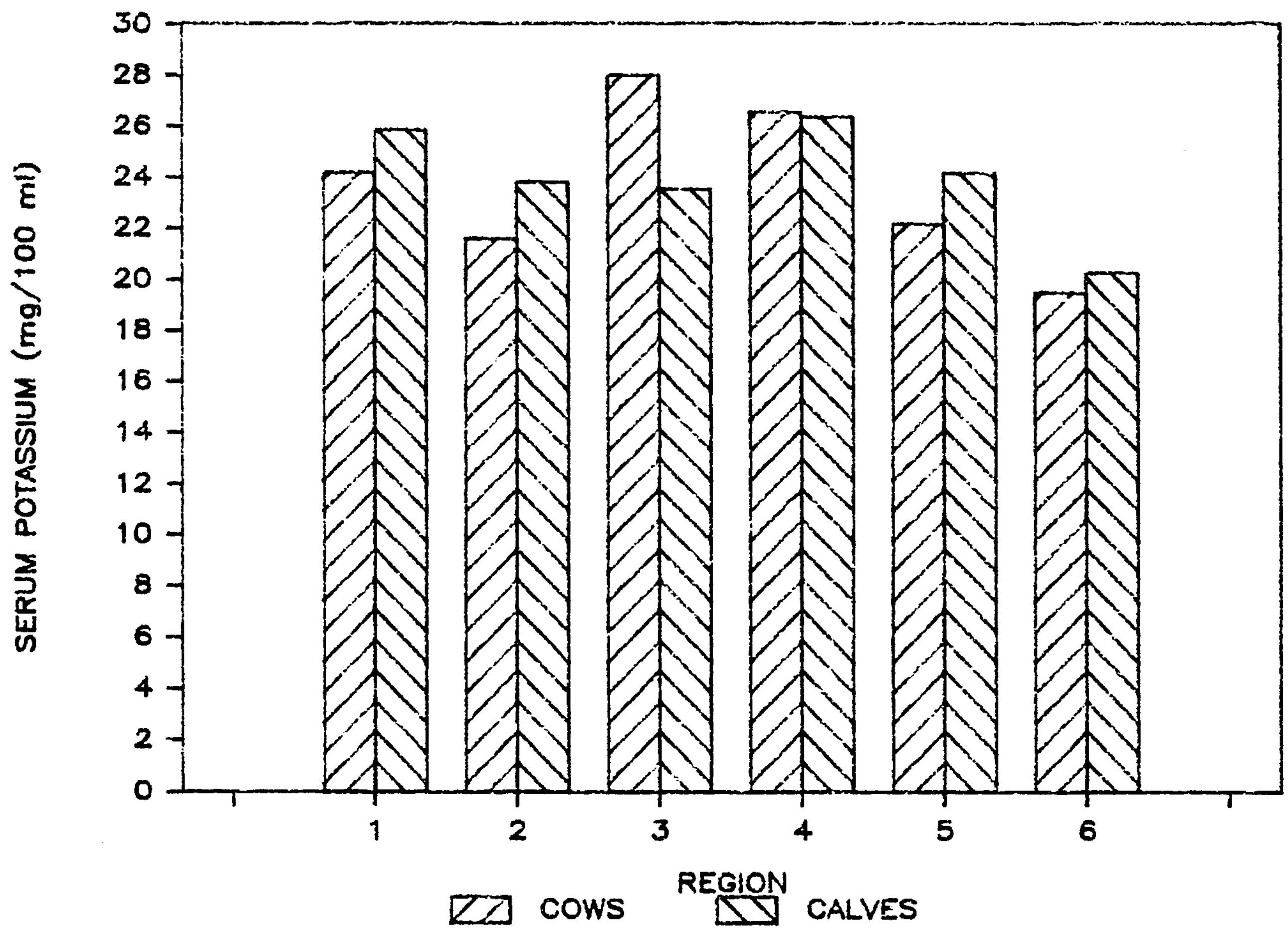

Figure 37. Potassium in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

for sodium and potassium in serum ($p > .05$), but the difference among farms within regions and the interction of type of animal with region were highly significant ($p < .01$). Young animals had a slightly higher sodium concentration in blood serum than adults ($p < .05$).

The correlation coefficient between serum sodium and pasture sodium was -0.214, and the correlation coefficient between serum potassium and pasture potassium was -0.135. All animals studied received salt supplementation. Serum concentration of sodium and potassium is not a good indicator of the adequacy of the diet in meeting the need for these minerals or of the nutritional status of the animal (Miller, 1974).

Iron

The concentration of iron, copper, zinc, manganese, and selenium in blood serum is shown in Table 11. Iron concentration ranged from 325 ug/100 ml in Michigan to 446 ug/100 ml in region 3 in Ecuador (Table 12, Figure 38). Typical iron concentration in blood plasma is around 150 ug/100 ml at sea level (Church, 1979). Blood's iron content is increased as a result of increased erythropoiesis due to the reduced atmospheric oxygen pressure. Hematocrit count in sheep exposed for 32 days to low pressure (348 mm Hg) similar to that found at 6200 m of altitude, was 37; in the control (640 mm Hg) the hematocrit count was 27 (Phillips et al., 1969). Relatively high values for serum iron found in Michigan (240 m above sea level) are probably due to partial hemolysis of red blood cells.

The means of regions did not differ significantly ($p > .05$),

Table 12. Iron, copper, zinc, manganese and selenium concentrations in the blood serum from calves and dairy cows from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

		IRON ug/100 ml		COPPER ug/100 ml		ZINC ug/100 ml		MANGANESE ug/100 ml		SELENIUM ug/100 ml	
REGION(2)	N	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)	$\overline{X}$	(SEM)
1 ECUADOR	60	443	(22)	83	(7)	184	(12)	4.48^{a}	(0.60)	2.62	(1.26)
2 ECUADOR	60	426	(22)	73	(7)	171	(12)	1.01^{b}	(0.60)	2.72	(1.26)
3 ECUADOR	60	446	(22)	86	(7)	167	(12)	2.26^{ab}	(0.60)	7.81	(1.26)
4 ECUADOR	60	392	(22)	72	(7)	171	(12)	0.77^{b}	(0.60)	4.09	(1.26)
5 ECUADOR	60	408	(22)	84	(7)	164	(12)	2.64^{ab}	(0.60)	5.90	(1.26)
6 MICHIGAN	20	325	(39)	90	(13)	164	(20)	3.45^{ab}	(1.04)	11.65	(2.36)
COWS	160	404	(7)	87	(2)	169	(3)	2.21	(0.09)	5.80	(0.18)
CALVES	160	430	(7)	74	(2)	172	(3)	2.40	(0.09)	5.87	(0.18)
Significance of F (3)											
Region		NS		NS		NS		*		*	
Farm/region		**		**		**		**		**	
Type of animal		*		**		NS		NS		NS	
Type X region		**		NS		*		**		**	

(1) N, X, SEM: number of observations, means and standard errors of means
(2) Region means within a column without a common superscript are different ($p < .05$)
(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

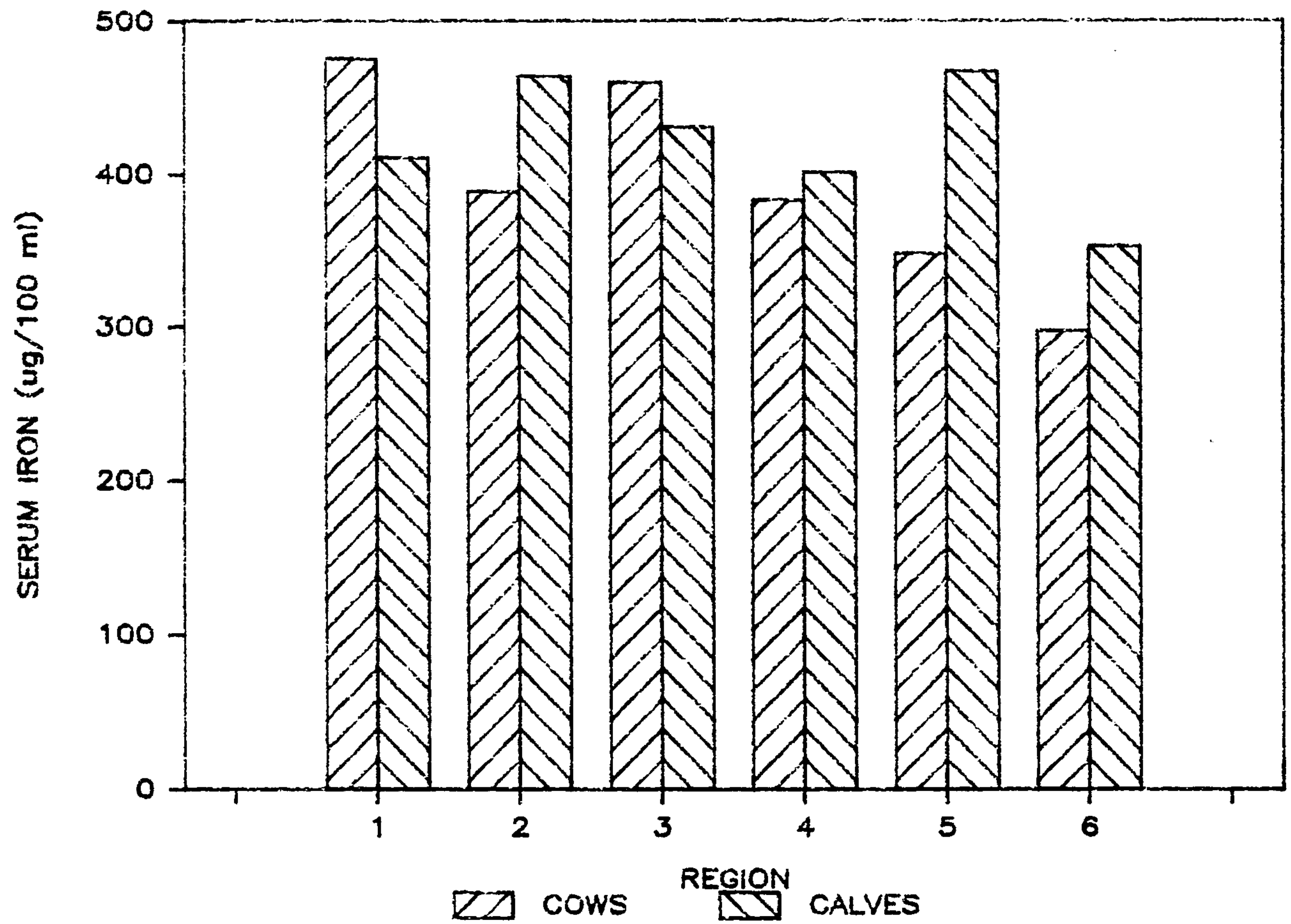

Figure 38. Iron in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

but there was significant variation among farms within region ($p < .01$) and between types of animal ($p < .05$). The interaction of type with region was also significant ($p > .01$). The correlation coefficient between iron in serum and iron in pastures was -0.082.

Copper

Normal copper concentration in the blood of healthy animals ranges from 50 to 150 ug/100 ml (Underwood, 1977). A concentration under 50 ug/100 ml is considered an indication of deficiency. However, animals will show signs of deficiency and lesions when fed copper deficient diets long before copper concentration falls in the blood. This is probably due to homeostatic mechanisms (Miller, 1974), and to the interaction of molybdenum and sulfur with copper (Mills, 1960). In fact, when sheep were fed a diet with supplementary molybdenum and/or sulfur their blood copper concentration increased (Bremner, 1976). In other cases, animals in which the copper level in blood is under 50 ug/100 ml do not show signs of deficiency (Mills et al., 1976). Puls (1981) considers normal serum copper levels to be 80-150 ug/100 ml, deficient levels to be 6-70 ug/100 ml, and a marginal or borderline deficiency to be 55-80 ug/100 ml.

In the present investigation, blood plasma copper values were within the range considered normal except in regions 2 and 4 in Ecuador, where levels averaged 73 and 72 ug/100 ml (Table 12, Figure 39). These levels can be considered marginally deficient. Animals from regions 1, 3 and 5 had 83, 86, and 84 ug/100 ml of serum copper. These values are on the low side of the range

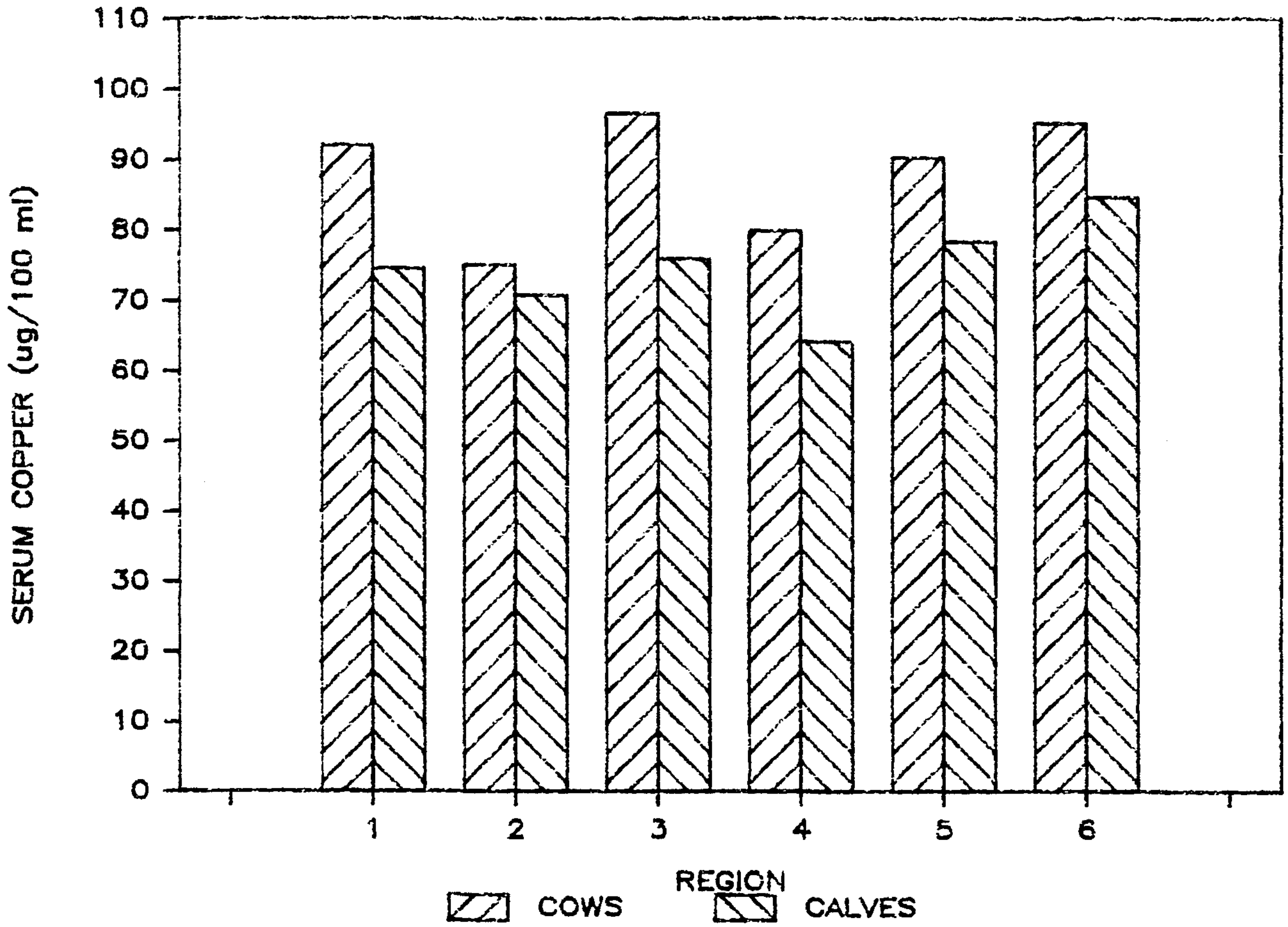

Figure 39. Copper in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

considered normal. Animals from region 6 had the highest copper serum value: 90 ug/100 ml. At the time of sampling these animals were receiving a trace mineral salt containing 0.03% copper. Copper content in soils and in pastures was also at the low or deficient levels in the areas studied. This seems to confirm a general copper deficiency and to indicate the need for copper supplementation in the diet of the animals in the regions studied, and also the need for copper fertilization.

Regional means did not differ significantly ($p > .05$), but the difference among farms within region was different ($p < .01$). Calves had lower plasma copper than cows ($p < .01$). This is consistent with the observation of Bingley and Dufty (1969) that calves had lower copper levels in blood than their mothers. The correlation coefficient between serum copper and pasture copper was 0.260, and the correlation coefficient between serum copper and pasture molybdenum was -0.077.

Zinc

Zinc concentration in blood plasma in Ecuador and in Michigan ranged from 164 to 184 ug/100 ml (Table 12, Figure 40). These values are high in relation to what is considered a normal range: 80-120 ug/100 ml (Church, 1976). Puls (1981) considers normal serum zinc level to be 70-140 ug/100 ml, and the toxic level to range from 520 to 7500 ug/100 ml. Blood zinc is sensitive to zinc changes in diet. Repeated observations of plasma zinc levels under 40 ug/100 ml are an indication of severe deficiency (Mills et al., 1967).

There was no significant difference among regional means

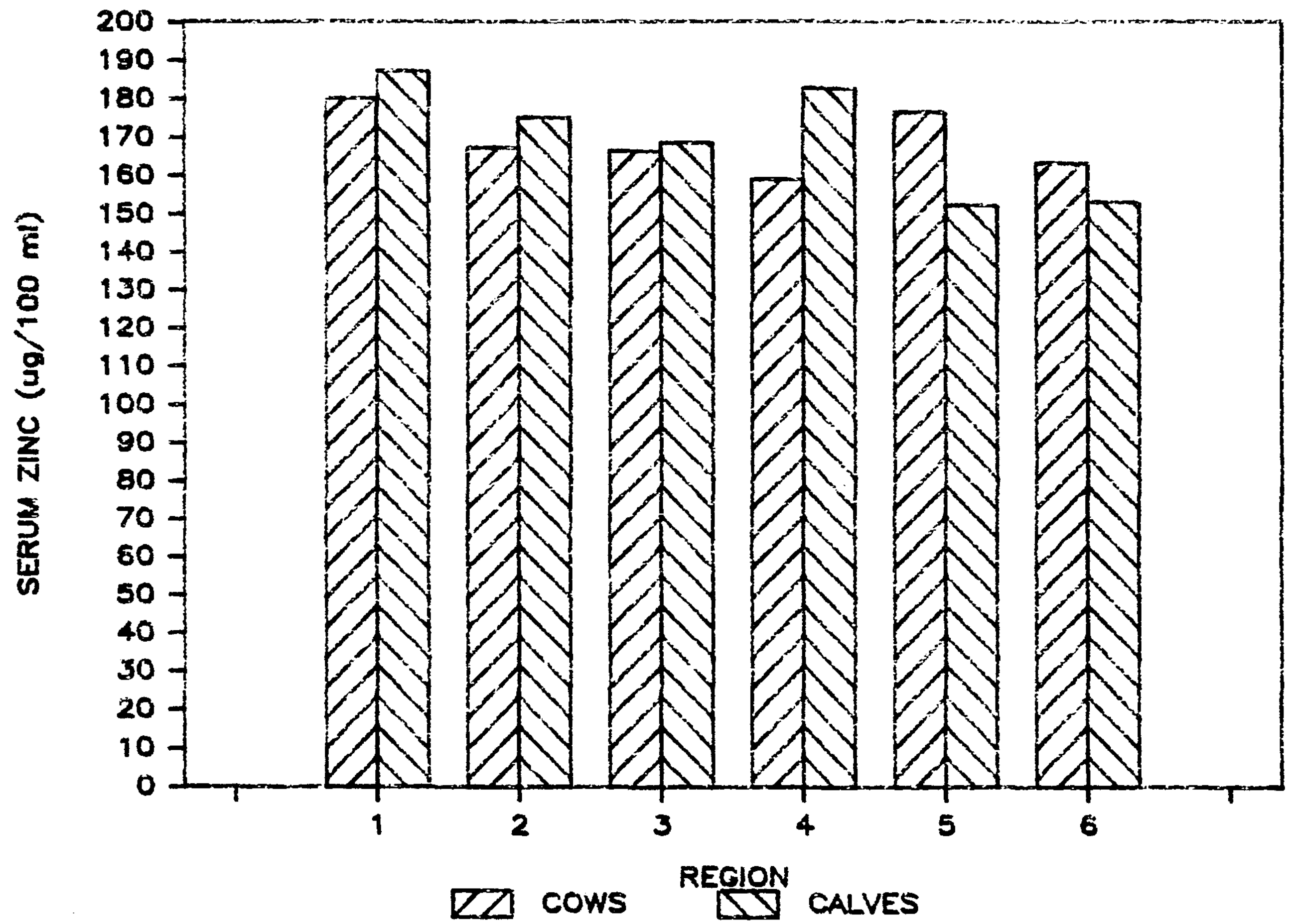

Figure 40. Zinc in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

nor among types of animal (p .05), but the difference among farm means within regions was significant (p .01). The interaction of type of animal with region was also significant (p .05). The correlation coeficient between serum zinc and pasture zinc was 0.107.

Manganese

Typical concentrations of manganese in blood plasma or serum are in the range of 2-3 ug/100 ml (Church, 1976). Puls (1981) considers 0.5 ug/100 ml to be a marginally sufficient or borderline manganese concentration in blood serum or plasma, and 0.6 to 3.0 ug/100 ml to be adequate. Data from several investigations show that the level of manganese found in blood varies considerably according to the analytical technique used. Concentrations found in cattle blood range from 0.5 to 27 ug/100 ml, but most values fall between 1 to 3 ug/100. Blood manganese concentrations decrease, but very slowly, in response to manganese deficiency in the diet (Hidiroglou, 1979).

In the present experiment, serum manganese ranged from 0.77 to 4.48 ug/100 ml (Table 12, Figure 41). There was a significant difference ($p < .05$) among regions. The difference among farms within regions ($p < .01$), and the interaction of regions with type of animal ($p < .01$) were significant ($p < .01$). Serum manganese levels for cows and calves did not differ significantly ($p > .05$). Levels under or close to 1 ug/100 ml in region 2 and 4 indicate a possible deficiency. Pasture manganese, as discussed above, was also low in some of the regions studied. Manganese may be supplied to the animals in the trace mineral salt. The

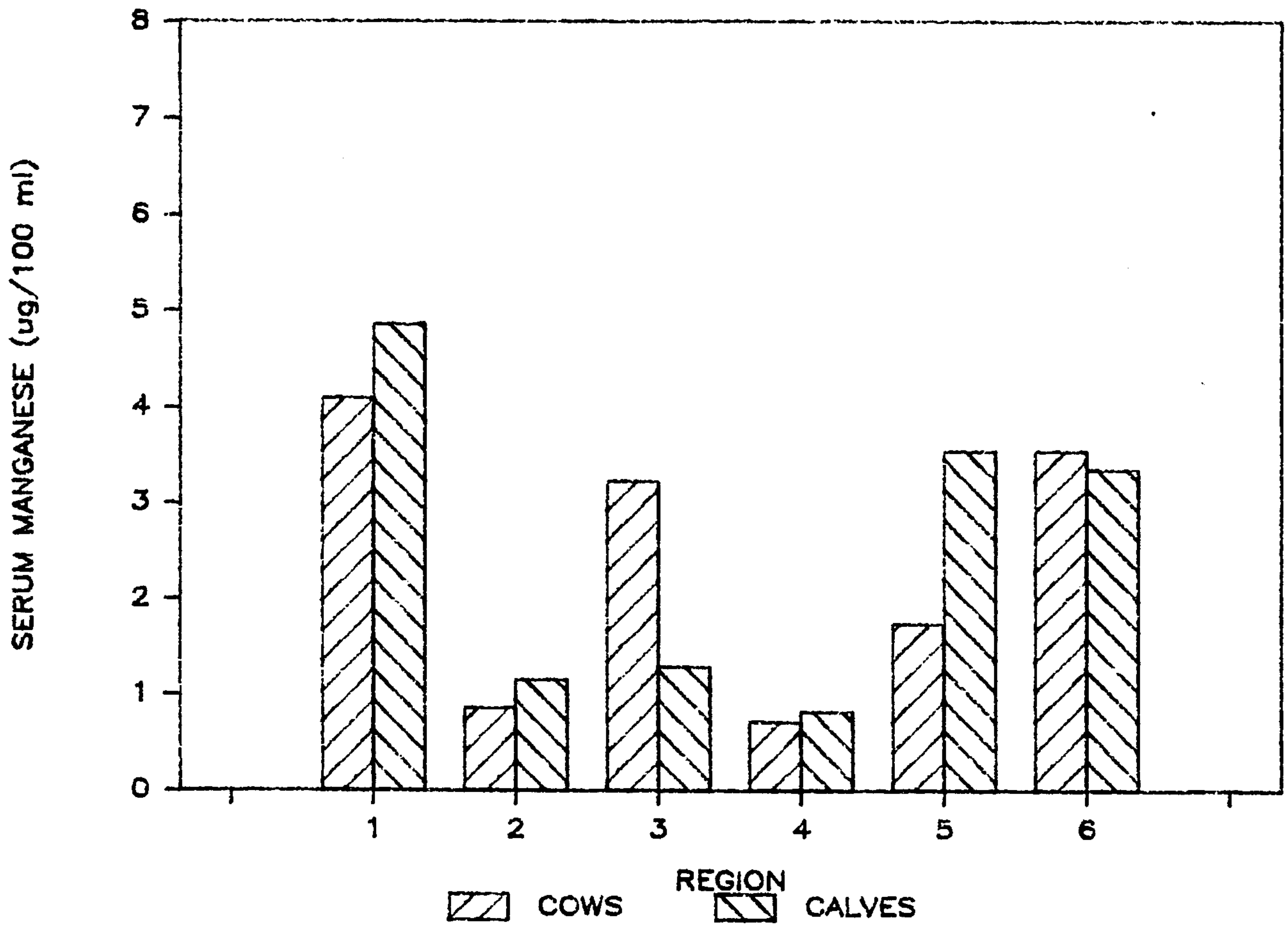

Figure 41. Manganese in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

correlation coefficient between manganese in serum and manganese in pastures was -0.122.

Selenium

Blood's selenium content varies with intake. Serum selenium of beef steers in Michigan was 4.4 ug/100 ml when the diet had 0.085 ppm selenium, and increased to 6.5 and 7.3 ug/100 ml when the animals' feed contained 0.206 and 0.294 ppm of selenium (Ullrey et al., 1977).

Blood plasma selenium levels of 1 to 5 ug/100 ml indicate deficiency. A blood level of about 10 ug/100 ml is desirable. Blood plasma levels of about 20 ug/100 ml indicate that the animal is receiving too much selenium and that a toxic situation may exist (Marczewski et al., 1982).

Plasma selenium in Ecuador ranged from 2.62 to 7.81 ug/100 ml for cattle not fed a selenium supplement. The average for Michigan cattle was 11.65 ug/100 ml when the animals were supplemented with a trace mineral salt containing 20 ppm selenium in the form of sodium selenite (Table 12, Figure 42). Blood plasma selenium content from animals in different regions differed ($p < .05$). Differences among farms within regions and the interaction of region with type of animal were significant ($p < .01$). It is possible that animals from the regions studied in Ecuador are deficient in selenium and need supplementation, even though pastures from those regions had apparently adequate selenium content.

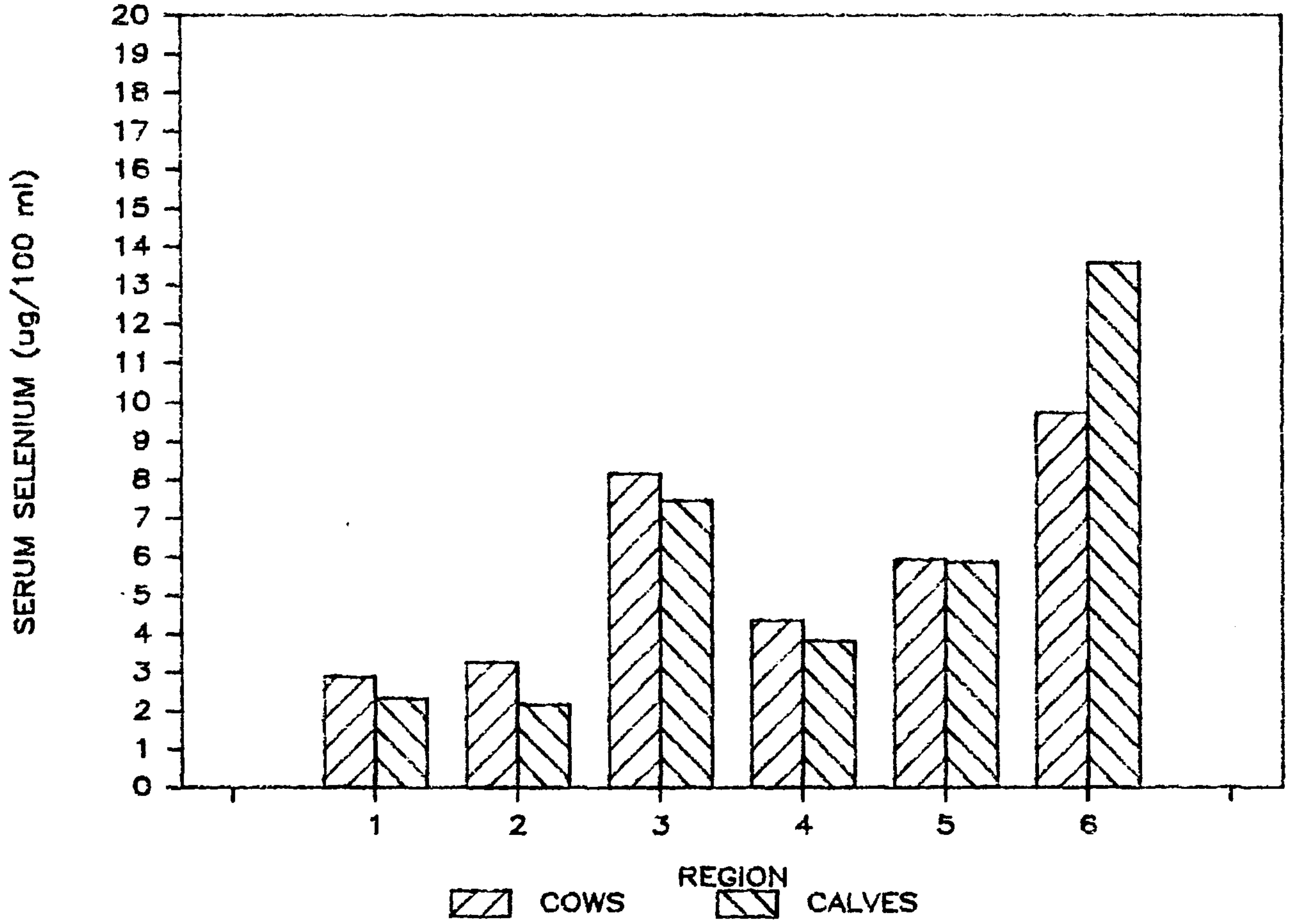

Figure 42. Selenium in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Cobalt

Cobalt levels in blood are very low, and the reports of cobalt concentration vary considerably depending on the method of analysis used. In human blood, values as high as 110 ug/100 ml and as low as 0.003 ug/100 ml have been reported. Using flameless atomic absorption spectrophometry, Barfoot and Pritchard (1980), found 0.12 to 0.20 ug/100 ml in human blood serum. McAdam and O'Dell (1982), using also atomic absorption, found 7.5 ug/100 ml of cobalt in the blood plasma of dairy cows.

Blood serum cobalt values ranged from 0.72 in region 5 in Ecuador to 1.39 ug/100 ml in region 1 in Ecuador. Animals in Michigan had 1.23 ug/100 ml cobalt in the blood serum (Table 13, Figure 43). They were receiving cobalt supplementation in the trace mineral salt (50 ppm). There was no significant difference among regions, and the interaction of region with type of animal was not significant either ($p > .05$). Calves had a significantly higher serum cobalt concentration than cows ($p < .05$).

Table 13. Cobalt concentration in the blood serum of calves and dairy cows from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan (1)

REGION (2)	1 ECUADOR	2 ECUADOR	3 ECUADOR	4 ECUADOR	5 ECUADOR	6 MICHIGAN
N	5	5	6	6	6	2
$\bar{X}$	1.39	0.78	1.05	1.20	0.72	1.23
SEM	(0.26)	(0.26)	(0.24)	(0.24)	(0.24)	(0.42)

ANIMAL	1 COWS	2 CALVES
N	15	15
$\bar{X}$	1.16	0.89
SEM	(0.09)	(0.09)

Significance of F (3)

Region	NS
Type of animal	*
Type X region	NS

(1) N: number of observations; $\bar{X}$: means; SEM: standard errors of means

(2) Region means within a row without a common superscript are different ($p < .05$)

(3) NS: non-significant ($p < .05$); **: $p < .01$; *: $p < .05$

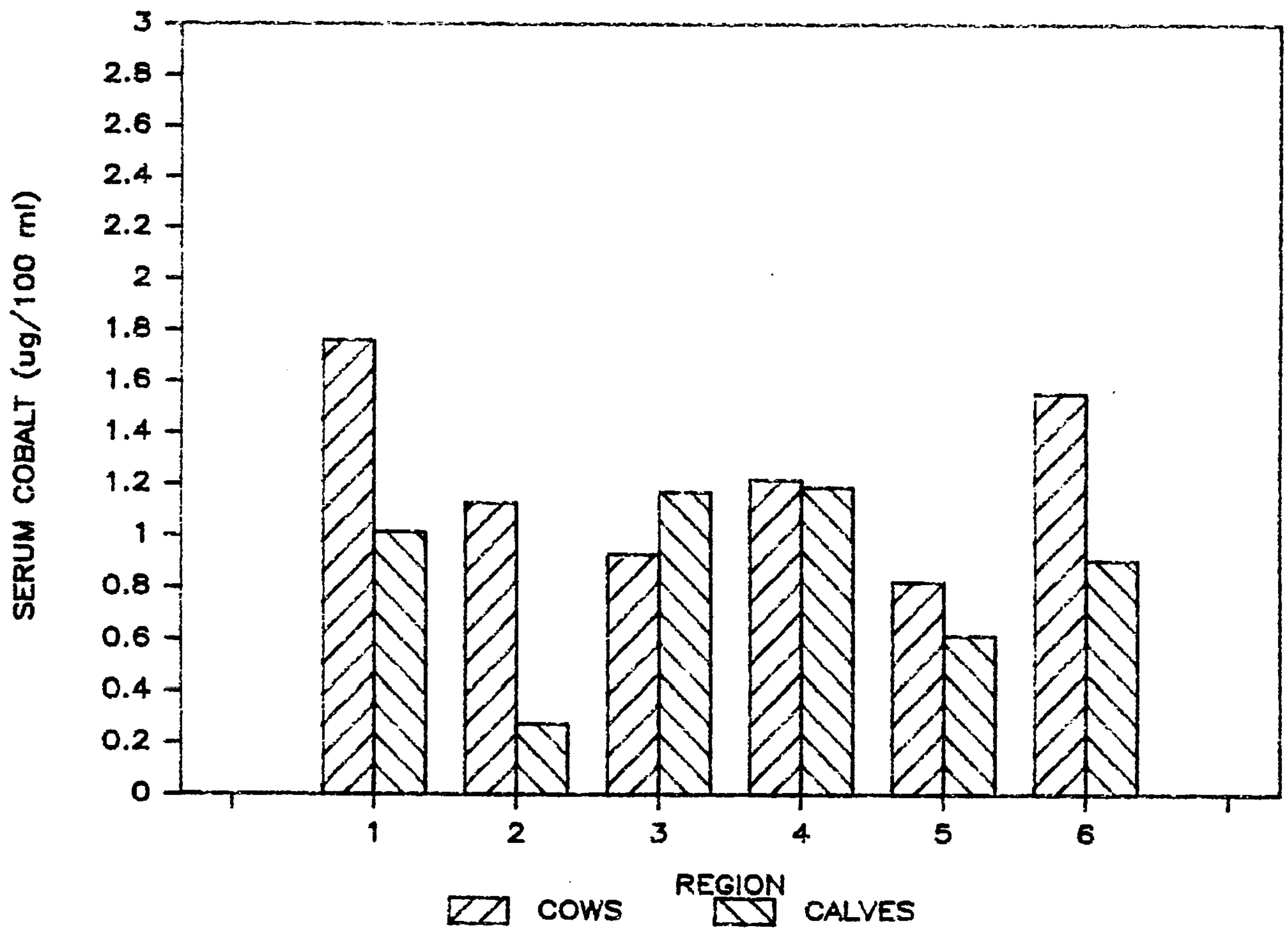

Figure 43. Cobalt in the blood serum of calves and dairy cows from five regions (1-5) in the Chimborazo province of Ecuador and one region (6) in Shiawassee County, Michigan.

Gastrointestinal Parasites

Dairy cattle are commonly infected with a variety of internal parasites. Several investigations have demonstrated that even low parasitism in young animals results in decreased growth and later in decreased milk production (Gibbs, 1982; Adrichem and Shaw, 1977a & b).

The main endoparasites in cattle are nematodes (round worms), trematodes (liver flukes) and coccidia. The nematode *Ostertagia ostertagi* is one of the most pathogenic and economically detrimental parasites in temperate regions such as the State of Michigan and Ecuador. The optimal temperature for the development of *Ostertagia*'s larvae in the pasture ranges from 15 to 25^{o} C. The optimal temperature for survival of the larvae is much lower: between 0 and 15^{o} C. High temperatures allow rapid development but a short survival period; low temperatures slow development but increase the survival time (Schillhorn van Veen, 1981). *Fasciola hepatica* is the most important trematode infesting domestic animals and the most common cause of liver fluke disease (Merk, 1979). Dairy cows infected with *Fasciola hepatica* had higher milk production when treated with hexachloroethane than did non-treated infected animals (Randell and Bradley, 1980). Coccidia infestation in cattle is typically a disease of young animals between the ages of one to two months and one year when they are raised in confined lots.

Results obtained in the present investigation of fecal egg counts are shown in Tables 14 and 15. Animals from region 6 in Michigan did not show signs of infestation, probably due to being

Table 14. Mean worm burden in feces of dairy cattle from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan

Region	Farm	Type of animal	Cooperia No.	Cooperia mean epg	Haemonchus No.	Haemonchus mean epg	Oesophagostomum No.	Oesophagostomum mean epg	Ostertagia No.	Ostertagia mean epg	Trichostrongylus No.	Trichostrongylus mean epg (1)
1 ECUADOR	1	COWS	0	0	4	325	2	100	1	100	3	330
	1	CALVES	0	0	1	200	1	300	1	100	2	200
	2	COWS	0	0	0	0	0	0	0	0	1	100
	2	CALVES	3	130	9	490	6	350	5	220	9	400
	3	COWS	0	0	0	0	0	0	1	100	0	0
	3	CALVES	0	0	0	0	0	0	0	0	0	0
2 ECUADOR	1	COWS	0	0	0	0	0	0	0	0	0	0
	1	CALVES	0	0	0	0	0	0	0	0	1	100
	2	COWS	0	0	1	300	0	0	1	100	1	200
	2	CALVES	1	600	1	100	0	0	0	0	2	100
	3	COWS	0	0	2	150	0	0	1	100	2	100
	3	CALVES	-	-	-	-	-	-	-	-	-	-
3 ECUADOR	1	COWS	1	100	1	100	0	0	0	0	0	0
	1	CALVES	0	0	0	0	0	0	0	0	0	0
	2	COWS	0	0	0	0	0	0	0	0	0	0
	2	CALVES	0	0	0	0	0	0	0	0	0	0
	3	COWS	0	0	1	100	0	0	0	0	0	0
	3	CALVES	1	100	2	200	2	100	0	0	2	100

(1) No. = number of positives out of 10 animals; mean epg = mean eggs per gram among positives

Table 14. (Cont'd.) Mean worm burden in feces of dairy cattle from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan

Region	Farm	Type of animal	Cooperia No.	Cooperia mean epg	Haemonchus No.	Haemonchus mean epg	Oesophagostomum No.	Oesophagostomum mean epg	Ostertagia No.	Ostertagia mean epg	Trichostrongylus No.	Trichostrongylus mean epg (1)
4 ECUADOR	1	COWS	0	0	0	0	0	0	0	0	0	0
	1	CALVES	0	0	4	175	2	100	0	0	4	150
	2	COWS	0	0	0	0	1	100	0	0	0	0
	2	CALVES	0	0	0	0	1	100	1	200	2	150
	3	COWS	0	0	1	100	0	0	0	0	2	100
	3	CALVES	0	0	0	0	0	0	0	0	1	100
5 ECUADOR	1	COWS	2	50	3	100	0	0	0	0	2	100
	1	CALVES	1	50	3	120	0	0	1	50	0	0
	2	COWS	0	0	0	0	0	0	0	0	0	0
	2	CALVES	-	-	-	-	-	-	-	-	-	-
	3	COWS	0	0	2	200	0	0	0	0	0	0
	3	CALVES	0	0	2	200	1	200	0	0	0	0
6 MICHIGAN	1	COWS	0	0	0	0	0	0	0	0	0	0
	1	CALVES	0	0	0	0	0	0	0	0	0	0

(1) No. = number of positives out of 10 animals; mean epg = mean eggs per gram among positives

Table 15. Mean nematodes, coccidia and <u>Fasciola hepatica</u> burden in feces of dairy cattle from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan

Region	Farm	Type of animal	Nematodes No.	Nematodes mean epg	Nematodes range	Coccidia No.	Coccidia mean epg	Coccidia range	Fasciola hepatica number of positives
1 ECUADOR	1	COWS	5	520	100-1400	0	0		0
	1	CALVES	3	470	100-1000	0	0		0
	2	COWS	1	100		2	100	100- 100	0
	2	CALVES	9	1330	700-2000	3	170	100- 300	0
	3	COWS	1	100		1	100		0
	3	CALVES	0	0		5	500	100-1900	0
2 ECUADOR	1	COWS	0	0		5	840	400-1700	0
	1	CALVES	1	100		0	0		0
	2	COWS	4	175	100- 300	7	770	100-1700	0
	2	CALVES	1	600		1	100		0
	3	COWS	2	300	300- 300	0	0		0
	3	CALVES	-	-	- -	-	-	- -	-
3 ECUADOR	1	COWS	0	0		0	0		0
	1	CALVES	2	100	100- 100	3	470	100-1100	0
	2	COWS	0	0		0	0		0
	2	CALVES	0	0		3	430	100-1000	0
	3	COWS	2	100	100- 100	2	150	100- 200	0
	3	CALVES	3	300	100- 500	2	250	200- 300	0

(1) No. = number of positives out of 10 animals; mean epg = mean eggs per gram among positives

Table 15. (Cont'd.) Mean nematodes, coccidia and *Fasciola hepatica* burden in feces of dairy cattle from five regions in the Chimborazo province of Ecuador and one region in Shiawasee county, Michigan

Region	Farm	Type of animal	Nematodes No.	Nematodes mean epg	Nematodes range	Coccidia No.	Coccidia mean epg	Coccidia range	Fasciola hepatica number of positives
4 ECUADOR	1	COWS	0	0		0	0		3
	1	CALVES	9	200	100- 400	0	0		10
	2	COWS	2	150	100- 200	0	0		0
	2	CALVES	3	270	100- 600	1	100		0
	3	COWS	2	150	100- 200	0	0		5
	3	CALVES	1	100		1	100		1
5 ECUADOR	1	COWS	8	90	50- 150				0
	1	CALVES	6	80	50- 150	0	0		0
	2	COWS	0	0		5	200	100- 400	4
	2	CALVES	-	-	- -	-	-	- -	-
	3	COWS	2	200	100- 300	3	130	100- 200	0
	3	CALVES	3	300	200- 500	0	0		0
6 MICHIGAN	1	COWS	0	0		0	0		0
	1	CALVES	0	0		0	0		0

(1) No. = number of positives out of 10 animals; mean epg = mean eggs per gram among positives

treated with thiabendazole two months before sampling. In Ecuador, farms from all the five regions studied had some nematode infestation. All the animals in Ecuador were on pasture all year around, except the calves in farm three of region one. Farms one and two from region one had the highest number of animals whose fecal samples had nematode eggs present and the highest mean egg per gram count.

In severe clinical cases, fecal counts of Ostertagia eggs usually exceed 1000 (Armour, 1970). Fecal egg counts alone, however, do not provide the best method of parasite infection diagnosis. Factors such as clinical signs, season of the year, grazing history, plasma pepsinogen, serum albumen and packed cell volume percentage, and results of post-mortem examination must often be considered to accurately assess the severity of nematode infection (Armour, 1970). In the herds studied, the presence of nematode eggs in several animals, and the fact that the animals were grazing all year around, indicates the need of preventive measures and periodic treatment.

Coccidia oocysts were present in several of the fecal samples of the animals studied in Ecuador (Table 15), but not in numbers high enough to indicate an acute infestation.

Fasciola hepatica eggs (according to qualitative analysis) were found in the feces of animals on farms one and three of region four, and on farm two in region five in Ecuador (Table 15). At these farms, the animals were grazing on wet pastures near creeks or swamps, and aquatic plants were present. In these cases, preventive management practices and antifluke treatment are necessary.

Nematode infestation, especially in young animals where it is more severe, can be prevented by the provision of clean pastures, either in the form of newly planted lots or pasture not grazed by cattle in the previous year (Armour, 1974). This is seldom possible, however, and under practical conditions the use of anthelmintics is necessary. For effective pasture rotation and treatment of the animals, a knowledge of the rain patterns is necessary because the infestation of nematodes in the animals is closely related to weather (Schillhorn van Veen, 1976).

In the areas studied in Ecuador, the rainy season (around 400 mm of rain/year) lasts from around October to April. In the case of Ostertagia, transmission occurs during the rainy season when the larvae grow better on the pasture, and the animals then show symptoms of the infestation at the beginning of the dry season. Transmission is low during the dry season. Animals should be treated at the beginning of the dry season, when the pastures are already dry, and then moved to clean pastures. If clean pastures are not available, a new treatment with anthelmintic four or six weeks after the first treatment is advisable (Armour, 1970; Schillhorn van Veen, 1976). In Michigan, if the grazing animals cannot be moved to clean pastures after a first treatment during a dry period in the summer, the treatment should be repeated at the end of the grazing season, around November (Schillhorn van Veen, 1976).

In the United States there are six anthelmintics approved for use in cattle: thiabendazole, levamisole, coumaphos, haloxon, phenothiazine and morantel. Thiabendazole and levamisole have high degrees of efficacy against adult gastrointestinal nematodes and some larvae, and they are the most widely used. Morantel is comparable in efficacy. Levamisole is also effective against lungworms. The remaining three compounds are generally less efficacious, but have specific uses. New anthelmintics recently approved or in the process of being approved by the FDA are ivermectin and the benzimidazole derivatives albendazole, fenbendazole, and oxfendazole (American Assoc. Vet. Pathologists, 1983).

The intermediary host of Fasciola hepatica is the lymnaeid snail (Lymnaea sp.) which lives in aquatic environments. Control measures for F. hepatica are designed to reduce the number of flukes in the host animal and to reduce the snail population in the environment (Merck, 1979). Whenever possible, cattle should not graze in pastures containing swamps or ponds or near creeks, where the snails grow. Hay from such pastures can be fed to the animals, since desiccation kills the metacercaria of the parasite. Molluscacides, such as copper sulfate, can be used to control the snail population.

Hexachloroethane was one of the most common treatments used for Fasciola in the United States until 1979 when the Food and Drug Administration removed it from the market as a potential carcinogen. Since then, there is no flukicidal drug available in the United States that is fully approved for use in livestock by the Food and Drug Administration. Albendazole, a broad-spectrum anthelmintic still being tested, has been approved for emergency use against F. hepatica and F. magna in cattle and sheep in some states (American Assoc. Vet. Pathologists, 1983). In other countries, however, there are several flukicides available for cattle such as rafoxanide, brotianide and nitroxynil. These compounds can also kill immature flukes (Merck, 1979).

Coccidiosis can be prevented by maintaining sanitary conditions when the animals, especially the young, are kept in confinement. Sulfa drugs and amprolium can be used to prevent further infection (American Assoc. Vet. Pathologists, 1983).

SUMMARY

The interrelationship of the mineral status of soils, plants, and animals was investigated in five regions of the Chimborazo province of Ecuador and in one region in Shiawasee county, Michigan. There were several mineral deficiency problems affecting plant and animal production. No toxic excesses of the minerals studied were detected.

Fertilization

Liming of the soils is needed in most regions for optimal legume production. Regions 1 and 4, where the pH was close to neutral, do not require liming.

Nitrogen fertilization is needed for corn and grass production. Alfalfa and mixed grass-legume pastures do not need nitrogen fertilization.

Most of the soils of the regions studied had low to medium phosphorus content. Phosphorus fertilization is needed in these areas for forage production. In general soils from region 6 had a high phosphorus content. However, phosphorus fertilization is needed in some fields of region 6 for maintenance of permanent crops such as alfalfa and grass-legume pastures.

Potassium content in soils was high in all regions. Potassium fertilization is needed, nevertheless, for maintenance of permanent crops such as alfalfa and grass-legume pastures.

Treatment of seeds with molybdenum will probably increase grass-legume pasture yields in region 1, where soil molybdenum was low. In region 6 soil molybdenum was relatively high, but

molybdenum concentration in the forages was low. In this region, liming the soil will probably increase the availability of molybdenum for legumes.

Zinc fertilization is needed in region 1 and in region 6 for corn cultivation. Zinc content in the soil and in forages was low in these regions.

Copper in the soils from regions 2, 3, 5 and 6 was low. Pasture copper was low in all regions except region 1. Forages, particularly legumes, grown in these regions will probably benefit from copper fertilization. Also, copper fertilization will increase copper concentration in forages, probably enough to meet animal requirements.

Sulfur fertilization is needed in region 1 and 6 for improved forage production. Soil sulfur in these regions was low.

Magnesium fertilization may be needed for corn and other responsive crops in region 6.

Calcium, sodium, cobalt, iron, manganese and selenium were found to be present in adequate amounts in the soils tested, so fertilization with these minerals is probably not needed.

Mineral Supplementation for Animals

Nitrogen supplementation is needed in region 3 for improved animal productivity. High-producing cows in all the regions will also need extra nitrogen to meet their requirements.

Calcium in pastures was found to exist in adequate amounts in all the regions studied. High producing cows, however, may need calcium supplementation. Calcium supplementation may also be needed where the animals are eating high-grain rations.

Phosphorus supplementation for cattle is needed in all regions, especially for high producing cows.

Magnesium content in forages from all the regions studied was found to be adequate to meet animal requirements. Lactating cows fed high-grain rations may need extra magnesium to prevent low milk-fat syndrome.

Potassium concentration in forages from all regions was found to be adequate to meet animal requirements. Animals on high-grain rations, however, may need extra potassium.

Sodium supplementation is needed for all cattle in all the regions studied.

Iron supplementation is needed for cattle in region 6. Iron can be provided to the animals in the trace mineral salt.

Zinc concentration in forages from regions 1 and 6 was low. Animals in these regions need zinc supplementation in the trace mineral salt in order to meet their requirements.

Manganese supplementation is needed in regions 1, 2 and 5. Forages from these regions had a manganese content too low to meet the manganese requirement of dairy cattle. Manganese salts can be provided to these animals in trace mineral salt.

Selenium content in the blood serum of animals from all the regions studied, except region 6, was below 10 ug/100 ml, which is considered a desirable level. Animals from these regions will probably benefit from selenium supplementation in the trace mineral salt.

Cobalt and molybdenum were found in the forages in amounts adequate to meet animal requirements. Inclusion of cobalt salts in the trace mineral salt will not produce toxic effects in the animals.

Copper concentration in blood serum was low or marginal in all the regions studied. Copper concentration in pastures was also below the requirement of 10 ppm in the ration. Copper supplementation is needed for the animals in all the regions studied. Copper sulfate may be added to the trace mineral salt at a rate of 0.5 to 1.0% of the mixture. The use of copper fertilizer will raise the copper content of forages and probably improve their yield.

Parasite Control

Nematode eggs were found in the fecal samples of animals from all the regions studied, except region 6. Relatively high numbers of coccidia oocysts were found in the feces of animals from regions 1, 2 and 3. *Fasciola hepatica* eggs were found in the feces from animals in regions 4 and 5. Chemotherapy and preventive measures of parasite control are needed in the regions mentioned.

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APPENDIX I

Table I.1. Nitrogen, phosphorus, potassium, calcium, maganesium, and sulfur in soils; method of extraction and sufficiency concentration range for alfalfa and corn

ELEMENT	EXTRACTING SOLUTION (1)	SUFFICIENCY RANGE (2)	
		CORN (3)	ALFALFA (4)
		%	
NITROGEN	Ca(OH)2 saturated	2.76-3.50	3.76-5.50
PHOSPHORUS	0.025N HCl in 0.03N NH_4F	0.25-0.50	0.26-0.70
POTASSIUM	1N NH_4OAc pH 7	1.71-2.50	2.01-3.50
CALCIUM	1N NH_4OAc pH 7	0.21-1.00	1.76-3.00
MAGNESIUM	1N NH_4OAc pH 7	0.16-0.60	0.31-1.00
SULFUR	$Ca(H_2PO_4)2$, P 500 ppm	0.16-0.50	0.31-0.50

(1) Recommended Chemical Soil Test Procedures for the North Central Region (N. Dakota Exp. Station)
(2) Vitosh et al. (1981)
(3) Ear leaf sample of initial silk
(4) Top six inches sampled prior to initial flowering

Table I.2. Iron, manganese, molybdenum, zinc, copper, and cobalt in soils; method of extraction, range in critical level and sufficiency concentration range for alfalfa and corn

ELEMENT	EXTRACTING SOLUTION	RANGE IN CRITICAL LEVEL (1)	SUFFICIENCY RANGE (2) CORN (3)	ALFALFA (4)
		ppm		
IRON	0.1N HCl		21-250	31-250
MANGANESE	0.1N HCl		20-150	31-100
MOLYBDENUM	$(NH_4)2C_2O_4$, pH 3.3	0.04-0.2	0.1-2.0	1.0-5.0
ZINC	0.1N HCl	1.0-7.5	20-70	21-70
COPPER	1.0N HCl	9-20	6-20	11-30
COBALT (5)	TOTAL	5.0		0.07

(1) Cox and Kamprath (1972)
(2) Vitosh et al. (1981)
(3) Ear leaf sample of initial silk
(4) Top six inches sampled prior to initial flowering
(5) Kubota and Allaway (1972)

Table I.3. Typical mineral concentrations in blood plasma or serum of ruminants (1)

CALCIUM	PHOSPHORUS	SODIUM	POTASSIUM	MAGNESIUM
		mg/100 ml		
9.0-12.0	4-9	300	14-18	1.8-3.0
IRON	COPPER	ZINC	MANGANESE	SELENIUM
		ug/100 ml		
5-10	100	80-120	2-3	10-20
COBALT (2)	0.35-6.30 ug/100 ml			

(1) Church (1971)
(2) Koch et al. (1951)

Table I.4. Kilograms of limestone per hectare required, as estimated from soil pH and texture, to raise the pH of a 23 cm plow layer to pH 6.5; add 1680 kg to raise soil pH to 6.8 (1)

Texture of Plow Layer	Soil pH Range 4.5-4.9	5.0-5.4	5.5-5.9	6.0-6.4
	Kg of limestone per hectare			
Clay and silty clay	17930	15130	12330	7850
Clay loams or loams	15130	12330	8970	6160
Sandy loams	12330	8970	7850	4480
Loamy sands	8970	7850	6160	3360
Sands	7850	6160	4480	1680

(1) Trasformed to metric units from Christenson et al., 1983

Table I.5. Nitrogen fertilizer guides for corn (1)

	Yield Goal/hectare					
Shelled corn kg/ha	1700-2550	2550-3390	3400-4240	4250-5090	5100-5950	5960-6830
Corn silage 1000 kg/ha (2)	22.4-31.4	33.5-42.6	42.7-53.8	53.9-67.3		
Previous crop or manure application						
Legume and 22000 kg manure/ha	0	0	56	112	168	224
Good legume	11	45	101	157	213	269
Manure 22000 kg/hectare	34	67	123	179	235	291
No legumes, no manure	78	112	168	224	280	336

(1) Transformed to metric units from Warncke and Christenson, 1980
(2) For sudan grass, sudax, and similar crops, use nitrogen rates comparable to silage productivity

Table I.6. Annual phosphorus (P205) and potassium (K20) recommendations for corn grown on mineral soils (1)

	Yield Goal/hectare				
Shelled corn kg/ha	2550-3390	3400-4240	4250-5090	5100-5950	5960-6830
Corn silage 1000 kg/ha (2)	22.4-31.4	33.5-42.6	42.7-53.8	53.9-67.3	
Test Level ppm	Phosphorus recommendations, kg P205/hectare				
0- 9	84	112	140	168	196
10- 19	56	84	112	140	168
20- 29	28	56	84	112	140
30- 39	28	28	56	84	112
40- 49	28	28	28	56	84
50- 59	28	28	28	28	56
60- 69	0	0	0	28	28
70	0	0	0	0	0
	Potassium recommendations, kg K20/ha, on sandy loams and loamy sands				
0- 49	168	224	280	336	336
50- 74	112	168	224	280	308
75- 99	84	112	168	224	252
100-124	56	56	112	168	196
125-149	0	28	56	112	140
150-174	0	0	0	56	84
175	0	0	0	0	0
	Potassium recommendations, kg K20/ha, on loams, clay loams and clays				
0- 49	168	224	336	448	448
50- 74	112	168	224	336	392
75- 99	56	112	168	224	280
100-124	0	56	112	168	224
125-137	0	0	56	112	168
138-149	0	0	0	56	112
150-162	0	0	0	0	56
163	0	0	0	0	0

(1) Transformed to metric units from Warncke and Christenson, 1980

Table I.7. Annual phosphorus (P_2O_5) and potassium (K_2O) recommendations for alfalfa grown in mineral soil (1)

Yield, 1000 kg/ha	6.7-8.9	9.0-13.5	13.6-17.9
Test level ppm	Phosphorus recommendations, kg P_2O_5/hectare		
0- 9	84	112	140
10-19	56	84	112
20-29	28	56	84
30-39	0	28	56
40-49	0	0	28
50	0	0	0
	Potassium recommendations, kg K_2O/hectare on sandy loams and loamy soils		
0- 24	336	392	448
25- 49	280	336	392
50- 74	224	280	336
75- 99	168	224	280
100-124	112	168	224
125-149	56	112	168
150-174	0	56	112
175-200	0	0	56
200	0	0	0
	Potassium recommendations, kg K_2O/hectare on loams, clay loams and clay		
0- 24	336	448	560
25- 49	224	336	448
50- 74	168	224	336
75- 99	112	168	224
100-124	56	112	168
125-149	0	56	112
150-174	0	0	56
175	0	0	0

(1) Transformed to metric units from Warncke and Christenson, 1980

Table I.8. Manganese recommendations for band application for responsive crops grown on mineral and organic soils (1)

Manganese (0.1 N HCl Extraction)								
	MINERAL SOILS				ORGANIC SOILS			
Soil test	Above pH 6.5		pH 6.0-6.5		Above pH 6.4		pH 5.8-6.4	
ppm Mn	Response	Mn-kg/ha	Response	Mn-kg/ha	Response	Mn-kg/ha	Response	Mn-kg/ha
Below 5	Probable	9	Probable	7	Certain	18	Certain	13
5-10	Probable	7	Possible	4	Certain	13	Probable	9
11-20	Possible	4	None	0	Probable	9	Possible	4
21-40	None	0	None	0	Possible	4	None	0
Above 40	None	0	None	0	None	0	None	0

(1) Transformed to metric units from Vitosh et al., 1981

Table I.9. Zinc recommendations for band application on mineral and organic soils (1)

Soil test ppm zinc	Zinc for Mineral and Organic Soils (0.1 HCl Extraction)					
	Above pH 7.5		pH 6.7 to 7.4		Below pH 6.7	
	Response	Zn-kg/ha	Response	Zn-kg/ha	Response	Zn-kg/ha
Below 2	Certain	5.6	Probable	3.4	Possible	2.2
3-5	Probable	3.4	Possible	3.4	None	0
5-10	Probable	3.4	Possible	2.2	None	0
11-15	Possible	2.2	None	0	None	0
Above 15	None	0	None	0	None	0

(1) Recommended rates are for inorganic salts such as zinc sulfate; use one-fourth this rate for chelated materials. Transformed to metric units from Vitosh et al., 1981

Table I.10. Composition and ingredients of a trace mineral salt (1)

Guaranteed analysis		Ingredients
	%	
Zinc, min.	0.350	zinc oxide
Manganese, min.	0.200	manganous oxide
Iron, min.	0.200	ferrous carbonate, ferrous sulfate
Copper, min.	0.030	copper oxide
Cobalt, min.	0.005	cobalt carbonate
Iodine, min.	0.007	calcium iodate
Selenium, min.	0.002	sodium selenite
Salt, min.	96.000	sodium chloride
Salt, max.	98.500	
		red iron oxide (for color only)
		mineral oil
		anethol

(1) Hardy Salt Co., St. Louis, MO 63166.

APPENDIX II

CALCIUM

		SERUM mg/100 ml			PASTURES % DM			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	7.83	8.78		0.61	0.58		3226
	2	11.07	8.88		0.61	0.58		3201
	3	10.21	10.04		1.16	1.05		3484
AVG		9.70	9.23	9.47	0.79	0.73	0.76	3303
2	1	9.69	9.12		0.32	0.30		3067
	2	8.39	8.84		0.34	0.36		2792
	3	8.20	8.33		0.48	0.57		3276
AVG		8.76	8.76	8.76	0.38	0.41	0.39	3045
3	1	8.99	10.07		0.62	0.55		2640
	2	9.23	7.41		0.36	0.28		1824
	3	7.33	8.37		0.35	0.31		1351
AVG		8.52	8.62	8.57	0.44	0.38	0.41	1938
4	1	8.13	9.70		0.52	0.42		3593
	2	7.76	9.43		0.57	0.33		2225
	3	8.71	8.13		0.62	0.50		2505
AVG		8.20	9.09	8.64	0.57	0.42	0.49	2774
5	1	9.86	10.06		0.36	0.51		4035
	2	9.26	9.73		0.57	0.36		2773
	3	9.87	10.98		0.79	0.94		2881
AVG		9.66	10.26	9.96	0.57	0.61	0.59	3230
6	1	7.57	8.71		0.70	0.61		1704
	2							
	3							
AVG		7.57	8.71	8.14	0.70	0.61	0.65	1704
GEN. AVG.		8.88	9.16	9.02	0.56	0.52	0.54	2688

PHOSPHORUS

		SERUM mg/100 ml			PASTURES % DM			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	5.73	7.08		0.30	0.36		12.4
	2	9.67	10.11		0.24	0.24		10.1
	3	3.74	8.97		0.32	0.32		54.7
AVG		6.38	8.72	7.55	0.28	0.31	0.30	25.7
2	1	5.73	7.44		0.22	0.22		12.0
	2	6.88	5.84		0.18	0.20		12.2
	3	7.37	8.13		0.29	0.31		6.5
AVG		6.66	7.14	6.90	0.23	0.24	0.24	10.2
3	1	5.93	8.12		0.29	0.28		72.5
	2	6.96	5.77		0.17	0.15		16.3
	3	4.18	6.55		0.17	0.18		26.6
AVG		5.69	6.81	6.25	0.21	0.20	0.21	38.5
4	1	4.77	6.05		0.28	0.34		15.7
	2	6.21	8.02		0.23	0.24		12.0
	3	6.50	7.25		0.26	0.27		17.9
AVG		5.83	7.10	6.47	0.25	0.28	0.27	15.2
5	1	4.53	5.30		0.15	0.18		5.1
	2	6.81	7.94		0.22	0.23		4.6
	3	6.17	8.66		0.25	0.25		31.2
AVG		5.84	7.30	6.57	0.21	0.22	0.21	13.6
6	1	4.62	6.43		0.25	0.24		61.6
	2							
	3							
AVG		4.62	6.43	5.52		0.25	0.24	61.6
GEN. AVG.		5.99	7.35	6.67		0.24	0.25	26.7

SODIUM

		SERUM mg/100 ml			PASTURES % DM			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	486	504		0.020	0.021		157
	2	542	511		0.015	0.016		126
	3	407	411		0.019	0.018		117
AVG		478	474	477	0.018	0.018	0.018	133
2	1	456	473		0.018	0.021		168
	2	473	442		0.017	0.019		190
	3	406	409		0.014	0.017		219
AVG		445	441	443	0.016	0.019	0.018	193
3	1	438	516		0.023	0.021		167
	2	542	568		0.022	0.023		110
	3	550	545		0.016	0.017		126
AVG		510	543	526	0.020	0.020	0.020	134
4	1	473	466		0.030	0.036		252
	2	464	345		0.029	0.033		211
	3	453	394		0.036	0.034		293
AVG		463	402	432	0.032	0.034	0.033	252
5	1	457	488		0.017	0.014		113
	2	504	494		0.018	0.014		144
	3	534	435		0.029	0.032		135
AVG		498	472	485	0.021	0.020	0.021	131
6	1	395	365		0.018	0.019		166
	2							
	3							
AVG		395	365	380	0.018	0.019	0.018	166
GEN. AVG.		474	460	467	0.021	0.022	0.022	168

POTASSIUM

		SERUM mg/100 ml			PASTURES % DM			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	22	24		3.00	3.26		426
	2	28	30		2.30	2.37		381
	3	22	23		3.47	4.07		735
AVG		24	26	25	2.92	3.23	3.07	514
2	1	24	23		2.31	2.17		240
	2	20	29		1.76	2.12		245
	3	20	19		1.88	3.18		200
AVG		22	24	23	1.98	2.49	2.23	229
3	1	34	22		2.03	1.77		364
	2	24	24		2.24	2.23		301
	3	26	25		1.83	2.02		486
AVG		28	24	26	2.03	2.01	2.02	384
4	1	25	24		2.38	3.30		372
	2	24	29		2.03	2.21		327
	3	30	26		2.83	3.25		450
AVG		27	26	26	2.41	2.92	2.66	383
5	1	23	24		2.31	2.87		381
	2	22	25		2.44	3.18		352
	3	22	23		2.45	2.76		859
AVG		22	24	23	2.40	2.94	2.67	531
6	1	19	20		1.76	1.66		175
	2							
	3							
AVG		19	20	20	1.76	1.66	1.71	175
GEN. AVG.		24	24	24	2.31	2.64	2.47	373

MAGNESIUM

		SERUM mg/100 ml			PASTURES % DM			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	2.94	3.31		0.27	0.33		815
	2	2.98	2.21		0.22	0.22		838
	3	3.85	2.95		0.25	0.24		758
AVG		3.26	2.83	3.04	0.25	0.26	0.26	804
2	1	3.06	3.05		0.21	0.23		793
	2	2.51	3.04		0.20	0.21		778
	3	3.13	3.24		0.30	0.31		873
AVG		2.90	3.11	3.00	0.24	0.25	0.24	814
3	1	3.48	3.41		0.23	0.22		654
	2	3.29	2.49		0.20	0.18		580
	3	2.63	2.44		0.16	0.17		471
AVG		3.13	2.78	2.96	0.20	0.19	0.19	568
4	1	2.82	3.02		0.25	0.31		569
	2	2.26	2.49		0.22	0.25		650
	3	2.21	1.86		0.31	0.38		687
AVG		2.43	2.46	2.44	0.26	0.31	0.29	635
5	1	3.01	3.80		0.15	0.16		612
	2	3.12	3.72		0.20	0.22		695
	3	3.68	3.47		0.24	0.29		768
AVG		3.27	3.67	3.47	0.20	0.22	0.21	691
6	1	2.01	2.24		0.21	0.18		308
	2							
	3							
AVG		2.01	2.24	2.13	0.21	0.18	0.19	308
GEN. AVG.		2.93	2.92	2.93	0.23	0.24	0.23	644

IRON

		SERUM ug/100 ml			PASTURES ppm			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	462	388		167	358		141
	2	522	489		134	318		239
	3	444	356		185	165		166
AVG		476	411	443	162	280	221	182
2	1	418	558		77	98		194
	2	388	411		78	138		268
	3	361	423		157	277		343
AVG		389	464	426	104	171	137	269
3	1	507	383		202	195		239
	2	451	440		64	50		176
	3	423	469		74	51		259
AVG		460	431	446	113	98	106	225
4	1	433	368		364	702		188
	2	313	392		311	295		99
	3	404	444		201	268		131
AVG		383	401	392	292	422	357	139
5	1	385	438		61	90		127
	2	336	516		124	131		120
	3	323	448		95	145		80
AVG		348	467	408	94	122	108	109
6	1	297	353		44	45		89
	2							
	3							
AVG		297	353	325	44	45	45	89
GEN. AVG.		404	430	417	145	206	175	170

COPPER

		SERUM ug/100 ml			PASTURES ppm			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	68	66		10.9	11.1		28.6
	2	99	72		5.7	6.6		35.2
	3	110	86		11.9	9.9		29.7
AVG		92	75	83	9.5	9.2	9.3	31.2
2	1	80	53		4.0	3.2		13.6
	2	66	91		5.2	4.0		11.8
	3	80	68		4.2	6.8		16.0
AVG		75	71	73	4.5	4.6	4.6	13.8
3	1	96	85		6.1	5.1		12.3
	2	83	70		5.0	3.7		14.3
	3	112	73		4.0	4.2		12.4
AVG		97	76	86	5.0	4.3	4.7	13.0
4	1	73	66		8.2	9.4		21.3
	2	67	48		5.9	5.8		26.5
	3	100	79		8.7	9.1		21.5
AVG		80	64	72	7.6	8.1	7.8	23.1
5	1	73	68		4.8	6.5		17.2
	2	102	73		8.0	7.6		20.4
	3	97	94		6.4	7.4		13.6
AVG		90	78	84	6.4	7.2	6.8	17.0
6	1	95	85		5.8	5.2		2.7
	2							
	3							
AVG		95	85	90	5.8	5.2	5.5	2.7
GEN. AVG.		87	74	80	6.5	6.6	6.6	17.1

ZINC

		SERUM ug/100 ml			PASTURES ppm			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	135	201		55	45		4.6
	2	187	168		34	24		4.6
	3	219	193		42	49		10.2
AVG		180	187	184	44	39	41	6.5
2	1	205	180		29	32		15.9
	2	161	186		56	34		9.9
	3	137	159		48	44		10.1
AVG		167	175	171	44	37	40	12.0
3	1	196	177		26	26		7.5
	2	152	147		38	38		8.5
	3	151	183		29	29		10.9
AVG		166	169	167	31	31	31	9.0
4	1	152	175		49	50		5.6
	2	133	158		26	19		4.9
	3	192	215		37	44		4.8
AVG		159	183	171	38	38	38	5.1
5	1	178	142		38	28		10.6
	2	174	158		65	36		14.4
	3	178	158		49	26		3.5
AVG		176	152	164	51	30	41	9.5
6	1	163	153		6	28		3.7
	2							
	3							
AVG		163	153	158	6	28	17	3.7
GEN. AVG.		169	172	171	39	34	37	7.7

MANGANESE

REGION	FARM	SERUM ug/100 ml COWS	YOUNG	AVG	PASTURES ppm WASHED	N-WASHED	AVG	SOILS ppm
1	1	7.23	5.69		30	43		91
	2	1.65	5.13		39	43		107
	3	3.41	3.76		28	29		144
AVG		4.10	4.86	4.48	32	38	35	114
2	1	0.96	0.98		24	34		53
	2	0.95	1.52		27	30		77
	3	0.67	0.95		54	50		64
AVG		0.86	1.15	1.01	35	38	36	65
3	1	4.28	2.03		48	35		65
	2	4.52	0.92		58	54		31
	3	0.88	0.90		36	58		102
AVG		3.23	1.28	2.26	47	49	48	66
4	1	0.58	0.85		60	54		99
	2	0.93	0.95		27	25		63
	3	0.63	0.66		42	45		71
AVG		0.71	0.82	0.77	43	41	42	78
5	1	1.90	1.31		19	19		59
	2	1.37	4.33		39	56		61
	3	1.93	4.99		18	14		43
AVG		1.73	3.54	2.64	25	30	27	54
6	1	3.54	3.35		46	45		60
	2							
	3							
AVG		3.54	3.35	3.45	46	45	46	60
GEN. AVG.		2.21	2.40	2.30	37	40	38	73

SELENIUM

		SERUM ug/100 ml			PASTURES ppm			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	1.07	1.19		0.42	0.50		0.20
	2	3.20	3.00		0.59	0.47		0.54
	3	4.40	2.83		0.35	0.47		1.18
AVG		2.89	2.34	2.62	0.45	0.48	0.46	0.64
2	1	3.75	1.31		0.66	0.59		0.45
	2	1.31	2.49		0.35	0.39		0.46
	3	4.76	2.72		0.51	0.82		0.06
AVG		3.27	2.18	2.72	0.51	0.60	0.55	0.32
3	1	8.29	3.22		0.48	0.33		5.72
	2	8.77	3.22		0.35	0.49		4.21
	3	7.40	15.98		0.41	0.37		0.30
AVG		8.15	7.47	7.81	0.42	0.40	0.41	3.41
4	1	6.52	5.31		0.45	0.43		0.06
	2	2.01	1.90		0.60	0.64		0.06
	3	4.56	4.26		0.47	0.48		0.14
AVG		4.36	3.82	4.09	0.51	0.52	0.51	0.09
5	1	4.86	3.60		0.43	0.40		0.39
	2	3.94	5.43		0.50	0.47		0.07
	3	8.99	8.56		0.66	0.73		0.08
AVG		5.93	5.86	5.90	0.53	0.54	0.53	0.18
6	1	9.73	13.58		0.21	0.17		0.41
	2							
	3							
AVG		9.73	13.58	11.65	0.21	0.17	0.19	0.41
GEN. AVG.		5.72	4.91	5.32	0.46	0.48	0.47	0.85

COBALT

		SERUM ug/100 ml			PASTURES ppm			SOILS ppm
REGION	FARM	COWS	YOUNG	AVG	WASHED	N-WASHED	AVG	
1	1	2.52	1.17		2.7	2.4		1.46
	2		1.71		1.8	2.1		2.73
	3	1.00	0.17		2.8	3.3		3.40
AVG		1.76	1.01	1.39	2.4	2.6	2.5	2.53
2	1	0.87	0.44		1.4	1.6		2.00
	2	1.38			1.3	1.5		1.58
	3	1.13	0.11		1.2	1.9		2.43
AVG		1.13	0.27	0.70	1.3	1.7	1.5	2.00
3	1	0.38	1.14		2.2	1.9		1.28
	2	0.77	1.38		2.4	2.3		1.11
	3	1.63	0.99		1.5	1.8		1.49
AVG		0.93	1.17	1.05	2.0	2.0	2.0	1.29
4	1	0.64	0.95		1.7	2.1		2.63
	2	1.40	1.12		1.2	1.5		2.28
	3	1.62	1.50		2.1	2.3		1.63
AVG		1.22	1.19	1.20	1.7	2.0	1.8	2.18
5	1	1.06	0.90		2.2	2.9		1.71
	2	0.33	0.42		2.5	3.1		1.53
	3	1.07	0.53		2.5	2.7		1.19
AVG		0.82	0.62	0.72	2.4	2.9	2.6	1.48
6	1	1.56	0.91		1.5	1.4		0.67
	2							
	3							
AVG		1.56	0.91	1.23	1.5	1.4	1.5	0.67
GEN. AVG.		1.16	0.89	1.02	1.9	2.2	2.1	1.72

MOLYBDENUM

		PASTURES ppm			SOILS ppm
REGION	FARM	WASHED	N-WASHED	AVG	
1	1	0.53	0.73		0.05
	2	0.57	0.64		0.04
	3	0.36	0.41		0.05
AVG		0.49	0.59	0.54	0.05
2	1	1.09	1.12		0.33
	2	0.71	0.87		0.26
	3	1.14	1.64		0.19
AVG		0.98	1.21	1.10	0.26
3	1	0.67	0.50		0.17
	2	2.94	3.19		0.30
	3	2.49	1.76		0.37
AVG		2.03	1.82	1.93	0.28
4	1	0.86	1.13		0.14
	2	0.89	0.88		0.15
	3	1.33	1.44		0.19
AVG		1.03	1.15	1.09	0.16
5	1	1.83	2.56		0.36
	2	1.81	0.52		0.18
	3	0.75	2.98		0.15
AVG		1.47	2.02	1.74	0.23
6	1	0.19	0.17		0.52
	2				
	3				
AVG		0.19	0.17	0.18	0.52
GEN. AVG.		1.12	1.27	1.20	0.24

PASTURES

		ASH (% DM)			CRUDE FIBER (% DM)		
REGION	FARM	WASHED	N-WASHED	AVG	WASHED	N-WASHED	AVG
1	1	12.2	13.7		39.4	37.9	
	2	13.8	16.2		33.6	31.5	
	3	13.1	13.2		34.5	35.8	
AVG		13.0	14.3	13.7	35.8	35.1	35.4
2	1	11.3	12.4		27.9	24.2	
	2	10.7	11.9		30.4	27.6	
	3	12.8	17.1		34.6	30.5	
AVG		11.6	13.8	12.7	31.0	27.4	29.2
3	1	14.1	14.3		33.7	32.5	
	2	10.7	10.8		33.9	35.0	
	3	9.6	9.5		37.3	38.4	
AVG		11.5	11.5	11.5	35.0	35.3	35.1
4	1	14.5	19.0		32.8	29.8	
	2	12.8	12.9		34.6	32.9	
	3	13.0	14.6		34.7	32.4	
AVG		13.4	15.5	14.5	34.0	31.7	32.9
5	1	9.9	11.5		37.4	34.4	
	2	12.3	11.6		34.3	33.6	
	3	10.2	11.7		36.3	34.0	
AVG		10.8	11.6	11.2	36.0	34.0	35.0
6	1	5.0	6.2		29.4	30.7	
	2						
	3						
AVG		5.0	6.2	5.6	29.4	30.7	30.0

REGION	FARM	PASTURE PROTEIN (% DM) WASHED	N-WASHED	AVG	SOIL NITRATE-NITROGEN (ppm)
1	1	14.0	16.0		9.9
	2	9.4	10.7		12.1
	3	16.6	17.1		13.8
AVG		13.3	14.6	14.0	11.9
2	1	16.7	18.4		10.9
	2	13.6	14.4		12.7
	3	13.0	16.5		15.0
AVG		14.5	16.4	15.4	12.8
3	1	11.7	12.7		18.3
	2	9.1	9.3		6.0
	3	10.1	9.8		7.5
AVG		10.3	10.6	10.4	10.6
4	1	14.1	16.8		8.0
	2	11.6	12.4		4.2
	3	12.3	14.3		5.9
AVG		12.7	14.5	13.6	6.0
5	1	12.6	13.5		14.8
	2	13.8	13.5		20.4
	3	18.5	16.1		15.3
AVG		15.0	14.4	14.7	16.8
6	1	14.1	14.0		15.9
	2				
	3				
AVG		14.1	14.0	14.0	15.9
GEN. AVG.		13.2	14.1	13.7	12.3

SOIL TEXTURE

REGION	FARM	% DM SAND	CLAY	SILT
1	1	46	21	32
	2	58	20	22
	3	63	16	21
AVG		56	19	25
2	1	53	11	36
	2	55	17	28
	3	48	17	34
AVG		52	15	33
3	1	61	11	27
	2	72	9	20
	3	66	9	25
AVG		66	10	24
4	1	56	14	30
	2	61	14	26
	3	62	13	25
AVG		60	14	27
5	1	56	14	30
	2	69	10	20
	3	69	9	22
AVG		65	11	24
6	1	55	22	23
	2			
	3			
AVG		55	22	23
GEN. AVG.		59	15	26

SOIL

REGION	FARM	pH	ORGANIC MATTER % DM	NITRATE-NITROGEN PPM
1	1	6.64	3.1	9.9
	2	6.60	4.5	12.1
	3	6.88	3.8	13.8
AVG		6.71	3.8	11.9
2	1	6.18	13.5	10.9
	2	6.55	7.6	12.7
	3	6.16	10.8	15.0
AVG		6.30	10.6	12.8
3	1	6.05	9.5	18.3
	2	5.86	10.2	6.0
	3	5.43	12.8	7.5
AVG		5.78	10.9	10.6
4	1	7.18	3.1	8.0
	2	6.96	6.1	4.2
	3	7.36	5.5	5.9
AVG		7.17	4.9	6.0
5	1	6.33	9.7	14.8
	2	5.52	12.0	20.4
	3	7.90	2.5	15.3
AVG		6.58	8.1	16.8
6	1	5.97	2.3	15.9
	2			
	3			
AVG		5.97	2.3	15.9
GEN. AVG.		6.43	6.9	12.3

APPENDIX III

Table III.1. Botanical composition of pastures from five regions in the Chimborazo province of Ecuador and one region in Shiawassee county, Michigan

REGION	FARM	SAMPLE	ALFALFA	CORN	FESCUE	ITALIAN RYEGRASS	KIKUYO GRASS	NEEDLE	OATS	ORCHARD	PERENNIAL RYEGRASS	RYE	SWEET VERNAL	VELVET GRASS	WHITE CLOVER	WEEDS
			percent of fresh sample													
1	1	1	82				3				4					9
		2	53				10				24					13
		3	90								8					2
		4	88								12					
		5	94				6									
	2	1	3				90									7
		2					87			10					3	
		3							100							
		4	4				86			4	6					
		5	98								2					
	3	1	98													2
		2	99													1
		3	99				1									
		4	85								15					
		5	9				29				24					30

Table III.1. (Cont'd.) Botanical composition of pastures from five regions in the Chimborazo province of Ecuador and one region in Shiawassee county, Michigan

REGION	FARM	SAMPLE	ALFALFA	CORN	FESCUE	ITALIAN RYEGRASS	KIKUYO GRASS	NEEDLE	OATS	ORCHARD	PERENNIAL RYEGRASS	RYE	SWEET VERNAL	VELVET GRASS	WHITE CLOVER	WEEDS
			percent of fresh sample													
2	1	1			5	60				22	4				5	4
		2							100							
		3				4				32	56				7	1
		4			100											
		5				25				15				17		43
	2	1				22								25	8	45
		2								42	50				8	
		3				11				60					10	3
		4				90								6	2	2
		5				100										
	3	1				6								5	4	85
		2				5				2				86	2	5
		3										100				
		4				93					3			2		2
		5				1								4	3	92

Table III.1. (Cont'd.) Botanical composition of pastures from five regions in the Chimborazo province of Ecuador and one region in Shiawassee county, Michigan

REGION	FARM	SAMPLE	ALFALFA	CORN	FESCUE	ITALIAN RYEGRASS	KIKUYO GRASS	NEEDLE	OATS	ORCHARD	PERENNIAL RYEGRASS	RYE	SWEET VERNAL	VELVET GRASS	WHITE CLOVER	WEEDS
			percent of fresh sample													
3	1	1	100													
		2								4	20			65		3
		3									21			70	6	3
		4									95					5
		5									86			4	7	3
	2	1								15				4	6	75
		2								83						17
		3			12					4			30	14		
		4			39					52				9		
		5			20					80						
	3	1								10				85		5
		2								90					10	
		3						100								
		4								7						
		5	94													

Table III.1. (Cont'd.) Botanical composition of pastures from five regions in the Chimborazo province of Ecuador and one region in Shiawassee county, Michigan

REGION	FARM	SAMPLE	ALFALFA	CORN	FESCUE	ITALIAN RYEGRASS	KIKUYO GRASS	NEEDLE	OATS	ORCHARD	PERENNIAL RYEGRASS	RYE	SWEET VERNAL	VELVET GRASS	WHITE CLOVER	WEEDS
			percent of fresh sample													
4	1	1	27			2	63							4	2	2
		2				3	12							2	1	82
		3	69			27									3	1
		4				25	53							12		10
		5				25	4							10		41
	2	1				4	49			4				3	2	30
		2				52								12		36
		3				54	21			8				6	3	8
		4														3
		5								5				40		55
	3	1				9				86					1	4
		2														7
		3				22				4					70	4
		4				62				2						
		5				46	41									13

Table III.1. (Cont'd.) Botanical composition of pastures from five regions in the Chimborazo province of Ecuador and one region in Shiawassee county, Michigan

REGION	FARM	SAMPLE	ALFALFA	CORN	FESCUE	ITALIAN RYEGRASS	KIKUYO GRASS	NEEDLE	OATS	ORCHARD	PERENNIAL RYEGRASS	RYE	SWEET VERNAL	VELVET GRASS	WHITE CLOVER	WEEDS
			percent of fresh sample													
5	1	1				38				50			8	2	2	
		2				34				7	5		10	5	39	
		3				57							5	8	38	
		4				11				78			4	4	3	
		5				16							36	13	35	
	2	1				2				55			40	1	2	
		2				12				33			34		21	
		3				50				40				1	1	
		4								90					10	
		5								91			9			
	3	1	100													
		2	100													
		3	100													
		4	22			77										1
		5	24			74	2									
6	1	1	100													
		2	100													
		3		100												
		4		100												
		5		100												
		6		100												