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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

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1972

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for the period

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Submitted to the

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16. Abstracts

In the humid tropics it is estimated that there are 1.5 billion acres of uncultivated land due to the infertile nature of the soil. Research conducted in these highly weathered and leached soils indicate that potential productivity can be achieved at a relatively low cost with the judicious use of fertilizers and lime in combination with good management practices. The soils are deep and well drained with good physical properties. The most effective and economic amounts and methods of application of nitrogen, phosphorous, potassium, liming materials, and micronutrients are examined. Nitrogen experiments indicate that a relatively high production level can be maintained with modest applications of fertilizer nitrogen. Post plant application in this respect is proven more effective than pre-

17. ~~Key Words and Document Analysis. 17a. Descriptors~~

plant. Phosphorous trials show that present methods for diagnosing the potential response to applied fertilizer phosphorous need to be refined. Soil acidity and liming process have a wide range in yield response on the highly acid soils to levels of lime applied depending on the kind of crop and the soil properties. Study of clay mineralogy indicate valuable information on the reactions of applied nutrients in the soil and their availability to plants. More emphasis is to be given to soil moisture studies in relation to the soil fertility research.

17b. Identifiers/Open-Ended Terms

*Soil fertility, *Soil acidity

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REPORT SUMMARY

A.

Project Title: 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. AID/csd - 2490

Principal Investigator: Matthew Drosdoff
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Contract Period: June 30, 1969 to June 30, 1974

Period Covered by Report: July 1, 1971 to June 30, 1972

Total A. I. D. funding June 30, 1969 to March 31, 1973: $ 851,846.00

Total expenditures and obligations, July 1, 1971 to June 30, 1972: $ 207,201.26

Total expenditures and obligations, July 1, 1972 to March 31, 1973: $ 252,846.00

Estimated expenditures, April 1, 1973 to March 31, 1974: $ 289,015.00

B. Narrative Summary of Accomplishments and Utilization

This is the third annual progress report of the research project to determine the most feasible soil fertility and soil management practices required to realize the high productivity potential of extensive areas of arable yet mostly uncultivated soils of the humid tropics. These soils are deep and well drained and have good physical properties but are presently unproductive or have low productivity because of plant nutrient deficiencies (nitrogen, phosphorus, calcium, zinc, etc.), aluminum or manganese toxicity, and other limiting factors related to soil fertility. It is estimated that there are over 1.5 billion acres of these soils in the humid tropics.

The project is designed to have application in Latin America, Africa, and Asia and the studies are being carried out in several tropical areas. Puerto Rico is used as an initial base for the research and additional field work has been started in Brazil.

Nitrogen Experiments: The last crop of corn was planted in April and May, 1972 at the four experimental locations in Puerto Rico on soils having characteristics similar to the related acid soils so extensive in the humid tropics (Oxisols and Ultisols). The main conclusions after four successive crops over a two-year period are: (1) continuous cropping of corn at relatively high productivity (100 bushels/acre) can be maintained on many of these soils with modest applications of fertilizer nitrogen (60 lb/acre); (2) postplant applications of nitrogen were generally much more effective than preplant; (3) crop residues are much more important in supplying nitrogen than has been previously thought;

(4) soil moisture deficiency resulting from dry periods during the rainy season substantially reduced productivity; (5) control of insects, diseases, and nematodes for high corn production in the humid tropics appears to be a greater problem than soil fertility management; high yielding corn varieties more resistant to plant pests are needed.

Soil Acidity and Liming: Field experiments have been conducted over the last two years with different levels of lime at five locations in Puerto Rico on highly acid representative soils. From the results of responses in the field to successive cropping with corn, green beans, and sweet potatoes supplemented by laboratory and greenhouse research, the main conclusions are: (1) there is a wide range in yield response on the highly acid soils (Oxisols and Ultisols) to levels of lime applied depending on the kind of crop and the soil properties other than pH; (2) on a clayey Oxisol, pH 4.7, addition of lime did not increase corn yields significantly but on a clayey Ultisol, at about the same initial pH, two tons of lime per acre doubled the yield but only increased the pH to 5.2; (3) two tons of lime applied to a clayey Ultisol at pH 4.2 resulted in a yield of over six tons per acre of green beans but only increased the pH to about 4.9; (4) the relatively high concentration of soluble and exchangeable aluminum is the main chemical factor limiting the productivity of the acid soils and it has been found that organic matter reduces aluminum toxicity as well as the addition of lime; (5) the kind and concentration of other ions in the soil solution were found to affect the toxicity of aluminum to different crops.

Phosphorus Experiments: Field trials supplemented by greenhouse and laboratory studies indicated: (1) in an experiment with corn on a clayey Ultisol no grain yield response was obtained to applications of phosphate even though greenhouse and chemical soil test indicated that there should be a response; there appeared to be a response in the field in the early stages of growth; (2) in another field experiment with corn in a different location on a severely phosphorus deficient clayey Ultisol as indicated by greenhouse and chemical soil tests, only a moderate grain yield response was obtained from applied phosphorus; in the early stages of growth there was a large response which gradually diminished; (3) residual phosphorus in the soil from previous applications over many years of cultivation may gradually become available during the growing season even though the commonly used chemical soil tests may indicate that the crop should respond; present methods for diagnosing the potential response to applied fertilizer phosphorus need to be refined for these conditions.

Soil Moisture Studies: Preliminary studies in Puerto Rico on infiltration, movement within the profile, storage, and availability of soil moisture have demonstrated the necessity for a more critical investigation of the soil moisture factor in relation to crop response to applied fertilizer and lime in the humid tropics.

Clay Mineralogy Studies: Studies on the characterization of the iron and aluminum oxides and distribution of positive and negative charges on the clay minerals, and scanning electron microscope examinations of clay size fractions have provided further insight on the reactions of applied nutrients in the soil and their availability to plants.

Utilization of Results: Reports on the data obtained during the past two years on various aspects of the project have been presented at five conferences and seminars. Advanced degree thesis research related to the project has been completed by five students, three of whom are from tropical countries. Three technical articles have been published or accepted for publication in technical journals and seven more have been submitted for publication.

ANNUAL RESEARCH REPORT

A. General Background

According to the best available estimates there are about 1.5 billion acres of the deep, well-drained infertile acid soils in the humid tropics (Ultisols and Oxisols) 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. Research by various investigators have indicated that these kinds of soils have a high potential productivity which can be achieved at a relatively low cost with the judicious use of fertilizers and lime in combination with good management practices. The development in recent years of high yielding and high quality adapted varieties of various food crops provide a greater incentive for making more intensive use of the extensive areas of the acid soils of the humid and subhumid tropics which now have a low level of productivity.

B. Project Objectives

The objective of this project is to determine the most effective and economic amounts and methods of application of nitrogen, phosphorus, potassium, liming materials, and micronutrients to help realize the productivity potential for food crops of the highly acid soils of the humid tropics. The project is designed to have application over extensive areas in Latin America, Africa, and Asia. Puerto Rico is being used as a base for the research because 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

also has an excellent library on Tropical Agriculture. Experiment Station personnel have carried out a substantial amount of research related to the project as have the scientists of the United States Department of Agriculture and they have provided valuable unpublished information and data for the project. Officials of the University of Puerto Rico have given excellent cooperation in providing personnel and facilities for the implementation of the project.

Though Puerto Rico is used as a base for the research project, an objective is to extend the research to on site locations on similar soils in other areas of the humid tropics which have a different climatic environment and some differences in the soil properties. In cooperation with the Brazilian Ministry of Agriculture and in collaboration with North Carolina State University, project supported research has been initiated at the Agricultural Experiment Station near Brasilia on soils representative of the hundreds of millions of acres of the acid soils of the Campo Cerrado.

C. Continued Relevance of Objectives

In the main the objectives as stated in the contract are still relevant. One modification suggested based on the project research in the past two years is that more emphasis needs to be given to soil moisture studies in relation to the soil fertility research. It has been assumed that in the humid tropics especially during the rainy season, soil moisture would not be much of a limiting factor. However it is now recognized that the dry periods can be sufficiently long to impede seriously the crop response to applied fertilizers and lime. This is especially so when the plant roots are restricted to the surface soil and are not able to exploit subsoil moisture because of the presence in the subsoil of toxic concentrations of aluminum and/or manganese or because

of a lack of calcium or other essential macro or micronutrients.

Another modification suggested for consideration is that some attention be given to resolving soil fertility problems in the more intensive management of grasses and legumes for livestock production in the Campo Cerrado of Brazil and other areas where livestock enterprises offer a high potential productivity. This work can be done in collaboration with forage and livestock specialists.

D. Accomplishments to Date

Nitrogen Experiments: In the field experiments in Puerto Rico beginning in April and May, 1970 the continuous cropping sequence has been corn, sorghum, corn, corn, and corn. The last crop was planted in April and May, 1972. These field experiments were designed to test the efficiency of utilization of nitrogen applied as urea at different rates and with different methods of application on representative Oxisols and Ultisols. The most recent results confirm the earlier data that postplant applications of nitrogen are more effectively utilized than preplant broadcast applications especially if there is normal rainfall after planting. A much higher percentage of nitrogen was recovered from the postplant applications than from the preplant. The 40 to 56 percent recovered in the postplant treatments is approximately the same as that observed in temperate regions and indicates that excessive losses do not occur under these particular soil and climatic conditions. Postplant nitrogen applications result, on the average, in higher yields, higher nitrogen and protein content of plants and less nitrogen lost from the soil as a potential pollutant of water supplies.

Sulfur coated urea was found to be less effective than regular urea in the yield response of sorghum and corn and the recovery of the nitrogen by the crop was less.

Generally, near maximum yields of corn were obtained with only 60 lb/acre of applied nitrogen. Apparently there is enough nitrogen in the organic matter in these soils and in the crop residues to supplement substantially the applied nitrogen. In one location on a clayey Oxisol, the nitrogen fertility can be built up to such an extent that yields of 100 bushels per acre of corn grain were obtained without added nitrogen and plant uptake of about 125 lb/acre of nitrogen has been recorded on plots receiving no additional nitrogen.

The final crop of corn planted in April and May, 1972 will not receive any nitrogen fertilizer in order to determine the residual effect of the applied fertilizers and to correlate yield and nitrogen uptake with a chemical extraction procedure which has been found to give a good correlation in greenhouse tests with corn.

A maximum yield of about 100 bushels of corn was obtained with the best corn variety available which is a variety developed in Jamaica for the humid tropics. Because of the cost of control of insects, diseases, and nematodes in the experimental plots it is apparent that high yielding varieties more resistant to these pests will need to be developed for high productivity of corn in the low humid tropics. The results of the field experiments demonstrate that the economic management of the nitrogen fertility is much less of a problem than pest control. Also the other major limiting factor which merits greater attention is the provision of adequate soil moisture either through supplementary irrigation or by techniques to provide greater root penetration to exploit subsoil moisture.

Liming and Soil Acidity: Field experiments with different levels of lime have been conducted at five locations representative of the acid Oxisols and Ultisols. A cropping sequence of corn, corn, and green beans was used. The objective of these experiments was to determine the minimum levels of lime required for optimum yields of corn and green beans and to devise improved

laboratory methods for predicting the minimum lime requirements. Yields of corn on a clayey Ultisol were doubled when the pH of the soil was increased from about 4.5 to 5.1 with two tons of lime per acre. However on a clayey Oxisol with about the same initial pH, addition of lime did not increase corn yields significantly. This is due to the fact that the Ultisol contains a relatively high concentration of soluble aluminum which is toxic to many crops while the Oxisol has little or no soluble aluminum although the soil may have a relatively low pH.

Although the yield of green beans was increased by the application of lime, apparently this crop is not as sensitive to aluminum toxicity as corn. On a highly acid Ultisol the yield of green beans increased from about five tons per acre with the soil at a pH of 4.2 to 4.6 to over 6.5 tons per acre with lime applied to increase the pH only to about 5.2. This soil has a relatively high content of organic matter and it is postulated that the organic matter is effective in neutralizing aluminum toxicity.

To test this hypothesis a greenhouse experiment with a soil high in aluminum was conducted with various combinations of lime and organic matter. The test crop was sorghum. The yield data showed that the organic matter was more effective than the lime in reducing aluminum toxicity and increasing yields. However the organic matter contained a substantial amount of exchangeable calcium which undoubtedly contributed to counteracting the aluminum toxicity.

In order to get more information on the rooting behavior of corn, sorghum, and stargrass relative to the concentration of soluble aluminum in a representative Ultisol and Oxisol, a greenhouse test was conducted supplemented by chemical studies. Sorghum roots were highly sensitive to soil solution aluminum, corn roots moderately sensitive, and stargrass roots tolerant. Soil solution aluminum concentration can be calculated satisfactorily from soil pH and

electrical conductivity of the saturated paste extract using an equation developed from the data presented.

Phosphorus Experiments: Field experiments with corn were designed to: (1) define the response curves for applied phosphorus fertilizers on representative Oxisols and Ultisols; (2) measure the relative efficiency of banded versus broadcast fertilizer phosphorus; (3) estimate the residual effects of the broadcast and banded fertilizer phosphorus. In one location on a clayey Ultisol no response to any of the phosphorus treatments was obtained with an initial sorghum crop followed by corn. Chemical soil tests and a greenhouse assay had indicated that this soil should respond to applied phosphorus fertilizers. This site had been under cultivation for many years and apparently enough residual phosphorus was available to meet the needs of the crop during the growing season even though this was not indicated by the chemical tests or greenhouse assay.

Another site on a representative Ultisol was selected for the phosphorus field experiment and here again the soil and greenhouse tests indicated severe phosphorus deficiency. With corn as the test crop the response to applied phosphorus fertilizer was very striking during the first two months of growth. By harvest time, however, the differences had diminished considerably although there still appeared to be yield differences between treatments. Unfortunately a disease infestation during the period the grain was maturing has negated any conclusive results from this experiment.

In order to get information on a wider range of soils on responses to applied phosphorus fertilizer and the interaction with lime treatments, surface and subsoil of three representative Ultisols and Oxisols were placed in 55 gallon bottomless steel drums sunk in the ground. The drum was filled with subsoil to within 12 inches of the surface and about 6 inches of surface soil was

placed on top of the subsoil. The first crop was sorghum which was planted in December, 1971. During the early stages of growth there were pronounced differences in plant response to applied phosphorus but at harvest time the differences were much less. However, the high phosphorus treatments did produced significantly higher grain yields.

Soil Moisture Studies: During the course of the soil fertility field experiments it became apparent that water stress on the growing crop during the dry periods in the rainy season was a serious factor limiting the response to fertilizer nutrients. Consequently during the summer of 1971 preliminary soil-water experiments were conducted in Puerto Rico on the different soils at the sites of the four locations of the field experiments. A typical experimental design consisted of a 3 meter by 3 meter plot instrumented with tensiometers to a depth of 120 cm. The plot was flooded with water and covered with plastic to stop evaporation. Water movement was monitored during infiltration and drainage for up to 35 days using the tensiometers.

In the tension range, 0 to 3/4 bar, correlation of soil-water content with soil-water tension was determined with undisturbed soil cores in the laboratory on Tempe Cells and on a pressure plate apparatus. At higher tensions disturbed samples were run on pressure plates. Use of these data permits conversion of soil-water tensions to values of soil-water content. Gravimetric samples of soil-water contents were taken in the field as a check against soil-water contents as determined indirectly using tensiometers.

The results are summarized as follows: (1) water infiltration into all soils was very rapid, the rate typically reaching about 8 cm/hour after one hour of continuous flooding; rate and amount of infiltration were inversely related to initial soil-water content; (2) on the clayey Ultisols lateral water movement downslope was a significant factor in observed high

rates of infiltration; (3) generally, values of soil-water tension after two to three days of free drainage do not exceed 20-80 cm of water (roughly 1/50 to 1/12 bar); field capacity was found to be about 1/15 bar for a sandy Oxisol and 1/20 bar for the clayey Oxisols and Ultisols; (4) in the two Oxisols studied the bulk of the water is released between field capacity and 1 bar; in contrast a high proportion of the water in the two Ultisols was available at tensions above 1 bar; (5) both the sandy Oxisol and clayey Oxisol tended to dewater at low tensions whereas soil-water release in the Ultisols extended over a wider range of tension; the sandy Oxisol failed to release appreciable water above 1 bar of tension; (6) calculations of capillary conductivity indicated that it was highly water content dependent; it was estimated that only 10 percent of the water required for evapotranspiration might be supplied as upward water movement from the soil beyond the root zone; (7) undisturbed core samples are required to measure water retention in the wet range (0-3/4 bar) and disturbed samples in the dry range (1-15 bars); an overestimation of soil-water storage will be made by employing either disturbed sample techniques at low tensions or undisturbed core samples at high tensions.

Clay Mineralogy Studies: These studies during the past year have focused on the characterization of the iron and aluminum oxides, distribution of positive and negative charges, scanning electron microscope examination of clay size fractions, potassium/calcium exchange selectivity, and phosphorus parameters.

The presence of large amounts of iron and aluminum oxides in the highly weathered soils of the tropics has a profound influence on the ion exchange properties. These oxides are responsible for the positive charges in the clay fractions and cause the fixation of the negative phosphate ions and at

the same time repel or allow the leaching of plant nutrients with positive charges such as potassium and calcium. In previous studies by other investigators the influence of organic matter on the charge characteristics of iron and aluminum oxides has been somewhat neglected because the laboratory techniques usually involve removal of the organic matter fraction from the surface soils or the study of subsoils with little or no organic matter present.

In the present studies the influence of the organic matter has been taken into account by using untreated surface and subsoil samples of soils representing a wide range in mineralogical composition of the highly weathered Oxisols and Ultisols. The positive and negative charges of the soils were determined before and after chemical treatments that selectively extract various forms of iron and aluminum oxides. The results indicate that there is an interaction between the organic matter and the iron and aluminum oxides such that the potential positive charges of the oxides are neutralized. This interaction can cause the surface horizons to have a net negative charge while subsurface horizons will have a net positive charge as a result of the lower organic matter content.

The implications of these findings point to the need for greater attention to be given to the maintenance or enhancement of organic matter in the highly weathered acid soils in soil management systems in order to minimize the fixation of applied phosphate fertilizers and the leaching of potassium, calcium, and other bases. Also the interaction of organic matter with the iron and aluminum oxides promotes the stable aggregation of the soil particles so that these soils have desirable physical properties.

E. Dissemination and Utilization of Research Results

As segments of the research project are completed, the data are assembled, analyzed, and interpreted and reports are prepared for conferences and seminars and for publication in appropriate technical journals. A list and abstracts of publications, articles submitted for publication, theses, and reports prepared for conferences is presented in the Appendix. Also short statements on use of the materials for seminars and conferences are given in the Appendix.

A number of graduate students, foreign and U.S., have either been directly involved in the project or in research related to the project. Mr. Ferreira of the Dominican Republic did his M.S. thesis research on a topic directly related to the project as did Mr. Santiago from Venezuela. Both of these men have returned to positions in their home country. Dr. Zandstra of Canada did his Ph.D. thesis research on a topic directly related to the project and is now assigned to Colombia on a technical assistance project sponsored by the Canadian government. Dr. Naderman of the U.S. did his thesis research in Colombia on a topic related to the project and is now on assignment in Brazil working on the project in cooperation with the Ministry of Agriculture. Mr. Ritchey of the U.S. is completing his Ph.D. thesis research in Puerto Rico directly related to the project and has a career commitment to continue to work in the tropics. Several other graduate students from the U.S. and abroad are initiating their thesis research on subjects related to the project objectives.

The Project Director served as Chairman of the Committee on Tropical Soils of the National Academy of Sciences. The outgrowth of the work of the Committee resulted in the publication of a book in June, 1972 on Soils of the Humid Tropics. This book contains a section on Research Needs and

summary articles on present knowledge of tropical soils in many subject matter areas. It is expected that this book will have a wide distribution among research workers, students, and teachers interested in soils of the tropics.

F. Research Linkages

1. The research carried on in Puerto Rico is cooperative under a subcontract with the University of Puerto Rico and several staff members of the Agricultural Experiment Station have been assigned to the project. There is also collaboration with U.S.D.A. soil scientists stationed in Puerto Rico.

2. Close collaboration is maintained with North Carolina State University which has a related research project, "Agronomic-Economic Research on Tropical Soils."

3. The research activities being initiated in Brasilia have been developed cooperatively with the Ministry of Agriculture scientists and in collaboration with North Carolina State University.

4. Cornell is one of five Universities including North Carolina State, Hawaii, Puerto Rico, and Prairie View, Texas, in a University Consortium on Soils of the Tropics. Semiannual meetings of representatives of Consortium members provide opportunities for exchange of information and ideas on tropical soils research activities.

5. A tropical soils research conference held in Ibadan, Nigeria in May, 1972 was sponsored by the International Institute of Tropical Agriculture (IITA) in cooperation with the French Agricultural Research Institute (IRAT). Members of the Cornell staff involved in the project participated in the conference which provided a unique opportunity to

interact with African soil scientists from several countries in addition to the French, British, Belgian, and U.S. soil scientists doing tropical soils research. Also, there was an opportunity to become familiar with the soils research activities of IITA. Following the conference the Cornell participants visited institutions in several African countries which have on-going soils research programs.

6. As Chairman of the Tropical Soils Committee of the National Research Council for two years, the project director was in frequent communication with the other eleven soil scientists on the Committee who all had much experience doing soils research in the tropics and who represented a broad spectrum of soil science disciplines. The Committee was composed of six soil scientists from the United States and six from France, Belgium, England, and Holland with long experience in the tropics of Africa, Asia, and Latin America. The Committee met formally three times for a week each time to discuss all aspects of soil research needs of the humid tropics. The reports which were prepared formed the basis of a book on Soils of the Humid Tropics, published in June, 1972.

7. An informal collaborative arrangement was established with the Colombian Agricultural Research Agency (ICA) and the Institute of Tropical Agriculture in Colombia (CIAT) for a graduate student to do his thesis research on the acid soils of the eastern plains of Colombia (Llanos). A graduate student from Colombia is now at Cornell and will be doing his thesis research on a soil fertility problem on the soils of the Llanos.

8. Dr. Silva of the University of Hawaii spent his Sabbatic year at Cornell working on crop response to applied silicate, comparing soils from Hawaii with related soils from Puerto Rico. A graduate student from the

Dominican Republic became interested in this subject and is doing his thesis research on crop response to applied silicate on soils from the Dominican Republic which are low in soluble silica.

9. Dr. Coulter, tropical soils advisor of the Overseas Development Administration of England, was a visiting scientist on the campus for six months. His many years of experience in Malaysia and the Caribbean islands and knowledge of tropical soils problems in Africa, Latin America, and Asia made him a valuable consultant for many of the students who were developing their ideas for research in their home countries.

G. Expenditures and Obligations - July 1, 1971 to June 30, 1972

	Cornell	Puerto Rico Subcontract
Salaries - U.S.	$ 49,810.95	$ 77,458.25
Cooperating	0	0
Consultants	0	0
Fringe Benefits	0	0
Overhead	17,116.40	30,983.31
Travel & Transportation	3,873.83	1,355.30
Allowances	0	0
Equipment, Vehicles, & Supplies	2,566.35	15,592.36
Other Direct Costs	4,628.09	3,816.42
TOTAL	$ 77,995.62	$ 129,205.64
GRAND TOTAL	$ 207,201.26	

H. Work Plan (April 1, 1973 to March 31, 1974)

Nitrogen Experiments with Cassava and Plantains: Following the four crops of corn and one crop of upland rice, cassava will be planted in April, 1973, at the four experimental locations in Puerto Rico having representative soils with characteristics similar to the acid soils so extensive in the humid tropics (Oxisols and Ultisols). As with the corn and rice crops, the objective will be to determine the efficiency of utilization of different rates of applied nitrogen in relation to the productivity of cassava on the different soils. In addition to the yield data, soil and plant analyses will help determine movement of nitrogen through the soil, uptake by the crop, and losses through leaching and volatilization.

Up until now the main emphasis in the nitrogen experiments has been given to the cereal food crops, corn, sorghum, and rice and in accordance with the original plan, attention will now be directed to responses of important tropical root crops such as cassava to levels and methods of nitrogen applications. A new high protein variety will be used on which very little information is available on its response to various rates and methods of application of nitrogen fertilizers.

Following the harvest of cassava in the late fall or winter of 1973 the next crop to follow at the four locations will be plantains, another very important food crop in the tropics on which there is only limited information on responses to nitrogen and other nutrients on the acid soils. In addition to these experiments an extensive field trial with plantains will be carried out on another clayey Ultisol in cooperation with the U.S.D.A. Agricultural Research Service soil scientists to determine nitrogen responses in various combinations with phosphorus, potassium, lime, and micronutrients.

Phosphorus Experiments with Cassava and Plantains: Following the field trials on a representative clayey Ultisol in Puerto Rico for rice on rates and methods of application of phosphate fertilizer, cassava will be the test crop and this will be followed by plantains. In addition to yield responses to different levels and methods of application, the residual effects of applied phosphate to successive crops will be measured.

On a clayey Ultisol in another location in Puerto Rico yield responses to levels and methods of phosphate application to the plantains will be determined. Plantains are reported to have relatively high phosphorus requirements but very few phosphate response studies have been made with this crop on the highly acid soils in the humid tropics.

The phosphorus experiments in the bottomless 55 gallon steel drums sunk in the ground will be continued. Surface and subsoils from three representative clayey Oxisols and Ultisols have been placed in the drums and successive crops of sorghum and corn have been grown with different levels of phosphate fertilizer in order to get information on a wider range of soils on responses to applied phosphorus fertilizer. The interaction of phosphorus with lime placed at different depths is also under study in relation to crop yields.

Chemical studies on phosphate retention and availability will be made on soil samples from the different field plots. The objective will be to develop extraction procedures for soil tests which would provide better correlations with crop response than can now be obtained on many Oxisols and Ultisols.

Soil Acidity and Liming Experiments: On five different Oxisols and Ultisols in Puerto Rico the field trials will be continued in order to get yield response to different levels of lime on a succession of crops. Following two crops of corn, one of green beans, one of sweet potatoes, one

of rice, and one on Irish potatoes, plantains will be grown during 1973-1974. The objective of these experiments is to determine the minimum levels of lime required for optimum yields of various crops on the different soils and to devise better laboratory methods for determining lime requirements.

On a representative clayey Ultisol high in exchangeable aluminum in another location the effect of incorporating lime in both the subsoil and surface soil will be compared with liming only the surface soil. The test crop will be sorghum which is particularly sensitive to aluminum toxicity. This work will be done in cooperation with the U.S.D.A. Agricultural Research Service soil scientists.

The field trials will be supplemented with laboratory and greenhouse studies with special attention being given to factors which affect aluminum toxicity to crops. Previous studies have shown the effect of the kind and concentration of other ions in solution on aluminum toxicity and these studies will be continued. The effect of organic matter in reducing aluminum toxicity has been shown in preliminary greenhouse trials with sorghum and further trials with other crops are planned.

Soil Moisture Studies: One of the most critical factors affecting crop response in the soil fertility experiments is availability of soil moisture. A deficiency of soil moisture frequently occurs during the rainy season when there are periods with little or no rainfall. Preliminary studies in Puerto Rico on infiltration, movement within the profile, storage, and availability of soil moisture have pointed up the necessity for a more critical investigation of the soil moisture factor in relation to crop response to applied fertilizers and lime. Root development in the subsoil is restricted in many of the acid Ultisols and Oxisols by the relatively high amount of aluminum and/or manganese and deficiency of calcium and/or other nutrients. Consequently even though there may be adequate subsoil moisture storage during the dry

periods in the rainy season, root development is restricted and the stored water cannot be exploited. It is planned to measure the soil water extraction patterns of various crops in relation to rooting depth as affected by the application of fertilizers and lime. This work will be done on representative Ultisols and Oxisols in Puerto Rico.

Soil Fertility and Moisture Studies on the Campo Cerrado in Brazil: In collaboration with the Ministry of Agriculture and North Carolina State University a series of field experiments were initiated in October, 1972 on two soils at the experiment station near Brasilia which are representative hundreds of millions of hectares of the deep, well-drained highly acid soils of the Campo Cerrado. The experiments now underway will measure responses of corn to different levels and methods of application of nitrogen, phosphorus, and lime. These experiments are similar in design to those which have been conducted in Puerto Rico. Though the soils are similar in many characteristics to those under investigation in Puerto Rico, there are important differences and the climatic environment is different.

Following the first crop of corn it is planned to have a sequence of crops such as upland rice, soybeans or other edible legumes, sorghum, and root crops. Irrigation facilities are available so that it is planned to have continuous cropping throughout the year. Soil moisture measurements will be made to determine water stress in relation to root penetration during the cropping periods. Particular attention will be given to subsoil root penetration and soil moisture extraction in a liming experiment involving deep placement of lime in comparison with surface applications. The relatively high percentage of soluble aluminum and very low calcium are important factors in these soils limiting the productivity of many crops.

As considerable emphasis will be given by the Ministry of Agriculture to beef cattle production on the Campo Cerrado, it is planned to initiate soil fertility trials with grasses and legumes in collaboration with the University of Florida forage and livestock specialists who have been contracted to develop a livestock improvement program for the Campo Cerrado with headquarters in Brasilia.

Clay Mineralogy Studies: In order to better interpret the reactions of applied nutrients in the soil in the soil fertility experiments, mineralogical analyses will be continued with special attention given to the interaction of the noncrystalline iron and aluminum oxides and organic matter and its influence on the charge characteristics of the surface horizons. The soil mineralogical properties which influence the absorption and release of added phosphorus to the crops will be determined. Also the affinity of the exchange complexes for potassium relative to that of calcium and aluminum will be measured on those soils which have a relatively low level of potassium.

Work Plan; Abstract and Time Table

Location	Starting Date	Expected Completion
PUERTO RICO		
1. Nitrogen and phosphorus experiments with cassava on different soils at 4 locations.	April '73	Dec. '73
2. Nitrogen and phosphorus experiments with plantains on different soils at 4 locations.	Jan. '74	June '76
3. Nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrient experiment with plantains at one location.	April '73	June '76
4. Subsoil liming on high aluminum soil with sorghum as test crop.	April '73	Oct. '74
5. Liming experiments with plantains on 5 different soils at 5 locations.	April '73	June '76
6. Soil water extraction patterns of various crops in relation to rooting depth as affected by fertilizer and lime treatments.	Oct. '72	Oct. '74
7. Laboratory and greenhouse studies on factors affecting aluminum toxicity to crops including concentration and kind of other ions, organic matter, etc.	Sept. '72	Sept. '73
BRASILIA, BRAZIL		
1. Nitrogen experiments: Rates and methods of application of nitrogen fertilizers for determining most effective utilization by corn, upland rice, sorghum, and root crops on two of the most extensive soils in the Campo Cerrado.	Oct. '72	June '76

Work Plan; Abstract and Time Table (Cont'd)

Location	Starting Date	Expected Completion
BRASILIA, BRAZIL (cont'd)		
2. Phosphorus experiments: Rates and methods of application of phosphorus fertilizer for determining most effective utilization by corn, upland rice, soybeans or other edible legumes, sorghum, and root crops. Same two soils as above.	Oct. '72	June '76
3. Liming experiments: Effect of deep placement of lime compared with surface applications on yields of corn, sorghum, upland rice, edible legumes and root crops. Same two soils as above.	Oct. '72	June '76
4. Nitrogen, phosphorus, lime, and micronutrient experiments with grasses and legumes.	April '73	June '75
5. Soil moisture studies to determine factors affecting the efficient use of water in the soil under natural rainfall and under irrigation.	Jan. '73	June '74
ITHACA		
1. Chemical studies on soil samples from field experiments in Puerto Rico and Brasilia to help interpret field responses to nitrogen, phosphorus and lime treatments and provide a basis for the application of the experimental data to similar soils in other areas in the humid tropics.	April '73	June '75
2. Clay mineralogical properties of the soils from the experimental plots in relation to their effect on ion absorption and release.	April '73	June '75

Budget Plan - April 1, 1973 to March 31, 1974

	Cornell		Puerto Rico Subcontract
Salaries - U.S.	$ 76,100.00		$ 87,300.00
Cooperating	11,500.00		0
Consultants	0		0
Fringe Benefits	0		0
Overhead	31,125.00		40,400.00
Travel & Transportation	9,790.00		1,700.00
Allowances	10,600.00		0
Equipment, Vehicles & Supplies	6,000.00		11,000.00
Other Direct Costs	1,000.00		2,500.00
TOTAL	$146,115.00		$142,900.00
GRAND TOTAL		$289,015.00	

Personnel - April 1, 1973, to March 31, 1974

Location		Man Months
PUERTO RICO		
Professional		
R. H. Fox	-Soil Scientist	10
T. W. Scott	-Soil Scientist	9
E. J. Brenes	-Soil Chemist	12
J. Badillo	-Agronomist	6
R. deValle	-Agronomist	12
A. Wahab	-Soil Scientist	12
J. Rivera	-Chemist	6
J. Rodriguez	-Agronomist	1
H. Talleyrand	-Res. Assistant	12
Nonprofessional		
A. Colon	-Lab. Technician	12
V. Santiago	-Lab. Technician	12
M. Malave de Garcia	-Secretary	12
Laborers (Field)		70
Laborers (Laboratory)		25
BRASILIA, BRAZIL		
Professional		
G. C. Naderman	-Soil Scientist	12
J. Wolf	-Res. Assistant	9
--	-Res. Assistant	12
ITHACA		
Professional		
M. Drosdoff	-Soil Scientist	3
R. M. Weaver	-Soil Scientist	6
D. R. Bouldin	-Soil Scientist	1
D. J. Lathwell	-Soil Scientist	1
--	-Research Associate	12
Nonprofessional		
M. Buyukcolak	-Secretary	12

APPENDIX
Dissemination and Utilization of Research Results

I. Bibliographic List and Abstracts

1. Nitrogen Fertilization in the Humid Tropics. Richard H. Fox. Paper presented at the Tropical Soils Research Conference in Ibadan, Nigeria, May 22-29, 1972.

The most salient findings of the N fertilization field experiments with corn and sorghum in Puerto Rico have been: (1) postplant applications of N were much more effective than preplant applications in increasing grain yield and N fertilizer uptake, (2) sulfur coated urea was less effective than urea as a preplant application, (3) near maximum maize yields were generally obtained with only 67 kg/ha of N applied, (4) N fertility can be built up to such an extent in continuously cropped and fertilized Oxisols that yields of 5.8 T/ha of maize grain, and plant uptakes of 141 kg/ha of N have been observed on plots receiving no additional N, (5) a maximum maize grain yield of 6.5 T/ha was obtained.

It should also be mentioned that the most serious problems encountered in producing maximum maize yields in Puerto Rico were drought, insects, nematodes and diseases, rather than lack of soil fertility.

2. Nitrogen Supplying Power of Some Tropical Soils of Puerto Rico and Methods For Its Evaluation. D. J. Lathwell, H. D. Dubey, and R. H. Fox. Accepted for publication in the November-December 1972 issue of the Agronomy Journal.

An evaluation of the N-supplying power of 10 representative Oxisols and Ultisols of Puerto Rico was made by continuous cropping in the greenhouse. Four chemical extraction methods as well as aerobic incubation procedures were used to obtain an index of N availability in these soils. Nitrogen produced during incubation was highly correlated with N released to the crops. Nitrogen extracted by all of the chemical methods used, especially total N extracted by 0.01 M $CaCl_2$ solution and potassium sulfate, was highly correlated with N uptake by plants. These results showed that substantial quantities of N can be removed from these soils upon cropping. It was also shown that laboratory chemical methods as well as incubation procedures provide a reliable means for evaluating the N-supplying power of these soils.

3. Relationships Among Physical and Chemical Properties of Representative Soils of the Tropics from Puerto Rico. W. R. Philipson and M. Drosdoff. Accepted for publication in the September-October 1972 issue of the Soil Sci. Soc. Proc. Am.

In investigating chemical and physical properties of tropical soils, relationships among 15 properties, of 448 horizons, from 84 Puerto Rican soil profiles, were studied by correlation and multiple linear regression analyses. In a series of 17 computer programs, 109 multiple regression equations were calculated with 15-bar moisture content, cation exchange

Bibliographic List and Abstracts (cont'd)

capacity, organic carbon, extractable iron and base saturation as dependent variables. The work was performed in two steps: (1) with all soil property data treated as a single group, and (2) with the same soil property data classed according to the order level of the USDA's 7th Approximation. This preliminary analysis indicates that it may be possible to eliminate certain laboratory determined properties from tropical soil data acquisition and still reliably estimate these properties on the basis of other selected soil properties.

4. Root Responses of Three Gramineae Species to Soil Acidity In An Oxisol and An Ultisol. E. Brenes and R. W. Pearson. Presented at the Annual Meetings of the Southern Agricultural Workers Association in Jacksonville, Florida on February 3-7, 1971. Paper has been submitted to Soil Science for publication.

Sorghum roots were highly sensitive to soil solution Al present in acid Ultisols and Oxisols. Corn roots were moderately sensitive and stargrass roots were tolerant. Representative acid soils from the humid region of Puerto Rico contained less soil solution Al than did several selected from the southeastern United States at the same pH level. This confirms the observation that critical soil pH range tends to be lower in soils of Puerto Rico than in those of the southeastern United States. Soil solution Al concentration can be calculated satisfactorily from soil pH and EC of the saturated paste extract using an equation developed from the data presented.

5. Electrochemical Properties of Some Oxisols and Alfisols of the Tropics. B. Van Raij and M. Peech. Soil Sci. Soc. Am. 36:587-593. 1972.

A study of the distribution of the electric charges in the Ap and B2 horizons of two highly weathered Oxisols and one Alfisol from Brazil was made by means of potentiometric titration and by direct measurement of adsorption of ions in the presence of varying concentration of electrolyte. The titration curves at different ionic strengths crossed at the common point of intersection, the zero point of charge (ZPC), or the pH at which the net electric charge is zero. Thus, the electrochemical behavior of these soils was found to be similar to that exhibited by many metallic oxides in which the surface potential of a reversible double layer is determined solely by the activity of potential determining H^+ and OH^- ions in the bulk solution. Direct determination of the adsorption of ions from NaCl, $CaCl_2$, and $MgSO_4$ solutions showed that pH, electrolyte concentration, and valence of the counter ion influence the magnitude of the electric charges on the soil particles. From known surface areas and ZPC of these soils, the values for the net electric charge calculated by the application of the Stern model of the double layer theory were found to be in good agreement with the experimental results.

Bibliographic List and Abstracts (cont'd)

6. Measurement of Aluminum Toxicity: I. Effects of Aluminum in Soil Solution on Root Growth. H. G. Zandstra and D. R. Bouldin. Submitted for publication to the Soil Science Society of America Proceedings.

The concentration of Al in soil suspensions was varied by additions of $Ca(OH)_2$ and concentrations of $CaCl_2$. Root growth in the suspensions was measured over a 60 hour period using corn and sorghum seedlings. The observed root growth was not a single-valued function of pH or Al, but it was a single-valued function of the solution parameters pH - 1/2pCa or 1/3pAl - 1/2pCa.

Studies found in the literature of root growth inhibition by such cations as H^+, Al^{+3}, Mg^{+2} and K^+ could all be related to the ratios $(Ca)^{1/2}/H$, $(Ca)^{1/2}/(Al)^{1/3}$, $(Ca)^{1/2}/(Mg)^{1/2} + K)$. The data is consistent with the hypothesis that all of these ions may induce a calcium deficiency in the meristematic section of the growing root tip and thereby have an important influence on growth of the whole plant.

7. The Role of Organic Matter in the Inhibition of Aluminum Toxicity in an Ultisol. Publio Santiago. A thesis submitted for the M.S. degree, May, 1972.

The objective of this study was to determine the effect of variable organic matter increments on the immobilization of active Al in an acid Ultisol and compare organic matter applications with lime rates relative to the growth of sorghum. It was found that: (1) organic matter neutralized more Al per unit of Ca in it than was true for $Ca(OH)_2$; (2) maximum yields were obtained on all treatments when the Al saturation was less than seven percent and soil solution Al was less than 0.68 meq/liter; (3) the rate of Ca either from organic matter or $Ca(OH)_2$ at which maximum yields were obtained was at a level equivalent to 100 percent of the exchangeable Al; (4) the yields of sorghum were drastically reduced when the Al saturation was 19 percent or more and the soil solution Al was 1.39 meq/liter or more; (5) the pH at which maximum yields were obtained ranged from 4.55 to 4.80; (6) the maximum yield obtained by adjusting organic matter at zero level of lime was statistically higher, and was obtained with a lower amount of Ca supplied to the soil, than the maximum yield obtained by adjusting $Ca(OH)_2$ at zero level of organic matter; this suggests the possibility of using less liming materials if adequately high levels of organic matter are maintained in acid tropical soils.

8. The Fate of Nitrogen Fertilizers Applied to Tropical Soils. F. F. Ferreira. A thesis submitted for the M.S. degree, August, 1972.

The objectives of these studies were to: (1) determine the rate of nitrification of urea and ammonium sulfate in some tropical soils in Puerto Rico under field conditions and (2) determine nitrate movement in several tropical soils under fallow conditions.

Bibliographic List and Abstracts (cont'd)

It was found that the rate of nitrification of ammonium sulfate and urea did not differ in the three soils under study, a sandy Oxisol, a clayey Oxisol, and a clayey Ultisol. The nitrate formed from either ammonium sulfate or urea moves with water through the profile at the same rate as chloride. Urea is rapidly hydrolyzed to ammonium carbonate in these soils; the ammonium peak appeared in fourteen days or less.

9. Aluminum Toxicity in Some Highly Weathered Soils of the Tropics. Hubert G. Zandstra. Thesis submitted for the Ph.D. degree, December 1971.

This study is consistent with the hypothesis that Al toxicity is primarily an inhibition of Ca uptake and that Al is one of several cations which may induce a Ca deficiency. The logarithms of the solution cation ratios $(Ca)^{1/2}/(Al)^{1/3}$ and $(Ca)^{1/2}/(H)$ were well correlated with rootgrowth in systems dominated by Ca and Al. These ratios were superior to either Ca activity in explaining variations in rootgrowth in such systems. Reductions in rootgrowth induced by K and Mg reported in the literature were related to similar ratios such as $(Ca)^{1/2}/(Mg)^{1/2} + (K)$.

The results indicate a nonspecific competition between interfering ions, and Ca, similar to that which occurs for exchange sites on an inert exchanger. On this basis, the reduction in rootgrowth associated with high solution concentrations of Al or other competing ions may be caused by a lack of Ca at the growing root tip. The competitive action of cations such as Al or Ca is not confined to the root tip, but also extend to the ability of the plants to absorb Ca.

10. Mineralogy of Highly Weathered and Leached Soils of the Humid Tropics. R. M. Weaver. 1973 McGraw-Hill Yearbook of Science and Technology. McGraw-Hill, New York. In press.

This is a review of the results of recent studies on the mineralogical compositions of highly weathered and leached soils of the humid tropics and the significance of these findings to the agronomic properties of these soils. In particular, attention was given to the presence of non-crystalline or amorphous material in these soils, and its possible role in nitrate or phosphate retention. The relationship of the mineralogical composition to the ion exchange properties was also discussed. Under the latter, it was pointed out that these soils are largely devoid of minerals that have a permanent, structural negative charge. Instead these soils are dominated by minerals that have a variable charge that is produced by proton migration across the solid-solution interface. It has been shown that with such minerals the sign and magnitude of the charge will depend upon the pH and the concentration of the solution surrounding the mineral. In general, positive charges that would cause repulsion of cations such as K^+, but retention of anions such as NO_3^-, PO_4^{3-} and SO_4^{2-} are dominant at acid pH values, while at neutral or alkaline pH values, negative charges that retain cations are largely present.

Bibliographic List and Abstracts (cont'd)

11. Clay Mineralogy of Some Highly Weathered, Humid Tropical Soils of Puerto Rico. R. M. Weaver. Submitted to Clays and Clay Minerals.

The clay-size fractions of three highly weathered soils from Puerto Rico, which represent important agricultural soils of the humid tropics, were investigated by X-ray diffraction (XRD), differential thermal analysis (DTA), scanning electron microscopy (SEM), and chemical analyses. The results indicated that poorly-ordered kaolinite (40-50%) dominated the clay fractions followed by amorphous or non-crystalline materials (15-25%), Al-chlorite (10-25%), gibbsite (0-10%), vermiculite (4-10%), and mica (2-13%). The mica, vermiculite, and Al-chlorite did not exist as separate species, but were present as a randomly interstratified mixture. The amorphous or non-crystalline material was not identical to allophanic-materials in that its removal by selective dissolution did not significantly alter the cation exchange capacity nor the low temperature DTA endotherms. The absence of greater amounts of gibbsite in the clay fractions of these soils was attributed to the presence of quartz in the sand and silt fractions which could possibly support a solution activity of $Si(OH)_4$ that would prevent desilication of kaolinite and/or the preferential precipitation of aluminum as hydroxy polymers in the K-depleted interlayer spaces of mica to form Al-chlorite zones.

12. Effect of pH and Dissolution Treatment on the K/Ca Exchange Selectivity of Some Ultisols and Oxisols. R. M. Weaver. Presented before Division S-9, Soil Mineralogy, 1972 American Society of Agronomy Meetings, Miami Beach, Florida

K/Ca cation exchange selectivity (CES) values were determined at pH 5 and pH 7 on surface and subsurface horizons of three Ultisols and Oxisols from Colombia and Puerto Rico. The CES values were also determined following treatments for the removal of organic matter, and interlayer Al-hydroxy polymers of the chloritized expansible layer silicates present in the clay fractions of the soils. The CES values were dependent upon the pH and the treatment, and in general were greater at pH 5 than at pH 7 for any treatment. Thus the pH dependent cation exchange capacity of these soils appeared to be selective for the adsorption of calcium over potassium. The CES values increased markedly at pH 5 or at pH 7 following the removal of organic matter or interlayer Al-hydroxy polymers. The large increase in potassium selectivity upon the removal of organic matter was attributed to the removal of organic molecules that were sterically or electrostatically blocking the selective potassium adsorption sites of expansible 2:1 layer silicates.

13. The Influence of Various Forms of Iron and Aluminum Oxides on Charge Characteristics of Highly Weathered Soils of the Humid Tropics. R. M. Weaver. 1972. Submitted to Soil Science.

The negative and positive charges of surface and subsurface horizons of three highly weathered soils of the humid tropics were determined as a function of pH before and after treatment to remove various forms of iron and aluminum oxides. The treatment effects were monitored by determination of the amount of iron and aluminum oxides plus organic matter extracted, determination of specific surface area, and differential thermal analysis. The amorphous or non-crystalline iron and aluminum oxides

Bibliographic List and Abstracts (cont'd)

constituted only a small portion of the more-ordered forms. The small proportion, however, contributed significantly to the specific surface area and charge properties of the soils. Specifically, it appeared that the amorphous iron and aluminum oxides interact with the organic matter in such a manner that the positive charges of the oxides are eliminated. The overall effect of the interaction was that the net negative charges of the soils were increased and there was a decrease in the possibility of the specific adsorption or fixation of anions such as PO_4^{3-} or SO_4^{2-}.