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Agency for International Development

Contract AID/ccd 2490 Res.

Cornell University, Ithaca, New York

SOIL FERTILITY REQUIREMENTS TO ATTAIN EFFICIENT PRODUCTION OF FOOD CROPS ON THE EXTENSIVE, DEEP, WELL-DRAINED BUT RELATIVELY INFERTILE ACID SOILS OF THE HUMID TROPICS

Annual Summary Progress Report

for the period

July 1, 1969 to June 30, 1970

to the

Agency for International Development

Contract AID/csd 2490

Cornell University, Ithaca, New York

Soil Fertility Requirements to Attain Efficient Production of Food Crops on the Extensive, Deep, Well-Drained but Relatively Infertile Acid Soils of the Humid Tropics.

Summary of First Progress Report for the period July 1, 1969 to June 30, 1970 Contract A.I.D./csd 2490 Cornell University, Ithaca, New York.

The objective of this research project is to determine the soil fertility and management requirements of the deep, well-drained, infertile acid soils of the humid tropics to help realize their high productivity potential for food crops. According to the best available estimates, there are about two billion acres of these soils in the tropics (mostly Oxisols and Ultisols) which are potentially arable yet mostly uncultivated. Much of the land has favorable topography, and the soils are generally deep and permeable with good drainage and favorable structure. One of the main factors limiting the productivity of these soils is their low fertility level. With the increasing availability of high yielding varieties of various crops which can approach their potential only under intensive fertilization and good management practices, the low natural fertility of the acid soils of the humid tropics is now a much more crucial limitation than heretofore. Research by various investigators on these kinds of soils indicates that they can be very responsive to fertilizers and lime in combination with appropriate management practices.

Puerto Rico is being used as a base for the field research. Supplementary laboratory and greenhouse studies are being conducted both in Puerto Rico and at Corenll University. Puerto Rico has a tropical environment and a range of soils broadly representative of the extensive areas of the humid tropics including the deep, well-drained, but relatively infertile acid soils. It is easily accessible from the United States and the close political relationship with the United States provides assurance of continuity in a long term research project and there is no balance of payments problem. Excellent research facilities are available at the agricultural experiment station, which has one of the most complete libraries on Tropical Agriculture. Officials of the University of Puerto Rico are providing full cooperation and collaboration of personnel and facilities in the implementation of the project.

The initial field experimental work in Puerto Rico is focused on three priority areas: (1) Nitrogen requirements and efficiency of nitrogen utilization by important food crops; (2) soil acidity and liming; and (3) phosphorus requirements including interactions of phosphorus and lime and evaluation of the residual effects of phosphorus.

<u>Nitrogen Experiments</u> - After considerable field checking supplemented by laboratory tests, four sites were selected for the nitrogen experiments, each with a different soil characterized by properties representative of extensive areas of acid soils in the humid tropics. After land preparation, corn was planted in April and May, 1970 at the four locations and the differential nitrogen treatments applied. Field observations in July after two months of growth show distinct differences in response to nitrogen treatments at the different sites. These appear to be related both to the kind of soil and the previous use and management of the fields. Soil analyses indicate that substantial amounts of nitrogen are leached below the root zone when nitrogen is broadcast before planting in contrast to that banded after planting.

Liming Experiments - Two sites have been selected for the field experiments which are now under way to determine the lime response at different acidity and soluble aluminum levels while maintaining other factors at or near optimum levels. Meanwhile, a series of chemical and root growth experiments are being conducted on soil samples from the experimental sites in Puerto Rico and related acid soils which occur extensively in the Llanos of Colombia. Displaced soil solutions are being analyzed to determine the quantitative relationship between aluminum in solution and the pH of the soil and how this relates to root growth. The evidence to date indicates that the exchangeable ions and concentrations of ions in the soil solutions and the behavior of the soils when limed will be very similar and probably for practical purposes, the same functional relationship can be used for the soils from the Llanos and those from Puerto Rico. These studies will serve as a basis for predicting crop responses to lime from relatively simple soil tests for the acid soils of the humid tropics.

Phosphorus Experiments - Two sites have been selected after considerable field checking and laboratory and greenhouse assays and field experiments will be initiated in the coming months.

Clay Mineralogy Studies - Preliminary investigations have begun on making quantitative determinations of the clay mineral composition of the soils from the field experimental sites. The objective of these studies is to help explain observed soil fertility reactions in the field, thus permitting a sounder extension of the experimental results to similar soils in other areas of the humid tropics. As soils of the humid tropics are characterized by their high content of iron and aluminum oxides, their structure (crystalline and amorphorus) will be examined by instrumental and chemical analysis. These studies should provide a basis for interpreting the availability and retention of phosphate and other nutrient cations and anions.

Correlation of Soils of Puerto Rico with Soils of South America - An objective of the project is to extend the ongoing research in Puerto Rico to other areas in the humid tropics with similar soils of wide extent and high potential productivity. The location of suitable sites in Latin America was given first priority and preliminary studies have been undertaken to identify more precisely the extensive soil areas in South America which are counterparts to the experimental sites in Puerto Rico. Available maps and reports are being collected to provide information on the most promising experimental soil sites in South America which are representative of extensive areas and at the same time, are closely related to the soils of Puerto Rico.

Coordination with other Related A.I.D. Projects - Prior to the initiation of this project, a planning conference was held with representatives of institutions involved in soils research projects in the tropics sponsored by A.I.D. This conference provided an opportunity to exchange information and ideas and facilitate coordination of the tropical soils research programs of the different institutions. It is planned to hold such conferences periodically.

INTRODUCTION

The objective of this research project is to determine the soil fertility and management requirements of the deep, well-drained, infertile acid soils of the humid tropics to help realize their high productivity potential for food crops. According to the best available estimates, there are 1.5 billion acres of these soils in the tropics (mostly Oxisols and Ultisols) which are potentially arable yet mostly uncultivated. Much of this land has favorable topography, and the soils are generally deep and permeable with good drainage and favorable structure.

One of the main factors limiting the productivity of these soils is their low fertility level. With the increasing availability of high yielding varieties of various crops which can approach their potential only under intensive fertilization and good management practices, the low natural fertility of the acid soils of the humid tropics is now a much more crucial limitation than heretofore. Research by various investigators on these kinds of soils indicates that they can be very responsive to fertilizers and lime in combination with appropriate management practices. The evidence indicates that high productivity can be achieved in many areas at relatively low cost. To achieve this potential, however, it is necessary to determine the most effective and economic amounts and methods of application of nitrogen, phosphorus, potassium, liming materials, and micronutrients in relation to cropping systems and management practices.

The project is designed to have application over extensive areas in Latin America, Africa, and Asia and complementary studies will be carried out in the other tropical countries as feasible. Puerto Rico is being used as a base for the research. It has a tropical environment and a range of soils broadly representative of extensive areas of the humid tropics including the deep, well-

drained, but relatively infertile acid soils. It is easily accessible from the United States and the close political relationship with the United States provides assurance of continuity in a long term research project and there is no balance of payments problem. Excellent research facilities are available at the agricultural experiment station, which has one of the most complete libraries on Tropical Agriculture. The Puerto Rico Agricultural Experiment Station has carried out a substantial amount of research and in cooperation with soil and plant scientists of the U.S. Department of Agriculture has provided valuable information and data which are related to the objectives of the project. Officials of the University of Puerto Rico are providing full cooperation and collaboration of personnel and facilities in the implementation of the project.

PROCEDURE

1. The contract for this research project became effective on June 30, 1969 and in accordance with its terms, a planning conference was held in September, 1969 at Raleigh, North Carolina with representatives of U. S. institutions involved in soil fertility/soil management problems in the humid tropics of Latin America. The following institutions were represented: North Carolina State University; University of Puerto Rico; Tennessee Valley Authority; U.S. Department of Agriculture; University of Florida; Utah State University; International Maize and Wheat Improvement Center (CIMMYT); Agency for International Development, and Cornell University.

At this conference, the representatives of the institutions outlined the soil fertility work which they were conducting and planning to do in Latin America. This provided an opportunity to exchange information and ideas and facilitate coordination of the tropical soil fertility programs of the different

institutions. An outline of the initial experiments proposed by Cornell University for starting the work in Puerto Rico was presented and discussed. There was general agreement among the soil scientists present that the research proposed was of high priority and would supplement the ongoing work in soil fertility of the other institutions.

As a result of the discussions and suggestions made at the Raleigh conference, plans for the initial field experiments were developed and submitted in October for written concurrence to the AID Office of War on Hunger/Agriculture and Rural Development Service. Following exchanges of correspondence and subsequent conferences with AID officials, written concurrence was received in mid-December, 1969 to initiate the field work in Puerto Rico.

The initial experimental work in Puerto Rico was to focus on three priority areas:

(1) Nitrogen requirements and efficiency of nitrogen utilization by important food crops;

(2) Soil acidity and liming; and

(3) Phosphorus requirements including interactions of phosphorus and lime and evaluation of the residual effects of phosphorus.

2. Meanwhile, recruitment of staff, ordering of equipment and supplies, preliminary selection of field experimental sites and laboratory and greenhouse studies proceeded. Tentative selections of soils were made in which there was reasonable assurance of extensive areas of their counterparts in the humid tropics of Latin America, Africa, and Asia. Advice and counsel of soil scientists with experience in the tropics were obtained in making the selections. The Tropical Soils Workshop held in Puerto Rico in August, 1969 sponsored by the U.S.D.A.

Soil Conservation Service provided an opportunity to discuss possible site selections with soil scientists knowledgeable about soils of the tropics.

3. Following approval by AID in December, 1969 to proceed with the field work in Puerto Rico, final selection was made of the most suitable experimental sites for the nitrogen experiments. After considerable field checking supplemented by laboratory tests, four sites were selected, each with a different soil characterized by properties representative of extensive areas of acid soils in the humid tropics.

4. After land preparation, corn was planted in the latter part of April and in May, 1970 at the four locations and the differential nitrogen treatments applied. Soil samples for analysis were collected before treatment and are being collected periodically during the growing period.

EXPERIMENTAL

1. Nitrogen Experiments

The objectives of the nitrogen experiments are primarily to:

(a) devise procedures for applying nitrogen to non-leguminous row crops to insure a reasonable recovery of fertilizer nitrogen, and

(b) to obtain enough subsidiary data which will give some insight into the relative importance of leaching and denitrification in nitrogen loss and conditions under which the two mechanisms are of most significance.

The following table gives the treatments for corn used at the four soil sites representing distinctly different conditions:

Treatment No.	Pounds per acre of nitrogen applied as urea: Preplant (Broadcast)	At Planting	Post Plant (In rows)
1	0	10	0
2	30	10	0
3	60	10	0
4	120	10	0
5	0	10	30
6	0	10	60
7	0	10	120
8	60*	10	0

* Sulfur coated urea supplied by TVA

Five replications are used in a randomized block design. The plots are 30 feet long and 15 feet wide. Each plot has six rows 30 inches apart, and the density of planting is about 17,000 plants per acre.

The four soils used in these experiments and their classification under the new USDA Comprehensive System of Soil Classification are:

1. Catalina - Oxisol (Typic Haplorthox, clayey, oxidic isohyperthermic);
2. Humatas - Ultisol (Typic Tropohumult, clayey, kaolinitic, isohyperthermic);
3. Piñas - Oxisol (Psammentic Haplorthox, sandy, isohyperthermic); and
4. Coto - Oxisol (Tropeptic Haplorthox, clayey, kaolinitic, isohyperthermic).

Field observations of the field experiments in July after two months of growth show distinct differences in response to nitrogen treatments at the different sites. These appear to be related both to the kind of soil and the previous use and management of the fields. The following table gives the mineral nitrogen content of the soils before treatments were applied:

Nitrogen Content of the Soils Before Treatment

Soil	Depth inches	Nitrogen Content in Parts Per Million NH_4+	NO_2-	NO_3-	Total
Catalina	0 - 8	4.8	0	60.4	65.2
	8 -20	4.3	0	25.3	29.6
	20-30	2.6	0	18.1	20.7
Humatas	0 - 8	4.0	trace	30.9	34.9
	8 -20	4.5	0	17.3	21.8
	20-30	4.6	0	8.5	15.1
Piñas	0 - 8	1.0	0	26.5	27.5
	8 -20	0.2	0	12.8	13.0
	20-30	0.8	0	9.3	10.1
Coto	0 - 8	3.6	0.3	8.6	12.5
	8 -20	3.6	0.3	8.0	11.9
	20-30	3.7	0.2	5.9	9.8

On the basis of these analyses, one might not expect much response to nitrogen applications to the Catalina soil because of the high initial nitrate content, but responses could be expected in the case of the other three soils provided factors other than nitrogen were not limiting. Field observations seem to confirm this, but any definite conclusions will have to await the quantitative yield data.

Analysis has been completed for mineral nitrogen in the soils from two locations one month after the application of broadcast preplant nitrogen fertilizer. The data from the experiment on Humatas soil are given in the following table:

Mineral Nitrogen in Humatas Soil One Month After Broadcast Preplant N Applications

N Applied lbs. per acre.	Soil Depth inches	Mineral N in the Soil (Parts Per Million) NH_4+	NO_3-	Total
None	0 - 8	0	18.8	18.8
	8 -20	0	24.3	24.3
	20-30	0	18.6	18.6
30	0 - 8	2.1	19.0	21.1
	8 -20	4.4	23.1	27.5
	20-30	4.1	15.8	19.9
60	0 - 8	5.2	17.7	22.9
	8 -20	2.0	24.2	26.2
	20-30	3.3	16.8	20.1
60 (sulfur coated urea)	0 - 8	4.3	22.0	26.3
	8 -20	3.0	16.6	19.6
	20-30	2.0	17.3	19.3

The data show that one month after nitrogen was applied broadcast just before planting, there was essentially no difference in the amount of mineral nitrogen in the soil regardless of treatment. The check plots had about as much nitrogen as those receiving the 120 pounds of nitrogen per acre. In the field all of the corn receiving preplant treatments are much paler green than those treated after planting. Apparently, much of the nitrogen has leached below the root zone.

It is of interest to note that in the field the sulfur coated urea treatment behaved essentially as the regular urea treatment though no determinations were made of the amount of urea not hydrolyzed. In earlier laboratory studies with the Humatas soil, it was found that all of the regular urea was mineralized within two weeks while sulfur coated took eight weeks for 80 percent of it to be mineralized. In the laboratory work, the urea fertilizer was applied at the rate

of 300 parts per million of N to a 500 gram sample and the soil cultures incubated at field moisture capacity at 24°C.

2. Phosphorus and Liming Experiments

(1) Phosphorus - After considerable field checking and laboratory and greenhouse assays, two sites have been selected in which the soils show a definite response to phosphorus in a greenhouse assay. These are Humatas and Cialitos, one an Ultisol and the other an Oxisol. Field experiments will be initiated in these locations in the coming months.

It is of interest to note that in the greenhouse tests of these soils using beans as the test plant, the subsoils produced only about half the dry weight of plant material as the surface soils when complete fertilizers were applied, including micronutrients. This big difference between the response of surface and subsoils has been noted by other investigators and no conclusive explanation has been made. This suggests that further study be made of possible factors limiting growth on the subsoils in addition to nutrient and moisture supply.

(2) Liming - These experiments are being carried out in cooperation with the U.S.D.A. research team which has a number of ongoing studies in Puerto Rico involving the relationship between level of acidity and soil solution composition and plant root development. Most of this work in the past has been concerned with forage crops, tobacco, sugar cane and other non-food crops. The cooperative field, greenhouse, and laboratory studies involved in this project will focus primarily on food crops. Two sites have been selected for the field experiments which are now under way to determine the lime response at different pH and soluble aluminum levels while maintaining other factors at or near optimum.

Meanwhile, chemical and root growth experiments are being conducted on soil samples from the experimental sites. Displaced soil solutions are being analyzed to determine the quantitative relationship between aluminum and manganese in solution and the pH of the soil and how this relates to root growth.

3. Soil Chemical Studies and Root Growth

(1) A series of chemical and root growth studies were carried out at Cornell on soils from the experimental sites in Puerto Rico and related acid soils which occurs extensively in the Llanos of eastern Colombia. The objectives of these studies were to: (a) characterize the exchange capacity; (b) determine the relationship between ionic concentrations in the soil solution and exchangeable ions; (c) relate the activity of aluminum in the soil solution as a function of exchangeable aluminum and pH; (d) determine the relationship between aluminum and calcium in the soil solution and plant root growth.

The principle findings are as follows:

(a) In the pH range 4.0 to 4.8 the soil solution concentration of aluminum is satisfactorily estimated by the relationship $[Al]\ [OH]^3 = 10^{-33.8}$ which is the expected relationship for solutions in equilibrium with gibbsite. This relationship holds for five different soils from Puerto Rico and soil samples taken from several sites in the Llanos of Colombia.

(b) In the pH range above 4.8, the concentration of aluminum in solution is as much as one to two order of magnitude higher than is predicted by the relationship found for the samples with lower pH. This is also true when samples below pH 4.8 are treated with lime to adjust the pH to values above pH 4.8. Samples from both Puerto Rico and the Llanos behave in a similar manner.

(c) The relationship between the calcium and magnesium in solution and the calcium and magnesium on the exchange complex is apparently the same for five

different soils from Puerto Rico.

(d) The theoretical relationship between aluminum and calcium on the exchange complex and aluminum and calcium in solution has been found on five different Puerto Rico soils. Similar studies are being made on soil samples from the Llanos of Colombia.

(e) In general, the exchange capacity, the exchangeable aluminum, calcium, and magnesium and the pH of the Puerto Rican soils are higher than those from the Llanos. Despite these differences, the evidence to date indicates that the exchangeable ions and concentrations of ions in the soil solutions and the behavior of the soils when limed will be very similar and probably for practical purposes the same functional relationship can be used for the soils from the Llanos and those from Puerto Rico.

(f) A series of studies with one soil from the Llanos has defined the relationship between concentration of aluminum in the soil solution and corn root growth. This relationship can serve as the basis for liming experiments in the field.

(g) The studies summarized above serve as a basis for formulation of hypotheses for predicting crop responses to lime from relatively simple soil tests for the acid soils of the humid tropics.

4. Clay Mineralogy Studies

Preliminary investigations have begun on making quantitative determinations of the clay mineral composition of the soils from the field experimental sites. The objective of these studies is to help explain observed soil fertility reactions in the field thus permitting a sounder extension of the experimental results to similar soils in other areas of the humid tropics.

To date, the surface soils from three experimental sites (Humatas, Catalina, and Piña soils) have been analyzed for clay minerals by x-ray diffraction, differential thermal analysis and wet chemical analysis. The dominant silicate clay mineral in all three soils is a poorly crystalline kaolinite. The Humatas and Catalina contain vermiculite (up to 10 percent of the clay fraction) and the Humatas also contains about five percent montmorillonite. While the latter expansible clay minerals are present in relatively small amounts, their physical and chemical properties are such that they will make a definite contribution to the soil cation exchange capacity and surface area. In addition, the vermiculite component is active in potassium and NH_4^+ - nitrogen fixation and the latter may be significant in connection with the interpretation of the results of the nitrogen experiments.

Experiments are now being conducted to determine the pH dependent cation exchange capacity and the relationship between pH and potassium fixation. Further research will extend the characterization of the clay minerals of the soils on which the field experiments are being run. As the soils of the humid tropics are characterized by their high content of iron and aluminum oxides, their structure (crystalline and amorphorus) will be examined by instrumental and chemical analysis. These studies should provide a basis for interpreting the availability and retention of phosphate and other nutrient cations and anions.

5. Correlation of Soils of Puerto Rico with Soils of South America

An objective of the project is to extend the ongoing research in Puerto Rico to other areas in the humid tropics with similar soils of wide extend and high potential productivity. The location of suitable sites in Latin America was given first priority and preliminary studies have been undertaken to identify more precisely the extensive soil areas in South America which are counterparts

to the experimental sites in Puerto Rico.

The latest information available, both published and unpublished, has been obtained from the U.S. Department of Agriculture World Geography Unit and the FAO on the distribution of the major soil groups in tropical South America. It is roughly estimated that Oxisols and Ultisols combined occupy about two billion acres. These are the order categories in the new USDA Comprehensive System of Soil Classification of the deep, well drained acid soils of the humid tropics and subtropics and are the broad soil categories on which the research in Puerto Rico is concentrated. A breakdown into suborders and their estimated acreage distribution in the different countries is given in the following table:

Occurrence of Oxisols and Ultisols in South America

Country	Oxisols Suborders	Ultisols Suborders	Approx. Acreage Millions of acres
Brazil	Orthox	Udults	
	Ustox	Aquults	
		Ustults	
		Humults	1,600
Colombia	Orthox	Udults	130
Peru	Orthox	Aquults	130
Bolivia	Ustox	Aquults	
		Udults	110
Guyana } French Guiana } Surinam}	Orthox		80
Ecuador	Orthox	Ustults	30
Paraguay	-	Udults	25
Venezuela	Ustox	-	25
			2,130

A soil map of South America has been prepared which is a generalization of the 1:5,000,000 Soil Map of South America now being readied for publication by FAO. The correlation of the original mapping units with taxa of the USDA Comprehensive System has been provided by the USDA World Geography Unit. The map shows that the predominant suborder of the Oxisols in South America is Orthox which is a counterpart of the Oxisol experimental sites in Puerto Rico. There is insufficient information available at this time on the distribution of the lower classification soil categories of Orthox in South America, but it is safe to assume that extensive areas will be encountered of soils closely related to those in Puerto Rico.

Soil surveys are available for only about 13 percent of the area of South America, and these areas are mainly located in southern Brazil, Guyana, and Colombia. The rest of the FAO soil map of South America has been compiled from exploratory surveys and general information. For selection of experimental soil sites in South America which are representative of extensive areas and at the same time are closely related to the soils in Puerto Rico, it will be necessary to do a substantial amount of soil correlation work in areas of countries which offer the best possibilities. Once the general areas are identified which appear most promising based on available information, and institutions in a country are interested in collaboration on the project, all available soil maps and reports of the area will need to be obtained and the pertinent literature reviewed. The most likely experimental locations should be examined and site selections made after discussions with local soil scientists familiar with the area.