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1971

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Agronomic-Economic Research on Tropical Soils

NORTH CAROLINA STATE UNIVERSITY AT RALEIGH

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ABSTRACT

The literature available indicates that crop yields and soil fertility decline rapidly after tropical soils are brought under cultivation. Soil surveys of varying detail are available. However, no groupings, especially of soils in different countries, have been made of soils with similar properties. This lack of systematic grouping has limited or prevented the extrapolation of research data from a soil in a given area to similar areas in other countries or even to similar soils in the same country. In order to utilize available data (i.e. existing maps, response data, soil tests) a set of criteria have been proposed for the technical classification of soil characteristics that interact with soil fertility management practices. These characteristics will be used to group together those soils that respond similarily to fertilization and management practices.

Most of the soils of the Llanos Orientales of Colombia and the Campo Cerrado of Brazil are quite acid and have a high content of exchangeable aluminum. The highly weathered Oxisols and Ultisols are usually deficient in phosphorus and require an addition of 100 to 150 Kg P_2O_5/ha to obtain optimum yield. Volcanic ash soils containing allophane fix large amounts of phosphorus. Nitrogen use is widespread throughout the tropical region, but at rates below those required for optimum yield and many farmers use little if any supplement nitrogen. Nitrogen responses are often lacking on recently cleared sites, but response increases in proportion to the length of time in production and after a few years, the magnitude of the response is similar to the nitrogen response in temperate zones. Responses to potassium have been obtained on many soils of the Campo Cerrado and in localized areas elsewhere. Sulfur deficiencies have been noted on many of the Campo Cerrado soils and also on some voldanic ash soils. Zinc appears to be the only micronutrient deficient over a wide area. Boron and molybdenum may be potential problems.

Results of economic analysis are sparse. One study indicated profit-maximizing levels with the addition of 120 Kg P_2O_5 and 92 Kg K_2O/ha. Preliminary analysis of risk and uncertainty effects indicate that fertilizer application of 80 to 85 percent of profit-maximizing levels would provide adequate risk adjustments.

Initial research efforts have been directed to obtaining physical and chemical soil properties for use in the capability classification. Soils from the Upper Amazon basin in Peru, Minas Gerais in Brazil, Llanos Orientales of Colombia and the Western Plains of Venezuela have been characterized as to their chemical and physical properties. Kaolinite was the predominant clay mineral in the well drained soils of the Upper Amazon basis, the Eutrustox from Brazil, and the non-flooded soils of the Llanos. The clays of the poorly drained soils from the Amazon basin were primarily montmorillonite or of mixed mineralogy. An Oxisol from the Llanos had phosphorus fixation characteristics similar to an Ultisol from North Carolina. Acid volcanic ash soils containing allophane adsorbed more phosphorus than Ultisols. Soils which contained primarily montmorillonite had low phosphorus fixation. Work is in progress or proposed in other broad areas to obtain information for the fertility capability classification.

I. INTRODUCTION

C. B. McCants

The tropical regions possess enormous potential as a source of food and fiber for not only its inhabitors but also those of other areas. This potential arises from the opportunity to increase crop yields on lands already under cultivation and from additions to the cultivation base from some of the vast undeveloped areas. The realization of this capability, however, will be influenced by progress in developing and implementing soil management systems which can recognize and modify those soil properties that restrict plant growth. While achievements in reaching this goal are encouraging, the heterogeneity in soil properties and complexity of their interaction with other growth-influencing factors necessitate even more information.

From its beginning, the Soil Science Department of North Carolina State University has been involved in programs related to studies on soils of tropical regions. Noteworthy among these are its graduate program, which has provided training in the principles of soil science for scores of students from the region - many of whom now serve in major leadership roles, the Agricultural Mission to Peru, and the International Soil Fertility Evaluation and Improvement Project (ISFEIP). An outgrowth of this latter project is the Tropical Soils Research Project.

This project was initiated on July 1, 1970 under a five-year contract with the Agency for International Development, through its Technical Assistance Bureau. The major objective is to provide relevant information to supplement and complement ISFEIP. The objectives of phase one of this project are to review, analyze and interpret published literature and other sources of information related to soil factors influencing crop production

in tropical regions and to identify major problems and sites for in-depth research in phase two. This report is directed toward those activities related to phase one.

II. ORGANIZATION

P. A. Sanchez

The first year activities of North Carolina State University have followed closely the objectives and procedures described in the contract approved on June 25, 1971. These activities are intimately related with those supported by the AID/csd 2835 grant under the 211(d) section of the Foreign Assistance Act and the AID/la 646 contract, International Soil Fertility Evaluation and Improvement Contract awarded to the Soil Science Department. Coordination with other AID-funded tropical soil activities at Cornell University, University of Puerto Rico, University of Hawaii, Prairie View A & M University and the Tennessee Valley Authority was achieved through two conferences held at Raleigh (November 12-13, 1970) and Mayaguez, Puerto Rico (April 12-16, 1971), joint travel with Cornell staff to Colombia and Brazil, and staff membership in an advisory committee of the AID-sponsored Tennessee Valley Authority fertilizer development contract.

Exploratory travel in Mexico, Guatemala, Costa Rica, Colombia, Peru, Brazil and Guyana by several faculty members had the purposes of designing and structuring a research program for the highest level of mutual interest to host countries, USAID and international centers. Meetings with Ministry, University and USAID personnel in these countries and the three international institutions, CIMMYT, IICA and CIAT, helped identify cooperating institutions and individuals as well as select sites representative of broad ecological regions to conduct the in-depth research needed to fill missing gaps in our knowledge about tropical soil fertilization and management

The approach developed from these contacts and discussions with USAID-Washington is as follows: North Carolina State University will combine its resources from the AID/csd 2806 contract and csd 2835 grant to identify and solve some of the major agronomic and economic limiting factors preventing the full productive potential of major soils of the tropical latitudes, with emphasis in Latin America. Region-wide activities include the compilation of tropical soils literature in a computerized storage-retrieval system, the economic interpretation of already existing fertilizer response and soil test data, and the testing of a fertility capability soil classification system. In-depth agronomic research activities will be concentrated on three principal sites representative of the volcanic ash-affected Central American Highlands, the wet-dry savannas and the humid tropical forests of the interior of South America. The specific sites have been identified as Central Guatemala, the Campo Cerrado near Brasilia, Brazil, and the Upper Amazon Jungle near Yurimaguas, Peru. A Memorandum of Understanding for these purposes has been signed with Brazil and proposals have been submitted for the other two sites. The Llanos Orientales of Colombia was first identified as an appropriate site for the wet-dry savannas and was also considered first priority in the Contract Document, but no action on the joint NCSU-Cornell proposal has yet been taken.

The following North Carolina State personnel have major responsibilities in this project:

<u>Soil Science Department</u>

C. B. McCants, Professor and Head

W. V. Bartholomew, Professor

S. W. Buol, Professor

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F. R. Cox, Associate Professor

G. A. Cummings, Associate Professor

E. J. Kamprath, Professor

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L. A. Nelson, Associate Professor

III. CONCLUSIONS OF LITERATURE REVIEW OF SOILS OF TROPICAL LATIN AMERICA

1 Introduction

One of the initial steps specified in the Contract was the compilation of available literature on soils of the American tropics. Through an arrangement with the North Carolina Board of Science and Technology, a search was made of Biological Abstracts for relevant work in Central and South America. Approximately 1000 abstracts were obtained on research results published since 1960. These abstracts were coded according to the keyword list previously prepared and entered into the storage-retrieval system. The North Carolina Board of Science and Technology made available their computer-based information storage and retrieval system for use by the project. The following are summaries of the present knowledge gained from the literature and from travel prior to and after the Contract, compiled by individual faculty members in their fields of specialization. Literature from tropical Asia, Africa and Australia is cited where relevant.

2. General Soil Conditions in Tropical Central and South America - S.W. Buol

The single unifying soil characteristic in tropical areas is a soil temperature regime that averages less than 5°C difference between the three coldest and the three warmest months. Except for some microclimatically controlled locations this criteria defines the soils between the tropics of Capricorn and Cancer and excludes soils of temperate latitudes. Although certain soil properties are much more extensive in tropical than in temperate areas, it appears correct to say that the range of chemical and physical soil properties in the tropics is as broad as those in temperate zones and further these ranges are for the most part overlapping. This is

not surprising in light of accepted soil genesis theory that soils form characteristics in response to the interaction of at least five external factors namely climate, organisms, parent material, relief, and time. All of these factors, except the temperature component of climate, exist in the tropics over the same range as sites in temperate zones. Thus, complexities of soil characteristics of similar magnitudes are reasonable to expect. Indeed an examination of published soil data from several areas within the tropics readily verifies this point.

Just as in the temperate areas, there are broad generalizations that can be made about the areal distribution of soil characteristics in tropical Central and South America. And, as in temperate zones, these general areas are interspersed with drastically different soil characteristics that occur in response to the genetical input of recent sediments along flooding rivers, steep topography and parent material of contrasting composition.

The following general areas are delimited in an attempt to illustrate the major areas of concern in tropical Central and South America.

2.1 Savannas of infertile soils: This condition is best characterized in the cerrado of Brazil and the upland Llanos of eastern Colombia. Soil conditions of low fertility, often complicated by high iron and aluminum contents are prevalent. A dry season of at least 2-3 months or more is experienced in these areas. These areas have smooth topography and deep friable soils. The limited use of these areas may be attributed to almost total inadequacy of these soils except for scattered high base status areas, to support primitive (no fertilizer) agriculture. Thus there is low intensity of inhabitation in most areas except for local occurances of high base status soils such as the Eutrustox areas of the Brazilian cerrado.

2.2 Tropical Rain Forests: Vast areas of sparsely populated jungle exist in the Amazon basin. Intrastructure of transportation has been limited almost entirely to rivers, although major road building efforts are currently underway. Soil conditions in these areas are not well documented. Conflicting reports and personal examination in part of this area in eastern Peru leads us to hypothesize that many of these soils are relatively fertile. Since almost all reports are confined to areas of close proximity to rivers, there is a strong probability of bias in the information.

2.3 Mountainous areas with soils of volcanic ash origin: The central chain of Andean mountains extending throughout Central America and near the west coast of South America typifies this general area. Climatically these areas vary according to altitude and also according to rather dramatic "rain shadow" effects. In general the soils are fertile enough to support primitive agriculture. This condition can be traced to a genetic background of young age due to the recent nature of volcanic parent material and/or rapid geologic erosion of the steep slopes that exposes relatively unweathered minerals to exploitation by plant roots. These areas are densely populated, usually by small farmers with limited management ability and are not attractive to agronomists because the steep topography precludes implementation of mechanized modern agriculture. Modern agriculture is also inhibited by the difficulty in managing phosphates in these soils with high contents of active, amorphous, clay minerals.

2.4 Seasonally flooded plains: Large areas of nearly level plains characterized by the western plains of Venezuela and that part of the Colombian Llanos north of the Meta iver present unique problems. In general the soils are quite fertile and free of complicating components

such as high Al, Fe, and amorphous concentrations. The monsoon type climate causes these areas to be alternately extremely dry or flooded. The magnitude of these areas taxes the imagination for possibilities to control the water. Population is sparse and transportation is limited. It appears that except for areas where water control is practical, little can be done to increase agricultural development.

2.5 Desert areas: A number of desert areas with low total annual rainfall exist at all altitudes and over a wide range of temperatures. These soils are usually quite fertile and the only outstanding need is for irrigation systems to transmit water. Some salinity and alkalinity problems may be noted as well as some fixation of fertilizer can be expected when free carbonate is present. These areas are sparsely populated except for the irrigated valleys, many of which support modern intensive agriculture.

Other general areas and conditions have been delimited by various authors. Examination of any such areal grouping systems in an attempt to delimit conditions under which to establish soil related research reveals the futility of such an approach. Whereas, social, economic, and climatic conditions can be delimited to reasonable homogeneous levels by such groupings, the active fertilizer interaction with the plant is encased in the confines of the soil profile. Thus, the interplay of fertility, uptake, release, and fixation is most directly controlled by the surrounding mineral and organic constituents in the soil, adjacent to the root. As stated earlier any geographic grouping includes a wide variety of contrasting soil conditions depending upon extremely local conditions of relief, etc. These local conditions are too small in extent for inclusion of any general grouping and the application of fertility management practices, though soil-test fertility recommendations are concerned with specific

field size areas which are certainly not reflected by such groupings.

There appears to be some middle ground to approach this problem. It is proposed that the soil conditions, having most direct influence on fertility management, can be used as criteria for classifying the soil for purposes of soil testing-fertility research. This can in some cases be done from existing soil survey information or, when necessary, on site examination, with needed samples if necessary, at the time the soil testing samples are taken. Such a system is discussed later in this report.

3. Soil Management in the Humid Forested Region - P. A. Sanchez

Shifting cultivation can be defined as a continuing agricultural system in which temporary jungle clearings are cropped for less years than they are fallowed. It is the predominant agricultural practice on about 3.6 billion hectares by over 200 million people in the most primitive areas of the tropics. The literature is extensive; over 1300 references have been compiled by H. C. Conklin on all aspects of the subject. Most of the soil research has been conducted in Africa which has been summarized in an excellent review by Nye and Greenland. This review indicates that otherwise infertile forested tropical soils increase their available nutrient supply during the fallow periods and lose it during cropping periods, although the rates of these changes have not been quantified. Most of the evidence is based on samples taken in cultivated and adjacent fallow areas at the same time. Research on soil ammendments are not related to time sequences.

In Latin America, shifting cultivation is the predominant agricultural system in the Amazon Jungle Basin which covers about 32% of Colombia, 40% of Ecuador, 60% of Peru and 45% of Brazil. Significant portions of the

Atlantic coast of Central America and the Pacific coast of Colombia are also under shifting cultivation. Observations of soils under this system have been reported from Mexico, Guatemala, Costa Rica, Trinidad, Guyana, Colombia, Peru and Brazil. Most of the information is semi-quantitative or qualitative. The concept of a closed nutrient cycle between a mature forest and a tropical soil has been recognized in Trinidad since 1936. Knowledge of its different components are sketchy at best. High organic matter and total N contents have been reported in forested soils of Colombia, Guyana and Guatemala, and attributed to a high proportion of leguminous trees in the first two cases. Present soils knowledge indicates that the sites studied in Colombia and Guatemala are probably volcanic ash soils, which are typically high in organic matter. Information on the amounts of nutrients stored in the vegetation prior to burning has not been found. The direct effects of burning and ash distribution on temporary pH increases, exchangeable base content and distribution in the profile are well documented in Popenoe's study in Guatemala.

Yield decreases after the first crop are extensively reported. Corn yields during the second crop decrease from 20 to 50 percent of the first crop grown after clearing the forest. Yield decreases in upland rice were not observed until the fourth consecutive crop in an Alfisol of eastern Peru. Cleared land is normally abandoned when crop yields decrease to half the yield of the original crop or when the labor requirement of additional weeding exceeds that of clearing a new patch. Although pest and erosion problems are mentioned, soil fertility decline and weed competition are considered the main reason why cultivators shift. Many soil parameters have been associated with yield declines in Latin America:

1. Increased soil compaction (Guatemala, Costa Rica, Peru, Brazil)
2. Stored soil moisture depletion in semi-arid climates (Mexico)
3. Increased drainage problems (Peru)
4. Rapid organic matter and N depletion (Yucatan, while no significant losses reported in Guatemala and Venezuela)
5. Phosphorus depletion (Venezuela)
6. Potassium depletion (Mexico)

An attempt to correct the fertility decline through fertilization schemes during eight years has failed in Campeche, Mexico. No similar attempts have been found in the available literature so far.

Shifting cultivation is considered the optimum soil management system for subsistence cropping in relatively inaccessible, primitive high land/man ratio areas with a carrying capacity of 15 to 25 people per square mile. When governments act to relieve their population pressure in the highlands through road construction and colonization projects, other alternatives for soil management must be developed. Such is now happening with the Transamazonic highway construction in Brazil and similar efforts in other Amazon Basin countries. Attempts to transplant foreign experience or solve one aspect of the problem (for example, mechanized land clearing in Peru) without considering the fertility decline and its solution, usually result in failures.

The knowledge of soil changes under shifting cultivation in general, and specifically in Latin America, is completely inadequate to determine the food production potentials of the new areas being made accessible by government projects. The need for data on changes in soil properties as a function of time, coupled with economically realistic fertilizer and management practices is obvious from the literature reviewed.

4. Nitrogen Transformation and Movement - W. V. Bartholomew

There are some soil nitrogen and organic matter transformation processes in the tropics as well as some soil nitrogen movement and crop absorption patterns which are quite different from those commonly observed in temperate regions. These differences result largely from differences in climate and not from any differences in the fundamental biological processes. In fact, fundamental principles should apply in any and all situations when due consideration is given to environmental factors.

In temperate regions, the annual cycle of growth of vegetation is restricted annually by cold temperatures. A variety of rainfall regimes are found in combination with the cold seasons. However, during the growing seasons the rates of evapotranspiration generally exceed the rates of precipitation. Also, in most temperate regions the growing season starts with the supply of available water in the soil.

In all but the wettest tropical regions, plant growth may be limited at one or more times during the year by drought. In seasons of heavy rainfall, excess water may move rapidly down through the soil and carry many soluble plant food elements with it. At the end of each wet season and during the onset of the dry season, the vegetation removes most of the available water within the range of plant roots. Consequently, the next cropping season starts without any reserves of water for the growth of the ensuing crop.

These basic differences in the rainfall and temperature regimes between temperate and tropical climates require important management innovations in the transfer of soil management technology from temperate to tropical agricultural systems.

Nitrogen is the element most likely to limit crop growth in tropical regions. The nitrogen needs in these regions will eventually be met either by natural supply processes or through fertilization. The natural supply processes have many inherent limitations and it is unlikely that any process with the possible exception of biological fixation could be improved sufficiently through management research to warrant the research input.

The needs for research lie in the area of improving the efficiency of use by crop plants of the so-called available nitrogen in the soil. General estimates place crop use at about 50% of the soluble nitrogen in the soil. The remainder escapes plant absorption either by loss processes which remove it from the field of action or by failure of the crop to absorb the nitrogen because of root-zone position, or because of unfavorable moisture situations. A better understanding of loss processes in tropical environments and of plant absorption processes from the root zones of tropical soils appears as the best avenue for improving crop production and for bettering the use of nitrogen resources.

Several technical areas relative to nitrogen have been examined in some detail through reviews of the literature, and the following generalizations and conclusions have been made:

4.1 Crop use of nitrogen: Actual crop use of nitrogen at varying yield levels can be found for the cereal crops (corn, wheat and rice) and for several commercial crops like sugarcane, pineapple and bananas. For the cereals, the information comes almost wholly from temperate zone research.

The quantities of nitrogen actually absorbed and used by crops needs to be known as a guide in planning fertilizer practices for any and all crops. Such information constitutes the standard by which fertilizer

efficiency is evaluated. For most crops nitrogen use is constant and predictable and varies largely with crop yield.

4.2 Volatile loss process: No direct measurement information was found in the literature review except from the temperate zones and from Australia. In general, in temperate zones such losses have been constant but not large, except under some abnormal environmental situations. Since we have not developed any management techniques to prevent such losses, it is not likely that research in this area could be made to have a major impact on nitrogen use practices.

4.3 Nitrification: There are widespread reports from tropical regions of nitrification occuring in soils. Two conditions which inhibit nitrification have been reported. One is the possible inhibition by grass. A second is acid soils, possibly the influence of aluminum.

The inhibition of nitrification by grass has been questioned. Also, its importance, if real, has little impact on crop production. The inhibition in acid soils generally will be eliminated when and if the soils are amended with lime and fertilizer to make them productive for crops. Research does not appear warranted in this area.

4.4 The impact of drying on rates of mineralization: The impact of drying on rates of mineralization of soil nitrogen has received considerable attention by a number of investigators working in tropical regions. Such phenomenon appears to have a significant influence on the supply of nitrogen available to crops at the onset of the wet season. The economic impact of this drying influence could be important only when the soils contained relatively large amounts of immobilized nitrogen. On the other hand, an understanding of this phenomenon could assist in the formulation of fertilizer management practices in tropical soils.

4.5 Nitrogen movement and leaching: Information from tropical zones relative to nitrogen movement in the soil is sparse. Most investigators have assumed the existance of extensive leaching during the wet seasons in the tropics. Actual measurements were found only for lysimeter studies.

Fluctuations in nitrate content of soils have been noted in a number of instances in tropical regions. These fluctuations generally have been related to the advent of the dry season to the beginning of the wet season. The extent of net vertical movement of nitrogen under specified rainfall, cropping, and soil conditions still must be determined. This would include downward displacement during the wet season and possible upward displacement during the course of the dry season.

4.6 Position of nitrogen in the root zone: In temperate regions the position of nitrogen in the root zone of crop plants has been shown to have an important influence on the rate of plant absorption of the nitrogen. Data are not available for the tropics, but similar influences would be expected. Since vertical movement patterns in soils of the tropics may be quite different from those commonly found in temperate zones, the direct transfer of soil management techniques from the temperate to the tropical zones is not possible. The impact of vertical as well as lateral position of nitrogen on rates and extents of crop absorption needs to be known for major tropical soils and crops.

4.7 The influence of water on crop absorption of nitrogen: It is well known that water has a profound influence on plant absorption of nitrogen as well as on the absorption of other nutrient elements. As a guide in nitrogen management in tropical regions, it would be quite important to determine the physical status of water in the several depth

horizons of tropical soils during both the wet and dry seasons and also to know the vertical zone from which crop plants use water.

5. Nitrogen Fertilization on Corn, Forages, Beans and Other Crops - G. A. Cummings

The need for supplemental nitrogen fertilizer depends primarily on the amount of N available from non-fertilizer sources in the soil. The nitrogen available in a given soil depends on the nature of the soil, such as texture and organic matter, its cropping history, climate, and especially under tropical conditions the length of time that it has been under cultivation. Attempts to determine the amount of nitrogen in soil that can be utilized by a given crop. especially in soils of the tropics, has met with only limited success. The relationship between the amount of nitrogen available and the amount of organic matter in the soil, though positive, appears not to be a criteria that can be employed without discretion. It has generally been shown that response to nitrogen fertilizer often is slight or lacking in newly cleared land in the tropics; however, the response to N fertilizer increases greatly each succeeding crop year. The amount of supplemental nitrogen required for a continuous and profitable agricultural without shifting cultivation remains, in many areas, to be ascertained.

The response to nitrogen must also be interpreted with full knowledge of cultural practices and especially the level of other nutrients and soil reaction. Those factors, i.e. soil mineralogy, wet-dry seasons, soil microflora, that influence either release or immobilization of nitrogen and their contribution to the amount of nitrogen soil will provide for a given crop must be determined. The influence of the nitrogen source must

be considered. Throughout Central and South America when different sources have been compared, responses from ammonium sulfate have been equal to or superior to other sources. This indicates that in many areas nitrogen response may depend to a great extent upon the available sulfur in the soil and whether that nitrogen source also contains sulfur.

Even though many questions remain to be answered where specific research has not been carried out, there has been sufficient research to indicate the response that would be anticipated with specific crops.

5.1 Corn: Widespread research from the expansive humid areas to the moderate climate of the highlands indicate that the response of N fertilization is quite variable both within and between the two areas. In the hot, humid areas the response on newly cleared land is often slight or lacking but response becomes greater with each year of cropping. However, reports of little or no response even after several years in cultivation are also evident. Either the inherent supply of nitrogen in these soils becomes available at rates different than in more temperate areas, atmospheric nitrogen accounts for more of the available N, or other factors i.e., fluctating water table may account for this lack of response. Regardless of the reason, research must be carried out to determine the amount of nitrogen these soils will supply before meaningful recommendations can be made. However, it is clear that in most of the soils with a history of several years cultivation that supplemental N is required and in amounts similar to soils of temperate areas.

In the highlands where corn is a staple, the utilization of N and response to supplemental nitrogen appear to be influenced by some factor not present in other areas. This may be related to the alternate wet-dry seasons in many areas of the highlands. Clearly, research is needed

to determine the movement of nitrogen in these volcanic ash soils, related to the wet-dry season, and to determine supplemental N required for optimum yields.

Up to the present time much corn has been grown with little, if any, supplemental nitrogen especially in the smaller producing units. Research data, as well as test demonstration plots, both in the Highlands and the hot humid areas indicate that yields can be markedly improved by nitrogen rates of 75 to 150 kg/ha. Information relative to the plants' requirement for nitrogen for specific yields is available, thus studies are needed to determine how much fertilizer nitrogen is needed to achieve desired plant nitrogen levels. Thus research priorities should be directed to determine the nitrogen regime in these soils and to the behavior of applied nitrogen in the soil.

5.2 Pastures and forage crops: Yield of forages are greatly curtailed throughout the tropics from shortages of nitrogen and numerous investigators report responses to nitrogen application. These responses are similar in magnitude of the responses in temperate areas, but total yield increase is higher because of continuous production throughout the year. The potential of the profitable use of nitrogen is widespread in areas of intensive agriculture. In extensive type agriculture, though responses are evident, the use of supplemental nitrogen may be only one facet to be considered in order to increase forage production. Improvement of native pastures, introduction of new species, and the utilization of legumes to supply nitrogen must also be considered. A concerted effort will be required to determine nitrogen requirements to maximize production in areas of intensive agriculture utilizing modern cultural practices, i.e., irrigation, high yielding species, and grazing or harvesting management. In

the more expansive areas, the savannah type vegetation, research will be required to determine the nitrogen response, but more important the economic value of the increased production must also be ascertained. One of the major problems in the tropics is not a lack of total calories but of the quality of the available food. Numerous reports show clearly that nitrogen application increases yield and protein content of forages. Increase in the use of nitrogen on forage affords the opportunity of increasing livestock production and increasing the portion of meat in the diet.

5.3 Edible beans: The production of edible legumes offer the possibility of a high protein supplement to low protein diets. The response to nitrogen applied to beans has been quite variable. Studies to determine the presence of symbiotic nodulating bacteria and factors limiting nodulation should be initiated. The response to nitrogen under controlled and field conditions should be ascertained after inocculation with symbiotic bacteria and the addition of soil amendments.

5.4 Other food crops: Data available relative to the response of other food crops to nitrogen application is sparse. Crops such as cassava, cereal grains, bananas, potatoes, and vegetables are widely grown, but data relative to response of these crops to nitrogen, though excellent in a given locality, may not be applicable to soils over a wide area. Response data from experiments with potatoes in Peru and Brazil, bananas in Central America and of cereal crops from several areas should be used as a basis to expand the work to similar soils in other areas.

Many of these crops, especially cassava, are grown in a subsistence type agriculture and response data to fertilizer application are sparse. The magnitude of the problem can be emphasized by data which indicates

that in many countries approximately 50% of the caloric intake of carbohydrate foods is derived from crops other than corn and rice.

6. Nitrogen Fertilization and Management of Rice - P. A. Sanchez

Rice is the most important crop produced in the tropics and ranks second or third in Latin America, with over 4.8 million has. planted; the average yield is only 1.72 tons/ha. Responses to moderate applications of nitrogen are almost universal while responses to other nutrients are less marked than in other crops due to the unique chemistry of constantly or intermittently flooded soils. More than 75 percent of the Latin American rice area is grown as a direct seeded, rainfall dependent (upland) crop, subject to alternate moisture stress conditions. Due to the poor water management of irrigated areas, these are subjected to alternate periods of flooding and drying.

Most of the nitrogen fertilization research in Latin America has been limited to rate trials utilizing tall-statured varieties, which respond positively to rates of 30 to 60 kg N/ha and negatively with higher rates due to excessive vegetative growth and subsequent lodging. Very high yields are being obtained with the new short-statured varieties but with higher N rates and better management. An average of 10 trials in the high solar radiation coastal areas of Peru have provided optimum yields of 11 tons/ha at an application rate of 320 kg N/ha with the IR 8 variety under high solar radiation and intermittent flooding. Areas or seasons with lower solar radiation produce lower optimum yields at lower nitrogen rates. For example, in the Magdalen Valley of Colombia, IR 8 yielded over 9 tons/ha at 50 to 100 kg N/ha under irrigated conditions and in the Selva of Peru, short-statured varieties produced between 4 and 5 tons/ha at

30 to 50 kg N/ha. These yields represent increases of 75 to more than 100 percent over those obtained by traditional varieties and N application levels.

The Latin American Data supports data from constantly flooded systems in other areas indicating that ammoniacal sources of N are superior to nitrate and that urea and ammonium sulfate are about equal in efficiency. Alternate flooding and drying result in high fertilizer nitrogen losses, particularily when applied in the way recommended in Asia or the United States for constant flooding. The apparent recovery of added nitrogen ranged between 20% and 30% under intermittent flooding in Peru. These figures can be increased substantially by the use of slow release sulfur-coated ureas, or by delaying the time of application of conventional sources.

Soil analysis have not been successful in predicting optimum N rates for rice, although research is in progress in various countries. Recommendations should be based on plant type, solar radiation, water management, soil moisture holding capacity, and field experience.

This review has pointed out the general lack of understanding of basic concepts of nitrogen relations in reduced soils in Latin America as well as the tremendous yield increasing potential of nitrogen fertilization, management practices and new varieties under poor or no water management. The full review was written in Spanish and presented to the Colloquium of Nitrogen Uses in the Tropics held by the Colombian Society of Soil Science in Palmira.

7. Soil Acidity and Liming - E. J. Kamprath

The highly weathered soils of the low Humid Tropics are generally quite acid. The soils in the Tropics currently being used for intensive

cultivation are the ones where soils acidity is not a problem. The large areas of soils not being used for cultivation such as the Campo Cerrado of Brazil and the Llanos Orientales of Colombia are quite acid.

Analyses of soils from these regions has shown that the soil pH values are generally less than 5. The predominant exchangeable cation is aluminum. In many instances exchangeable aluminum accounts for more than 60 percent of the exchangeable cations. The amounts of exchangeable calcium and magnesium in these soils are quite low. Studies in the southeastern United States with soils having a similar exchangeable aluminum saturation have indicated that the growth of cultivated crops such as corn, soybeans and small grains is severely restricted due to toxic effects of aluminum. Only a few field studies on liming have been conducted in the tropics with these soils. Without the application of lime growth has been severely restricted. In the past attempts to lime these soils to pH 7, as has been the practice with soils in the temperate areas, has resulted in poor plant growth. When soils in Brazil were limed to pH 6.7, yields of sweet potatoes were severely reduced. Similarly liming of soils in Brazil with pH values ranging from 5.6 to 6.6 depressed yields of dry beans. The depression of yields caused by liming soils to pH 7 has been associated with decreased phosphorus and micronutrient availability. Boron availability often is decreased when highly weathered acid soils are limed. As a consequence of results like this, a feeling has developed that liming of tropical soils is not beneficial and actually may be detrimental.

Crop response to liming generally has been quite large below pH 5. The responses have been obtained with relatively low rates of lime. Above pH 5.5 crops have not often responded to liming. These kind of responses

suggest that neutralization of exchangeable aluminum is one of the main benefits of liming. It seems logical, therefore, that lime recommendations for soils in the Tropics be based on neutralization of the exchangeable aluminum.

Very few liming studies have been based on neutralization of exchangeable aluminum or a portion of it. Rates of lime in future studies should be based on reduction of the exchangeable aluminum saturation to various levels. Studies of this kind are important to obtain information for use in making lime recommendations and in making the most efficient use of lime particularly where it has to be transported long distances. Information is also needed as to how long an application of lime based on neutralization of exchangeable aluminum will be of benefit.

One benefit of liming particularly with legumes is increased availability of soil molybdenum. Very few studies have been conducted to delineate the effects of liming on neutralization of exchangeable aluminum and availability of soil molybdenum. Seed treatment with molybdenum may be a better approach than adding lime merely to increase the availability of soil molybdenum beyond that needed for neutralization of exchangeable aluminum. Liming studies should include molybdenum treatments in order to evaluate the lime-molybdenum interaction.

Many of the highly weathered acid soils are low in magnesium. Where this situation exists, magnesium will have to be added either in the form of dolomitic lime or as a soluble salt. Studies are needed to determine the soil level of available magnesium required for optimum plant growth, amounts of magnesium that need to be added where soils are deficient, and how long magnesium additions will be of benefit.

8. Phosphorus Fertilization and Fixation - E. J. Kamprath

The soils of the tropical regions are often very low in available phosphorus. As a consequence, sustained high crop yields are not possible on many soils without the addition of fertilizer phosphorus. Another problem encountered is that phosphorus fixation may be quite high on tropical soils, such as Oxisols, Ultisols containing large amounts of hydrated oxides of iron and aluminum and on volcanic ash soils containing allophane.

8.1 Phosphorus fixation: The properties of the soils in the tropics vary widely depending on the parent material from which they are formed and their stage of weathering. Studies to group soils according to their potential for phosphorus adsorption have given varied results because of the range of soil properties within soil groups.

Phosphorus fixation within a soils series in Sao Paulo, Brazil, was correlated with the iron oxide content. However, there was no correlation over a range of soil series. There were apparently differences in the crystallinity of the iron compounds. The less crystalline materials adsorb phosphorus in greater amounts and bind it more strongly than the more crystalline materials. This points out the need for grouping soils according to their chemical properties in order to extend research data from one area to another.

The aluminum content extracted with 1 N NH_4OAc at pH 4.8 was related to the phosphorus fixation of volcanic ash soils. Phosphate fixation in one study with volcanic ash soils was found to be highest in the youngest soil. Liming had very little effect on the adsorption of phosphorus except when exchangeable aluminum was present.

In general the following statement can be made about phosphate fixation in soils of the Tropics. Latosols containing a high content of

amorphous hydrated oxides of iron and aluminum will fix large amounts of fertilizer phosphorus. Soils formed from volcanic ash which have measureable amounts of allophane generally will fix large amounts of phosphorus in a relatively insoluble form. The so-called latosols from the Amazon basin of Brazil had less phosphorus adsorption capacity than other highly weathered soils.

8.2 Forms of soil phosphorus: Considerable work has been done in the laboratory to identify the forms of phosphorus present in soils. Older volcanic ash soils had most of their phosphorus in the inorganic forms with essentially all of the phosphorus bound to aluminum and iron compounds. These aluminum and iron phosphate compounds are very insoluble and would supply very little phosphorus for plant growth. Recent volcanic ash soils had a fairly large proportion of organic phosphorus but with time, the amount of organic phosphorus tends to decrease.

The main form of phosphorus in unfertilized latosols was iron phosphate which is very insoluble. Most of the fertilizer phosphorus added to these soils was bound to iron and aluminum compounds. Some of the soils from the Amazon basin and Sao Paulo in Brazil had a significant proportion of phosphorus in the organic form. Initially when these soils are brought into cultivation mineralization of the organic phosphorus might supply fair amounts of phosphorus for a few years.

Alluvial soils throughout the tropics have low phosphorus adsorption and a large amount of phosphorus in the more soluble forms.

A number of factors affect the forms of phosphorus in the soil. With increasing weathering of a soil there is a shift from calcium phosphates to iron phosphates. This is to be expected since the amounts of hydrated iron oxide would increase, other factors being similar, as the soil becomes

more weathered. Studies with soils in Central America indicated that calcium phosphates were the dominant form above pH 5.5 while aluminum and iron phosphates predominanted below pH 5.5. The moisture content and drainage of the soil also influence the form of phosphorus. Ferric phosphate increased during the dry season while aluminum phosphates increased under anaerobic conditions.

8.3 Soil tests: A study with 110 soils from Central America indicated that 66% were extremely deficient in phosphorus and only 15% contained adequate phosphorus for crop production. Correlation of soil tests with phosphorus uptake indicated that the Olsen method - 0.5 M $NaHCO_3$, Bray I - 0.05 N NH_4F + 0.025 N HCl, and the Mehlich method - 0.05 N HCl + 0.025 N H_2SO_4 were equally good in predicting phosphorus availability. Approximately 72% to 75% of the variation in phosphorus uptake was explained by the soil tests.

For the terra roxa soils of Brazil, the Olsen method - 0.5 M $NaHCO_3$ gave the best measure of phosphorus availability. In Peru, the Olsen method gave the best measure of phosphorus availability for mountain soils on which potatoes are grown. A critical level of 7 ppm of P separated the responsive from the non-responsive soils.

8.4 Crop response to fertilization: Crops responded to phosphate fertilization on the highly weathered acid soils which previously had not been fertilized. Responses were generally greater when the soils were limed. Where these soils had a history of fertilization, responses were fairly small indicating that there is an appreciable residual effect. Many of the alluvial soils have adequate phosphorus and crop response to phosphorus fertilization is small. On the other hand, crops grown in the Andean Mountains and inter-mountain plateaus were very responsive to

phosphorus fertilization. Many of these soils have been developed from volcanic ash and have a high phosphate adsorption capacity.

The amount of phosphorus fertilizer required is influenced not only by the soil but also by the crop characteristics such as amount of dry matter produced, kind of root system, and the size of the root system. The rates of phosphorus which are given in the following section are for soils deficient in phosphorus.

Corn, soybeans, and beans grown in Sao Paulo gave maximum yields with 100 to 150 kg P_2O_5/ha. Upland rice grown in the same region gave maximum yields with 60 kg P_2O_5/ha. Yield increases on the Campo Cerrado soils were quite large especially with corn, soybeans and beans.

Sugar cane yields were increased 40 tons cane/ha from the application of 90 kg P_2O_5/ha in one study in Sao Paulo, Brazil. Fields that had previously received 2 to 5 applications of phosphorus had responses of less than 12.5 tons cane/ha. A rate of 385 kg P_2O_5/ha is applied at planting on the volcanic ash soils of Hawaii which are extremely high fixers of phosphorus.

Wheat yields were increased 7 fold with 160 kg P_2O_5/ha in southern Sao Paulo. Similarly in Colombia on savanna soils in the mountains maximum yields were obtained with 160 kg P_2O_5/ha.

Potatoes are a crop which often respond to phosphorus. Studies in Sao Paulo indicated a rate of 180 kg P_2O_5/ha was needed for optimum yields. The average increase in yield in four different regions of Sao Paulo was 42%. In the Sierra of Peru, potatoes responded to phosphorus in 95% of the experiments. On soils low in phosphorus, the optimum rate was 160 kg P_2O_5/ha. On volcanic ash soils in Colombia the average potato yields

without phosphorus were 4 tons/ha and with the application of 450 kg P_2O_5/ha yields were 15 tons/ha.

Both yield and quality need to be considered in evaluating the response of grasses and legumes to fertilization. Phosphorus deficiencies of grasses in Panama were found on a large percentage of the soils. A similar situation exists with many of the Campo Cerrado soils in Brazil. Yields of grasses and legumes without phosphorus fertilization were only 5% to 10% of yields obtained where phosphorus was applied. With the volcanic ash soils of Chile, trumao soils, a minimum of 100 kg P_2O_5/ha is needed for the establishment of grass-legume pastures.

8.5 Research needs: The amount of phosphorus adsorbed and the resulting available phosphorus level as measured by soil tests should be determined for those regions where information is lacking. The soils with similar phosphorus adsorption characteristics should be grouped together for the purpose of extrapolating research data.

Long tern field studies should be started on the major soil groups to determine the level of available phosphorus required for sustained high crop yields, the residual effect of previous fertilization, and rates of fertilization required to maintain a given level of available phosphorus. Studies are needed on the effectiveness of various phosphorus carriers such as rock phosphate, partially acidulated rock phosphate, and superphosphate in quenching the phosphorus fixing capacity of soils in the tropics. Information is needed on the most efficient method of applying phosphorus particularly on the high phosphorus fixing soils.

9. Potassium Fertilization - F. R. Cox

Potassium fertilizer trials have been conducted with many crops grown

on tropical soils. The variable responses noted with this vast array of crops emphasizes differences with regard to potassium requirements for high yields. For example, sugar cane usually responds to K whereas beans seldom do. Therefore, it seems that in calibrating a soil test for each crop the critical soil level and K rates that must be applied may vary widely.

Plant analysis has been used to detect K deficiency. Surveys have been conducted with several crops. In the case of sugar cane grown in Brazil a survey indicated that K was the element most often deficient. Apparently, critical levels intissue are recognized and used, although few have been reported. Only two were indicated in the literature and those were both for corn.

Data establishing levels of K in the soil, even low, medium, and high, are not well documented for soils of the tropics. Soil testing laboratories are being used, however, so undoubtedly there is considerable experience on which to base such levels.

It appears that the ability to predict responses from soil test information needs further work for some crops. For example, with potatoes grown in Peru the K soil test was much less useful in predicting response than was the P soil test. Work not yet reported with non-exchangeable K appears to be clarifying the situation. This approach may be needed with other crops.

Another variable affecting the soil test interpretation is fixation. There have been several reports related to K fixation in soils of the tropics. These include the effects of drying, mulching, incubation, and soil reaction. Another report inferred that there was a significant climatic effect on the soil test level. These aspects need clarification in

order to interpret the K soil test properly.

Potassium responses have been found in the acid highly leached soils in the Tropics. Soils not responding to potassium fertilization apparently release sufficient potassium from non-exchangeable forms. Response to potassium on volcanic ash soils is related to the nature of the volcanic material. Although in certain volcanic ash soils the total potassium content may be low, it becomes readily available for plant use. There is a need to identify the soil conditions in the tropics under which an appreciable reserve of weatherable potassium is present and methods for measuring these reserves.

10. Sulfur Fertilization - E. J. Kamprath

Many of the soils of the tropics are quite low in sulfur and crop growth is limited without the addition of sulfur. In many of the highly weathered soils, sulfur is present as organic sulfur. When the soils are first brought under cultivation, mineralization of organic sulfur may be sufficient to meet the crop needs for several years. Large response to sulfur fertilizers have been obtained on the soils of the Campo Cerrado in Brazil. Sulfur deficiencies have also been reported in Central America.

The highly weathered soils containing appreciable amounts of hydrated oxides of iron and aluminum have the capacity to adsorb sulfate. Fertilized soils generally contain more adsorbed sulfate in the subsoil than in the surface soil because phosphate is held more strongly than sulfate. Adsorbed sulfates are readily available for plant growth and may be an important source of sulfur depending upon their depth and upon factors which restrict root growth into the subsoil.

Volcanic ash soils containing allophane have been found to bind sulfate very strongly. In order to supply sufficient sulfur for adequate plant growth in volcanic ash soils, high supplemental rates of sulfur may be required.

Surveys should be made of the important soils as to their level of available sulfur. Wherever possible, a treatment containing no sulfur should be added to planned field experiments in order to delineate the effects of sulfur per se particularly where ordinary superphosphate is used. Experiments should be conducted on representative soils to determine the amounts of sulfur required to correct deficiencies and how long there will be a residual effect.

11. Micronutrients Status - F. R. Cox

The micronutrient literature was reviewed with respect to response to fertilization, soil test levels, and plant symptoms or analysis. There were few reports on these subjects, and most reports were concerned with more than one nutrient. This is indicative of the exploratory nature of the studies conducted to date.

The literature on micronutrients is also biased by the degree of reporting from an area. Apparently, many deficiencies have been observed that have not been formally studied and recorded. In other areas, however, resuls have been published much more freely. The latter seems to be the case for Brazil, as much of the total review came from that country.

A summary of the review by element on crop response, soil and plant content is presented in the following paragraphs.

11.1 Zinc: Corn has responded to zinc fertilization in Brazil and Mexico. Even less sensitive crops such as soybeans have shown yield

increases due to zinc application, indicating rather severe problems in certain areas. Practically no reports gave levels of soil or plant zinc that would tend to verify response data. Deficiency symptoms have been observed on other crops such as coffee but these are rarely cited in the literature.

11.2 Boron: A response to boron fertilization has been noted on cotton in Brazil. There are no reports of soil analyses nor observed deficiencies. The impression is, however, that a lack of boron is considered a significant potential problem, and that many observations simply have not been reported.

11.3 Molybdenum: Several crops have responded to Mo applications in the Campo Cerrado of Brazil. Some soil analyses have been conducted that also indicate a lack of Mo in that area. Coffee has shown deficiency symptoms in Sao Paulo and Parana. There has also been a report of bananas responding to Mo in Honduras, but aside from this, essentially all the work reported has been from Brazil.

11.4 Copper: No crop responses to Cu nor deficiency symptoms in plants have been reported. Copper deficiency in animals has been noted in the Brazilian coastal area of Piaui Some soil and plant analysis data from Puerto Rico and Colombia is in the literature, but there is little evidence of a severe copper problem in any area.

11.5 Iron: Iron deficiency has been observed in coffee and sugar cane in Brazil. There are no reports of plant or soil content nor of responses to Fe that would indicate that lack of Fe is a significant problem.

11.6 Manganese: There are no reports of deficiency symptoms nor responses to Mn. Studies of soil from volcanic ash have shown low, but apparently adequate, levels of soluble or exchangeable Mn.

11.7 Summary: The literature, although somewhat biased by areas reporting, indicates that zinc deficiency is the most significant micronutrient problem. The impression is given that boron may be lacking in some areas, whereas Mo deficiency has been shown in the Campo Cerrado of Brazil. It appears that Cu, Fe and Mn are generally adequate.

There are not enough reports giving soil analysis data for the micronutrients to even begin establishing the status of these elements in tropical soils. It would appear that survey information is needed to determine typical soil levels from throughout the region.

12. Soil Physical Properties - J. F. Lutz

12.1 Climate-soil-plant interrelations: Climatic tables for the world have been prepared and these data make it possible to calculate soil water balances in various sections of the tropics. Where evapotranspiration data have not been determined they can be calculated from Thornthwaite's, Penman's, or other formulas and related to plant growth. Some work has been done on this in Brazil where the growth of beans was correlated with soil moisture conditions as calculated from the Thornthwaite equation. The climatic data also have been related to certain natural vegetation and soil conditions. Such ecological investigations relating climate, vegetation, and soils have been carried out in the "Gleba Arinos" rubber estates in the Matto Gross area of Brazil. Soil organic matter, temperature, and precipitation relations have been studied in the Cauca River Valley in Colombia. Considerable data have been published on the physical properties of a number of soils from the state of Sao Paulo, Brazil. These data include bulk density, total porosity, particle size analysis, and certain moisture constants including moisture equivalent and maximum capillary

moisture capacity. Marbut published data on the particle size analyses (and a number of chemical analyses) on 65 soils from various areas of the Amazon Valley and related the properties to certain climatic and geologic situations.

12.2 Soil water: Some research has been done on almost all aspects of water relations in tropical soils. Soil moisture constants or soil moisture tension curves have been made on a wide variety of soils and related to certain physical characteristics of the soils. The moisture holding property of Trumao and Nadis soils in the province of Osorno, Chile were studied. Like in Hawaii, drying volcanic ash soils of Chile produced significant irreversible changes. The clay became irreversibly aggregated, the cation exchange capacity, the soluble phosphorus, soluble iron, and water adsorption capacities were reduced. Work at North Carolina State University with apparently dry volcanic ash soils from Mexico has shown that they lose 35% of their weight upon oven-drying at 105°C.

Studies of latosols, andosols, and alluvial soils from Costa Rica have shown that the differences in water retention were related to differences in texture, organic matter content, or compaction. Moisture constants were determined on 108 samples in northeast Brazil. Fifty-six of the samples were from the humid region and represented 14 profiles of latosolic, podsolic, and hydromorphis soils; 52 were from less humid and semi-arid regions and represented 14 profiles of podsolic, hydromorphic, regosolic, rego-latosolic, grumusolic, and alluvial soils. The 15-bar percentages highly correlated with values obtained using a physiological method.

Work has been done in Hawaii on the influence of soil structure on water retention and water movement in low humic latosols. As would be

expected, the water-holding capacity at low tensions was affected by the "Macro-fabric" and at the high tensions by the "Micro-fabric".

Some work has been done in Argentina, in Brazil, and in Puerto Rico on hydraulic conductivity as affected by several factors. In Argentina, hydraulic conductivity of certain soils was related to seasonal climatic changes and to the geological origin of the soils. In the state of Sao Paulo in Brazil, soils covered with "Cerrado" vegetation had essentially the same water-holding capacity and the same water availability as cultivated soils. In Puerto Rico, it was found that the hydraulic conductivity of subsoils in the Lajas Valley was very slow and this was attributed to the typography in the upper valley. Infiltration rates were studies on 57 main soil types in Puerto Rico with a total of 740 individual samples. Mean infiltration rates varied from .07 to 11.49 inches of water per hour in the various soils. When grouped according to the system of classification now used in the United States, mean values for vertisols ranged from .07 to 3.83 inches of water/hr. Higher values were found in mollisols, oxisols, and ultisols.

The higher rate of irrigation reduced crop yields in wet years (when the rain came following irrigation) due to excessive leaching of the fertilizers. There was a response to irrigation in Puerto Rico throughout the whole year with the exception of the growing period from November to December when Guinea grass was not affected by irrigation, and from January to February when Para grass did not respond. The average increase in total annual yields from irrigation was 8,804 lbs. of dry matter per acre. Studies in Mexico showed that cotton yields were increased from 2.82 to 4.65 tons per hectare by the use of 100 kilograms of nitrogen per hectare when optimum moisture was supplied, and from 2.71 to 3.91 tons per hectare at the

lowest moisture treatment. The percentage of fiber decreased when soil moisture stress increased regardless of fertilizer treatment. At Turrialba, Costa Rica, studies were made of the use of soil water by a grass association and a forest stand. Moisture changes in the 0 to 18 inch depth were very similar during wet seasons but the grass removed more water then the forest during dry seasons. The difference was attributed to the higher water-holding capacity of the soil under the grass and to difference in root distribution with the grass using more of the water in the 0 to 18 inch depth.

Studies have been made on the consumption of water by sugarcane in Catende, Brazil in relation to some geographic and ecological factors. Potential evapotranspiration and a water budget were calculated by Thornthwaite's method and there appeared to be a water deficit for sugarcane in the amount of approximately 500 mm per year. If calculations were based on 90% of the average monthly rainfall (apparently assuming 10% runoff) the deficit amounted to 700-800 mm per year. Other work on the consumption of water has been done by the Faculted Nacional de Agronomia de Palmira with the purpose of determining the consumption of water and the consumption coefficient (K) for the Blaney and Criddle formula under local conditions. Other work has been done on water budgets for Copra on a coconut estate in Trinidad.

12.3 Soil structural properties: Studies in many areas of the tropics have related soil structure to root growth. In Malay rice paddies developed a hard structureless, impermeable zone which forms a very effective barrier to root development immediately below the cultivated layer. The layer below the hard zone is usually relatively dry. Soils not cultivated such as rice paddies do not develop this hard layer. Work at Turrialba

has shown that a knowledge of the bulk density of topsoils is very important in determining the best use of the soil under field conditions and for interpreting soil chemical analysis from a weight to an area basis. Other work has shown that sugarcane root growth was more closely correlated with penetrometer measurements of soil strength than with determinations of either bulk density or air porosity. Critical values of bulk density for root growth varied with different types of soils.

Work on the Maracay soil seried in Venezuela has shown that phosphorus increased the degreee of aggregation, increased the water-holding capacity, decreased the modulus of rupture and the viscosity of the clay suspensions. All of these changes improved the soil for plant growth. These results are similar to those obtained with an Ultisol in North Carolina. Other studies in Venezuela have shown that many of the Savanna soils have a hard layer of gravel and conglomerates at various depths. This layer serves as a mechanical barrier to root penetration and apparently has been one of the principal factors in causing the Savanna type vegetation. In some areas where the mechanical barrier is deep, trees do develop unless the young seedlings are destroyed periodically by fire.

Work in the Ivory Coast has led to the development of an index of structure and of drainage for tropical soils. The index of structure is a function of the aggregate stability, the percentage of large pores and the amount of available water. The index of drainage is a function of the percentage of large pores and the hydraulic conductivity.

Studies on the aggregation of two soils of Puerto Rico have shown the organic matter was the principal cementing agent between clay particles. The organic matter content of these well drained upland soils was as high as that usually found in temperate zones.

Work with volcanic ash soils has shown that they are lower in bulk density and have a greater total porosity and hydraulic conductivity than non-volcanic ash soils. Because of these characteristics they are easily leached under heavy rainfall.

Limited research has been done relating bulk density, soil moisture-tension curves, and certain other physical properties to soil aeration and plant growth, and on the effects of prolonged poor drainage on certain physical and microbiological properties of soils.

13. Economics of Fertilizer Use - R. K. Perrin

The problems which have been encountered in deriving fertilizer recommendations from fertilizer test results can be divided into two categories: Theories of soil-plant relationships and tests of these theories; and economic theories of the behavior of farmers with respect to profits and risks.

An unresolved problem in the theory of plant response to fertilizer is the choice of an algebraic function to represent plant response. One line of thought, following that of Liebig, is that the plant responds in a linear fashion until some critical level of the nutrient is applied beyond which no further response (positive or negative) occurs. A second theoretical proposition is that the plant responds in curvilinear fashion — initial response of the plant to a dose of nutrient may be quite high, but as additional doses of nutrient are applied responses become smaller and smaller, perhaps even becoming negative at high rates of application. With respect to plant response to applied nutrients, there seems to be a consensus that the curvilinear response is appropriate. Beyond this, however, there is considerable debate as to the appropriate algebraic function

which can best approximate the true response. There are no statistical tests which can be reliably used to choose between two algebraic specifications. On the other hand, it does seem clear that there is no single algebraic specification which is appropriate for all nutrients on all soils. Since the quadratic response function is particularly amenable to economic analysis, and since many researchers have deemed it an acceptable approximation, it appears to be a good first choice provided some check is made later to ascertain the conformity of the fitted equation and the data.

A second physiological problem encountered is the relationship between applied nutrients and soil nutrients. Much less attention has been given to this question than to that of response to applied nutrients alone. The most frequent assumption has been that a pound of applied nutrient is equal to some fraction of a pound of soil nutrient. After estimating the appropriate conversion factor, it was assumed that applied nutrient and soil nutrient could be treated as a single factor in plant response. The results from this type of research have not been very consistent in that estimated conversion factors vary from nutrient to nutrient and from soil to soil. Since the procedures for estimating this factor are rather cumbersome, a second approach has been to consider applied and soil nutrients as completely separate factors of production, allowing for an interaction between them. For purposes of economic analysis, the latter approach is adequate since it allows the shape of the response to applied nutrient to change depending upon the level of soil nutrient. Both agronomists and economists using the latter method have found it to be a useful approach. Finally, few researchers have seriously considered the problem of

experimental design in estimating soil-applied nutrient relationships. This problem arises because it is necessary to include a wide range of soils in the experiment in order to realize a range in soil nutrient "treatments".

Quite apart from the problems of statistically and biologically determining response to applied and soil nutrients, economists have encountered conceptual difficulties in deriving recommendations for farmer clients. Profit-maximizing levels of fertilizer are easily determined from most response functions, but this over-simplified approach ignores the uncertainty associated with the statistical estimates, as well as the effects of fertilization of the overall riskiness of the crop enterprise In addition to quantifing the extent of such uncertainties and risks, the economist is faced with the problem of recommending an appropriate balance between average profits and risks. Some attempts have been made to measure farmers' aversion to risk, but common sense tells us that risk aversion will vary from person to person depending upon tastes and wealth. While it is clear that a farmer would not likely want to maximize "expected" profits if there is considerable risk as to the level of profits which will be realized, it is not clear what combination of profit and risk he <u>would</u> desire. At present, it appears that the best approach is to attempt to quantify the risk and uncertainty and to make an intuitive recommendation based on such considerations as the risk-profit tradeoff at various levels of fertilization and the probability of negative profit at various levels of fertilization.

14. Summary of Research Needs - P. A. Sanchez

The most widely known soil-plant relations in tropical Latin America are those of plantation or export crops such as bananas, coffee and sugar. Research on basic food crops is more abundant in the highly populated alluvial soils near major cities, although in many cases adequate information is lacking. Of the major carbohydrate food crops consumed in tropical Latin America (cassava, corn, rice, wheat, potatoes and sweet potatoes), soils information on cassava, the one consumed in largest quantities, is almost nonexistent. The vast areas of savannas and forests and the volcanic ash upland areas are the main limitations preventing realization of the full food and fiber production potential of soils of tropical Latin America. Specifically, the following problems have to be attacked in all three areas:

1. Characterization of the soluble nitrogen and water movement in the soil and landscape during wet and dry seasons as a means for devising more efficient nitrogen management systems.

2. Characterization of phosphorus fixation and release patterns and the economically optimum fertilization practices needed for major food crops.

3. Use of lime to neutralize exchangeable aluminum and thereby permit more efficient utilization of soil and fertilizer nutrients.

4. Obtain information about specific secondary and micronutrient needs with emphasis on sulfur, zinc, and boron.

5. Help devise economically sound cropping, fertilization, and management schemes for the highly leached savanna soils presently not used or in pasture.

6. Help devise economically sound cropping, fertilization, and management schemes to partially or totally counteract the fertility decline of cleared soils presently under shifting cultivation.

7. Instead of compiling additional survey data, the proposed fertility capability classification system should be thoroughly evaluated.

8. Characterization should be made of climatic parameters, such as rainfall, temperature and solar radiation. Compilation should be made of past records and at the same time additional data should be collected in order that these parameters can be correlated with crop growth.

IV. FERTILITY CAPABILITY CLASSIFICATION

S. W. Buol

1. Rationale

Reviews of literature on soil conditions in tropical areas have emphasized the following points: (1) Soil survey programs usually consist of a soil mapping program with adequate laboratory characterization for "routine" chemical characterization; (2) Many taxonomic schemes are used to name the map units; (3) There is a great deal of emphasis on economic interpretation of areas based on numerous criteria but all relying heavily upon the judgement of the person making the survey. Further examination of each of these points reveals that: (1) The laboratory data, although done by various techniques which cause interpretation difficulty, can be used to inform the researcher and soil tester of expected problems in an area. Often more sophisticated data, especially of mineralogy, is lacking. Further, the data is usually in obscure files and reports not readily available to fertility workers. (2) The multitude of naming systems is very difficult to interpret. Many units are not quantitatively constructed thus retrieval information is at best only qualitative. Also, any attempt to group soils at higher levels of a taxonomic system have been done in accordance with prevailing theories of soil genesis. Usually these do not consider the adaptability of the soil for plant growth but rather stress minor differences in color. (3) The type of interpretation that is used is usually defined in terms of expected, or observed, difficulty in producing a crop on the soil in question. As such the reasons for the degree of difficulty are often rather obscure and soils with quite different limitations are grouped together mainly on the

estimated cost of overcoming the limitation.

It is therefore, concluded that a great deal of valuable information exists in already completed soil surveys and inventories that is of value to the soil fertility research program but that this information has not, and is not, being utilized because it is fragmented into taxonomic groupings that are too numerous for consumption and according to criteria that is not directly meaningful to fertility practices needed in growing plants. The situation is further aggravated because soil survey and fertility research personnel are oftentimes separated by location, time or administrative boundaries.

2. Proposed System

The following course of action has been initiated as an attempt to alleviate the aforementioned problems. A format has been proposed (Table 1) to serve as a technical classification of the soil characteristics that bear a direct role of interaction with soil fertility management practices. Management practices as seen here are not only those practices of fertilizer formulation but also include the interpretation or calibration of soil test results which serve as the basis for fertilizer recommendations. The goal is to define a reasonable number of soil groups, within which the same or similar soil test correlations and fertilizer application practices can be made. It is assumed that the environmental parameters that control soil test interpretation and fertilization reactions are, in the main, characteristics of the soil that can be measured and are thus incorporated in soil characterization studies that accompany good soil survey investigations. Thus the results of soil fertility studies can be

Table 1: Fertility Capability Classification[1/]

Class	
LH	Loamy soils with CEC > 5 meq/100 gm of soil
LL	Loamy soils with CEC < 5 meq/100 gm of soil
CH	Clayey soils with CEC > 5 meq/100 gm of soil
CL	Clayey soils with CEC < 5 meq/100 gm of soil
SH	Sandy soils with CEC > 5 meq/100 gm of soil
SL	Sandy soils with CEC < 5 meq/100 gm of soil
O	Soils with more than 30% O.M. to a depth of 50 cm

Subclass	
a:	> 60% of CEC occupied by Al: (connotes severe Al toxicity and Al-P fixation)
h:	10-60% of CEC occupied by Al: (connotes Al-P fixation and Al toxicity in some crops)
x:	X-ray amorphous (allophane) > 25% of the less than 2 μ fraction (connotes amorphous P fixation problems)
i:	Free iron oxide content to clay ratio > 0.2 in some layer within 50 cm of surface (connotes Fe-P fixation)
Ca:	Free $CaCO_3$ within 50 cm (connotes Ca-P fixation)

[1/] CEC determined with neutral salt.
Loamy is less than 35% clay but not loamy sand or sand.
Clayey is more than 35% clay.
Sand is loamy sand or sand.
Texture class is the 20 to 100 cm average texture.
CEC is in top 20 cm.

Table 1: (Continued)

Subclass	
k:	Mica plus K - feldspar content > 10% of silt and < 100 μ sand or > 10% illite in the clay (connotes more than expected K release under humid tropical conditions).
n:	Na + > 15% of CEC in some layer within 1 m of surface (connotes sodium problems).
s:	Saturated extract conductivity > 4 mmhos/cm at 25°C in some layer within 1 meter of surface (connotes salt problems).
g:	Gley (≤ 2 chroma colors) or saturated with H_2O > 6 months a year within 60 cm of the surface (connotes poor internal drainage or high water table).
d:	Soils dry (water storage to 1 m exhausted) > 60 consecutive days a year (connotes an annual dry season).

extrapolated via existing soil surveys or in a general way by reasonable soil genesis theory to areas where detailed characterization studies with fertility trials have not been carried out.

The following reasoning has been applied in the formulation of the groups in Table 1. The next step is testing the groups for homogeneity with respect to the goal of producing groups with possessing homogeneous soil fertility related problems and management solutions.

3. Class Criteria

Texture: Three groups are formed based on the average particle size distribution in the 20 to 100 cm layer. Primary consideration is given to this depth as it is seen to control the rooting depth and movement of soil solutions. Loamy sand and sand classes (by USDA textural triangle) are called sandy (S). Those soils with more than 35 percent clay are called clayey (C) and the name loamy (L) is used for intermediate textures. Organic soils (O) are those containing more than 30% O.M. to a depth of 50 cm.

With only a few exceptions we find most soils have a coarser textured plow layer (0-20 cm) than the specified layer and by making textural groupings at these depths it is hoped we are using criteria that are not easily modified by management but that exert profound influence on fertilizer movement and root development.

CEC: Each of the textural classes, except organic soils, is further divided into high (H) and low (L) CEC groups. This measurement is based on the plow layer (top 20 cm). This measurement, made by neutral unbuffered salt extraction, should identify the soils with respect to its ability to interact with cations. It should also stratify to a

degree high O.M. contents and/or high charge clays in the plow layer.

4. Subclass Criteria

After placement of all soils into the created major classes, each soil is examined for particular characteristics that will be expected to possess an interaction with one or more of the fertility elements and/or the soil test interpretation for that element.

If none of the specified conditions exist the soil would only carry the major class designations:

a: This subclass indicates an aluminum toxicity soil condition for all known crop plants. For definition, a content of > 60% of the CEC occupied by Al in some horizon within 50 cm of the surface.

h: Acid soil conditions with from 10 to 60% of the CEC occupied by Al in some layer in the top 50 cm. This condition would indicate toxicity to some crops (soybeans, cotton) and also require additional lime and phosphate management techniques.

x: Soils with more than 25% of their clay fraction composed of x-amorphous (allophane) material. Much uncertainty exists on this limit but the attempt is to group those soils, usually of volcanic ash origin, because of their P fixation potential and high variable charge exchange complex.

i: Those soils with free iron oxide to clay ratio in excess of 0.2 in some layer within 50 cm of the surface. These soils can expect to have distinctive Fe-P fixation problems.

Ca: Soils with free $CaCO_3$ within 50 cm of the surface. This condition indicates Ca-P fixations.

k: Soils where illite constitutes more than 10% of the clay fraction and/or the mica plus the K-feldspar content is > 10% of the silt and sand fraction in some layer within 1 meter of the surface. Whereas this would be the usual situation in many arid and semi-arid conditions as well as in many Fluvents (Alluvial soils) it is considered an unusual condition for Ultisols and not possible for Oxisols. From N.C. experience it appears that different K fertility requirement interpretations need to be made of soil test results when this content of K bearing minerals are present.

n: Those soils with a sodium content greater than 15% of the CEC in some layer within 1 m of the surface.

s: Soils with a saturated extract conductivity > 4 mmhos/cm at 25°C in some layer within 1 m of the surface.

g: Gley (≤ 2 soil color chromes) and/or saturated with water for more than 6 months within 60 cm of the surface. This indicates a condition that needs maintenance of artificial drainage for most crops and may be a factor in the nitrogen picture.

d: Soils that are dry to 1 m for more than 60 consecutive days in most years. This condition is expected to have an influence on season of the year during which samples are taken for soil test as well as other management practices.

This scheme has been developed to make it possible to include almost all the soils known. At the present time, it appears that only a limited number of the possible groups will be represented in significant areal extent to warrant intensive research. The groups formed by these criteria will need to be tested by use of existing data to determine the degree of homogeneity attained from the standpoint of technical problems. At the same time, the groups will need to be tested to determine the homogeneity they create in analysis of economic parameters. It is hoped that by creating such groups of soil characteristics, that is environmental parameters exerting direct influence on fertility response, we will have created a base upon which to build valid management models.

V. SUMMARY OF RESEARCH RESULTS

1. Economics of potato fertilizer response in Peru - R. K. Perrin and J. E. Ryan

Economic analysis has been concentrated on an excellent set of data on potato response in the mountains of Peru. Since these experiments were conducted over a wide variety of sites and years they were very useful in estimating the effect of soil nutrient levels on fertilizer response. Measured soil characteristics were: soil phosphorous, potassium, organic matter, and pH. Preliminary results indicate little or no correlation between organic matter and potato response to applied nutrients, but very high correlations between potato response and soil phosphorous, potassium and pH. These results indicate that the level of nutrients in the soil can change the profit-maximizing level of application by as much as 120 kg P_2O_5/ha and 92 kg K_2O/ha. From a sample of soil test values, it was estimated that on the average, farmers would earn about S/.1600 per hectare ($15 per acre) more if they based applications on soil tests rather than a general recommendation for all potato farmers. At the present time, however, very little fertilizer is applied at all.

Using the procedures developed for potato yield analysis, simple calculations can be made in a soil testing laboratory to derive fertilizer recommendations appropriate to the level of soil test values for a particular sample. Preliminary analysis of risk and uncertainty effects indicated that for most farmers, applications at a rate of about 80 to 85 percent of profit-maximizing levels would provide adequate risk adjustments.

2. Soils of the upper Amazon Basin - P. A. Sanchez and S. W. Buol

Six representative soil profiles near Yurimaguas in the Peruvian Amazon Jungle were characterized with the purpose of obtaining basic data to estimate their productivity potential. The well drained Yurimaguas and Shanusi soils are Typic Paleudults while the three poorly drained Pucallpa profiles were classified as Aquic Paleudalfs, Typic Tropaquepts and Typic Tropaqualfs, respectively. The Paleudults were predominantly kaolinitic but presented small quantities of montmorillonitic or of mixed mineralogy. The fertility status of the Paleudults, although low, is not as extreme a situation as found in other areas. The aquic soils have a fairly high base status. These soils are apparently representative of large areas in the humic tropics under forest and shifting cultivation, which were previously considered as Latosols.

3. Soils of the Llanos Orientales of Colombia - R. Guerrero and S. W. Buol

Seven soil profiles of the Llanos Orientales (Eastern Plains) of Colombia, near Orocue and south of the Meta River, were selected to study their composition and classification. Additional samples of alluvial materials were taken within the same area to establish the mineralogical influence of wind-blown materials brought south of the Meta River by strong northeastern-trade winds.

The area studied is representative of the tropical, treeless, non-flooded, savannas of Colombia. They are located approximately 4°50' north latitude and have an annual average temperature of 28°C and annually receive 1.734 mm of rainfall. The parent materials for all soils were mixed alluvial acid sediments.

Within the soil profiles, clay content increased with depth, particularly the finer clay fraction (< .2μ), but clay skins and argillic horizons were absent. Complete soil dispersion was possible only when the free iron was removed. Water-dispersible clay content decreased abruptly to less than 4 percent below the third horizon. Higher sand content in the soil profiles nearer the Meta River suggests greater influence of the wind blown sands, but mineralogical specie differences were not found to change with proximity to the river.

The soils are very acid, have a very low cation exchange capacity, very low base retention, low percent of base saturation, high amount of exchangeable aluminum, and relatively high contents of free iron oxides, and organic carbon. Surface layers are very low in available phosphorus and low in micronutrient content.

Kaolinite was the predominant clay mineral in the very fine and fine clay fractions of selected horizons Intergradient 2:1-2:2 clay minerals and pyrophyllite were present in most samples and minor amount of mica, feldspars and a "vermiculite-mica stratification" pattern were found in some subsoil samples. Quartz was predominant in the silt and sand fractions.

The chemical data and the absence of weatherable minerals in the upper horizons, but their presence in trace amounts in the bottom horizons, indicated advanced weathering of the soil solums. Depletion of bases and mineral transformation appear to be the main pedogenic processes. No relationship was found between water table level, soil color, free iron oxide content and plinthite-like formations.

According to the Comprehensive Soil Classification System - 7th Approximation, subsoil horizons meet the requirements for oxic horizons; therefore, the soils are classed as Oxisols although some intergrade to Ultic subgroups.

4. Soils of the Llanos Occidentales of Venzuela - R. Schargel and S. W. Buol

Physical, chemical, mineralogical and micromorphological studies were made of three soils from the Western Plains of Venezuela. These soils have formed a similar mixed alluvium parent material on elevated parts of floodplains, under similar dense forest vegetation, in tropical climates with marked dry season, and on groundsurfaces of different age, ranging from late Pleistocene to Recent.

The Fanfurria soil which formed on the youngest groundsurface showed a thin surface horizon of organic matter accumulation. The Porta soil, on the intermediate aged groundsurface, showed a thick dark surface horizon with the characteristics of a mollic epipedon and some iron oxide segregation. The large amount of litter from the forest vegetation together with the earthwork activity seemed responsible for the formation of the mollic epipedon. The Caño Raya Soil, on the oldest groundsurface, showed the development of an argillic horizon and considerable iron oxide segregation.

The clay mineralogy of these soils showed vermiculite, illite and kaolinite predominating in Porta and Fanfurria; and montmorillonite, kaolinite and illite in Caño Raya.

Fanfurria, Porta and Caño Raya were classified according to the 7th Approximation as Ustifluvent, Haplustoll and Haplustalf, respectively.

These works have not yet been published but the work of Moura should prove to be a valuable guide in the more fertile soils of the Cerrado and the work by Sanchez and Buol characterize major soils found in the upper Amazon basin of Peru and probably more extensive parts of the humid tropical area.

5. Soil characteristics and management effects in the Campo Cerrado of Brazil - W. Moura and S. W. Buol

Three Latosol Roxo (Eutrustox) soil profiles representing different management systems and lengths of cultivation were selected, described, and sampled in the Triangulo area of the state of Minas Gerais, Brazil.

In addition to chemical and physical characterization, micromorphological observations and field measurements of the infiltration were conducted. Results from such studies supported the hypothesis that the "hardpan" found in some cultivated fields is caused by the reduction in the total and non-capillary porosities upon the use of machinery in the cultivation practices. The solum thickness, high amounts of colloidal clay (particles less than 0.2μ in diameter), and large quantities of kaolinite and gibbsite in this size fraction of these soils indicates a high degree of weathering. The soils contained from 19.6 to 23.7% free iron oxide as determined by the sodium dithionite-citrate procedure. The soils could not be completely dispersed unless the free iron oxide was removed. Distribution of the water dispersible clay in the profiles indicated some clay translocation after the clearing of the forest.

Content of exchangeable bases and pH values were much higher than expected in highly weathered soils. Microscopic studies indicated that the semiconcentric characteristics of what appears to be free iron oxide in the fabric of the fine granular peds could be the explanation for this deviation from the expected trends of the chemical analysis.

A Latosol Roxo (Eutrustox) in the Trianguio area of Minas Gerais, Brazil, was selected, described, and sampled from 0-20-cm depth. The clay, ($< 2\mu$) was separated into water-dispersible and water-stable fractions. Parts of each fraction were further treated to remove "free" iron, X-amorphous material, and interlayers resulting in eight samples for analysis.

Total elemental analysis, X-ray diffractograms, thermograms, IR absorption spectra, surface area, and CEC values for the clay samples were obtained.

Air-dried soil was fractionated into three aggregate-sized fractions (2-0.5 mm, 0.5-0.25 mm, and < 0.25 mm). Portions of each fraction and of the whole sample had their microstructure mechanically altered. To evaluate the influence of the structure, basic cations and phosphorus were extracted by dilute acid solution in spearate procedures ("standard", variable shaking time, and leaching columns) using 1:10 soil-extractant solution ratio and phosphorus was also extracted by 0.025 $\underline{N}$ $(NH_4)_2SO_4$ to estimate the adsorbed P against increases in time of shaking.

In both natural and altered samples, phosphate reactions were studied using the aggregate fractions and the total sample both in their "natural" structural condition and after their structure was mechanically altered. The phosphorus sorption of the clay samples was also studied.

The mineralogy of both water-dispersible and water-stable clays (< 2μ) from this soil is dominated by kaolinite 41%, iron oxides 21-24%, X-amorphous 20-21.5%, gibbsite 13%, and 6% intergradation materials and 6.5% TiO_2. It is concluded that no mineralogical differentiation is caused by water dispersion, but it appears that the finest particles are preferentially dispersed by water. It is unclear why the water-dispersible "fine clay" is not observed in the subsoil as argillans.

Mechanical alteration of the microstructure causes an increase in acid-extractable Ca, Mg, and P and this difference could not be completely overcome by the modified extraction procedures used. The amounts of acid-extractable Ca, Mg, and P were found to be greater from small aggregates than from larger ones. Thus, reproducibility of the routine "standard" Brazilian procedure for this soil may be affected by sample preparation. It is suggested that either increasing the shaking time or the use of successive extractions will tend to increase reproducibility, the latter being easier and faster is recommended for further research. High base status is postulated to be the result of entrapment of bases within peds as percolating water wets the soil after the prolonged dry season. The intra-ped matrix is so fine that moisture leaves the peds primarily in the vapor phase and leaching within the ped is retarded. Smaller aggregates and crushed samples were found to have higher P sorption and higher availability of the sorbed P.

Free-Fe oxides are the major clay component responsible for P sorption by the clays. Some P was found to also be associated with Ca but no P was found to be associated with Al except in the occluded fraction.

The main reaction of this soil material with added P appears to be an adsorption reaction. It is suggested that there is a need for research on the availability of P using large initial applications of phosphate fertilizer.

6. Phosphorus fixation in Southeastern Mexico and the Colombian Llanos - C. Rivera and E. J. Kamprath

Determinations were made of the amount of phosphorus that had to be added to soils to give a concentration of 0.2 ppm of P in the soil solution for a group of tropical soils from southeastern Mexico, and a soil from the Llanos Orientales of Colombia and from the Piedmont of North Carolina. A concentration of 0.2 ppm P in the soil solution has been reported by a number of researchers as adequate for plant growth. To obtain 0.2 ppm P in the soil solution, 600 ppm of fertilizer P had to be added to acid volcanic ash soils, 395 ppm P to an oxisol from Colombia, 360 ppm to an ultisol from North Carolina, and 50 to 120 ppm P to volcanic ash soils at pH 7 or above.

The volcanic ash soils containing allophane adsorbed larger amounts of phosphorus and held it more strongly than acid soils containing kaolinite coated with iron oxides. Soils which contained primarily montmorillonite or degraded 14°A clays adsorbed relatively low amounts of phosphorus.

The 0.5 M $NaHCO_3$ extractant appeared to give a good measure of that portion of the adsorbed phosphate which was in equilibrium with the soil solution P and apparently controlled to a large degree the concentration of P in the soil solution.

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