AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

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Batch 97

1. SUBJECT CLASSIFICATION
A. PRIMARY: Serials — Y-AE25 -0000-GG50
B. Food production and nutrition--Soil fertility, fertilizers, and plant nutrition--Tropics

2. TITLE AND SUBTITLE
Soil fertility requirements of food crops on extensive, deep, well-drained but relatively acid soils of the humid tropics; progress report, 1972/1973

3. AUTHOR(S)
(101) Cornell Univ. Dept. of Agronomy

4. DOCUMENT DATE: 1973
5. NUMBER OF PAGES: 56p.
6. ARC NUMBER: ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Cornell

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)
(Research summary)

9. ABSTRACT

10. CONTROL NUMBER
PN-AAG-282

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Soil fertility
Tropics

13. PROJECT NUMBER

14. CONTRACT NUMBER
CSD-2490 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

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 Progress Report

for the period

July 1, 1972 to June 30, 1973

Submitted to the

U. S. Agency for International Development

Contract AID/csd 2490

Cornell University
Ithaca, New York

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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, Department of Agronomy, Cornell Univeristy, Ithaca, New York 14850

Contract Period: June 30, 1969 to June 30, 1974

Period Covered by Report: July 1, 1972 to June 30, 1973

Total A.I.D. funding, June 30, 1969 to March 31, 1974: $ 1,126,846

Total expenditures and obligations, July 1, 1972 to June 30, 1973: $ 270,000

Total expenditures and obligations, July 1, 1973 to March 31, 1974: $ 230,000

Estimated expenditures, April 1, 1974 to March 31, 1975: $ 275,000

B. Narrative Summary of Accomplishments and Utilization

This is the fourth annual progress report of the soil fertility research project to determine the most effective amounts and methods of application of nitrogen, phosphorus, potassium, liming materials, and micronutrients to achieve the production potential for food crops on the acid soils of the humid tropics. The ultimate objective of the project is to provide recommendations to cultivators for improved soil and crop management practices on these soils which are very extensive in the humid tropics, over 1,500 million acres according to recent estimates. 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, aluminum or manganese toxicity, and other limiting factors.

The project is designed so that the results would be applicable to extensive areas of acid soils in Latin America, Africa, and Asia. The field research was initiated in Puerto Rico in the spring of 1970 in cooperation with the University of Puerto Rico and in collaboration with research personnel of the U.S. Department of Agriculture. Research was started in Brasilia in the summer of 1972 in cooperation with the Brazilian Ministry of Agriculture and North Carolina State University.

Puerto Rico: A total of 15 corn and 3 sorghum crops have been harvested in the nitrogen experiments since 1970. The yield data of grain and stover were supplemented with several thousand soil and plant analyses to help in the interpretation of the results. The main conclusions are : (1) Confirmation of the lower efficiency of preplant applications of nitrogen fertilizer in comparison with postplant; (2) the clayey Oxisols and Ultisols have a relatively high nitrogen supplying capacity; (3) the yield potential of about 100 bushels of corn per acre of the corn hybrid used was obtained in only 4 of the 14 corn

crops because of drought, diseases, and insects which emphasizes the need for critical studies of the soil moisture and for the development of varieties more resistant to plant pests for efficient production of corn in the humid tropics.

The liming experiments have demonstrated the wide range of tolerance of various crops to soil acidity and aluminum toxicity and that, in general, much lower levels of lime need to be applied to highly acid soils of the humid tropics than has been previously thought. The importance of counteracting subsoil acidity to increase root penetration and reduce moisture stress during dry periods has been demonstrated and methods for practical application to field situations are being tested.

A significant response of corn to applied phosphate on a severely phosphorus deficient soil was obtained with the winter crop but not with the summer crop. It appears that a more rapid mineralization of organic phosphorus during the warmer summer months is an important factor in the supply of phosphorus to the crop.

The first crop of plantains in a phosphorus and nitrogen study averaged 12 tons per acre of edible fruit which is several times the average production in Puerto Rico. The availability of a new nematocide, Dasanit, has made it possible to reach very high levels of production of plantains, especially if the ratoon crops will have a high production as anticipated.

Brazil: The first crop of corn was grown during the rainy season from November, 1972 to April, 1973 on a soil at the Experiment Station near Brasilia. This soil, Dark Red Latosol in the Brazilian classification, and closely related soils are representative of extensive areas in the Central Plateau of Brazil. The average yield of corn in the nitrogen experiment ranged from about 50 bushels per acre with only about 18 pounds per acre of nitrogen applied as urea to over 100 bushels per acre with 135 pounds per acre of nitrogen. The highest yields were obtained with 36 to 54 pounds per acre of nitrogen 20 days after planting plus 36 or 54 pounds applied 52 days after planting.

Broadcast applications of superphosphate gave greater grain yields than equivalent amounts banded. The maximum yield (130 bushels per acre) was obtained with 1150 pounds per acre of P_2O_5 applied as simple superphosphate. An important problem to be resolved is how to effect a more efficient use of applied phosphate on this kind of soil which has a very high phosphorus fixing capacity.

Incorporation of lime to a depth of 12 inches was more effective than incorporation to a depth of 6 inches in increasing yields, root penetration, and utilization of subsoil moisture. There was no significant difference in yield between the appliecation of one ton of lime per acre and two or four tons.

The rate of water infiltration into the soil was rapid ranging from 16 to 24 cm/hour. There was little diminution in rate of infiltration after two successive floodings. Calculations from soil-water release curves showed that only about 50 mm of water can be stored in the soil to a depth of 30 cm. With evapotranspiration of 7 mm or more per day, water stress is likely after a week without rain or irrigation if the rooting depth is no more than 30 cm. This was confirmed by field observations.

ANNUAL RESEARCH REPORT

A. General Background

In view of the continuing need to expand world food production despite the successes of the "green revolution," it is essential to utilize the available soil resources which have good potential productivity. The best estimates indicate that there are about 1.5 billion acres of deep, well-drained, acid soils (Ultisols and Oxisols) in the humid tropics which are potentially arable but largely uncultivated. Much of this land has favorable topography and the main limiting factor is the very low natural fertility and often soil moisture deficiency at critical growth periods. Research has shown that these soils have a high potential for food production at a relatively modest cost provided that proper soil, crop, and water management practices are used. There are many soil fertility and water management problems which need to be resolved under the different ecological environments in the humid tropics but previous research provides much encouragement for the economic utilization of extensive areas for food production.

In addition to the extensive areas in the humid tropics which are not now under cultivation, most of the soils which are cultivated have produced rather poorly. There are large areas under traditional agriculture where the introduction of modern technology can increase food production substantially: This includes the judicious use of fertilizers along with other improved soil and crop management practices, including water conservation and control, use of improved seed, and the application of pesticides.

B. Project Objectives

The contract for the first five years of the project became effective on June 30, 1969. The immediate objective was to determine the most effective and economic amounts and methods of application of nitrogen, phosphorus, potassium, liming materials, and micronutrients to achieve the production potential for food crops on the acid soils of the humid tropics. The ultimate objective as a result of the research is to provide recommendations for improved soil and water management practices for the humid tropics within the capability and resources of the cultivators.

The project was designed so that the results would be applicable to extensive areas in Latin America, Africa, and Asia. The field research was initiated in Puerto Rico in cooperation with the Agricultural Experiment Station of the University of Puerto Rico and in collaboration with research personnel of the U.S. Department of Agriculture stationed in Puerto Rico. Though Puerto Rico was selected as the base for the research, an objective was 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 characteristics of the soils. Consequently, field experiments supplemented by greenhouse and laboratory studies were initiated in July, 1972 at the Agricultural Experiment Station near Brasilia, Brazil in cooperation with the Brazilian Ministry of Agriculture and in collaboration with the University of North Carolina. Preliminary discussions have been held with officials of the Soils Research Institute at Kumasi, Ghana to initiate cooperative soil fertility studies on the acid soils in that area.

C. Continued Relevance of Objectives

The major objectives as stated in the contract are still relevant. Following the experiments with cereal crops such as corn and sorghum, attention has been given in the research to other food crops such as cassava, plantains, and legumes. More emphasis is now being given to the soil moisture factor in relation to soil fertility requirements. It had been assumed that during the rainy season in the humid tropics soil moisture would not be an important limiting factor. However, it was found that dry periods of a week or longer could seriously affect crop responses to fertilizers and lime especially during critical growth periods. This was especially true when the plant roots were restricted to the surface soil and not able to exploit subsoil moisture because of the presence in the subsoil of toxic concentrations of aluminum and/or manganese or a lack of calcium or other essential macro or micronutrients. Deep incorporation of lime, supplementary irrigation during critical growth periods, and the use of acid tolerant species or varieties are a few of the approaches being used to help resolve the problem of moisture stress of the crops as it relates to the soil fertility studies.

D. Accomplishments to Date

Puerto Rico

Nitrogen Experiments: These experiments were begun in April and May, 1970 with corn and sorghum as the test crops to determine the most effective means of applying fertilizer nitrogen on five representative acid soils. Other objectives were to determine the apparent recovery of fertilizer nitrogen by the crops; the interrelationships between crop yield, nitrogen fertilization, and soil inorganic nitrogen content; and the effectiveness of slow release sulfur-coated urea as a source of fertilizer

nitrogen for corn and sorghum on acid soils in the humid tropics. The results of the first two years have been summarized in earlier reports.

The last crop of corn was planted in late spring of 1972 at three of the experimental sites to determine the residual effects on yield of the nitrogen fertilizer applied to the previous crops. The results indicated that there is very little residual effect. Analyses of soil samples taken in the fall of 1972 showed that there had been no change in organic matter or total nitrogen contents in the surface soils since the experiments were started in 1970. There was also no difference in the content of organic matter or total nitrogen between those soils which had received 120 pounds of nitrogen per acre for four crops and those which had received no nitrogen fertilization.

During the five growing seasons of the nitrogen experiments, three rates and two times of application of fertilizer were applied to fifteen corn and three sorghum crops on two Ultisols and three Oxisols representative of the acid soils in the humid tropics. A manuscript on this research has been submitted for publication in a technical journal. The main conclusions are:

(1) Confirmation of the lower efficiency of preplant applications of nitrogen fertilizer for increasing corn yields; there is little reason to consider preplant nitrogen applications in the humid tropics except where the soils are very deficient in nitrogen in which case a relatively small amount of fertilizer nitrogen is needed at planting; the bulk of the fertilizer nitrogen should be applied just before the period of most rapid growth which with corn begins approximately six weeks after germination;

(2) In spite of the humid tropical climate and history of intensive cropping in Puerto Rico, the clayey Oxisols and Ultisols have a relatively high

nitrogen supplying power. The high nitrogen status of these soils is probably due to a history of high application rates of nitrogen fertilizer, and to the fact that two of the sites were in fertilized pasture when the experiment was initiated. With the absence of a long dry season, weeds very quickly cover fallow fields and absorb inorganic nitrogen, thus reducing leaching losses;

(3) There does not appear to be any basic difference between the fate of fertilizer nitrogen in Oxisols and Ultisols except that, with the high aluminum saturation in the Ultisol subsoils, any nitrogen leached below the plow layer is unavailable to aluminum sensitive crops such as sorghum;

(4) The yield potential of about 100 bushels per acre of the corn hybrid used, Pioneer X-306, was obtained in only four of the fourteen corn crops. The grain yield of five summer crops was reduced by drought and of three winter crops by a relatively uncommon disease (Phyllachora maydis). The occurrence of a dry period for two weeks or more in the rainy season during critical growth stages of the crop reduced substantially the beneficial effects of applied nitrogen fertilizer. This emphasizes the need for more critical studies of the soil moisture factor in relation to responses to applied fertilizers.

(5) Because of the high cost of control of insects, diseases, and nematodes in the experimental plots, it is apparent that varieties more resistant to these pests will need to be developed for efficient production of corn in the humid tropics.

Liming and Soil Acidity: Field experiments using different levels of lime with a number of crops have demonstrated the wide range of crop tolerance to soil acidity and aluminum toxicity. To date the crops grown at five locations on representative Oxisols and Ultisols are: Corn, sorghum, green

beans, sweet potatoes, rice, and soybeans. Little or no response to lime was found above pH 5.1 with any of the crops tested. In some cases there was no response above pH 4.5. Sweet potatoes, for example, appears to be quite tolerant to acid soils with relatively high amounts of soluble aluminum. With this crop there was no significant increase in yields as the pH was increased from pH 4.1 to over 5.0. Yields of corn, however, were doubled on a clayey Ultisol when the pH of the soil was increased from about 4.5 to 5.1 with the addition of two tons of lime per acre. On a clayey Oxisol, however, with about the same initial pH, addition of lime did not increase yields significantly.

Some crops such as sorghum are very sensitive to soluble aluminum and their rooting depth on Ultisols is limited to the depth to which lime is applied. During short dry periods the roots cannot exploit subsoil moisture because of the presence of toxic concentrations of aluminum and consequently the plants suffer from lack of moisture. This can occur during the rainy season. A field experiment with sorghum as the test crop was begun this year to determine the effectiveness of subsoil liming for increasing root penetration to exploit subsoil moisture thereby minimizing the serious moisture deficits during the dry periods. Subsoil liming is being compared with surface applications of lime and other calcium compounds. Recent studies have indicated that surface applications of calcium nitrate may be effective in neutralizing subsoil aluminum toxicity.

In summary, the liming experiments have demonstrated the wide range of tolerance of various crops to soil acidity and aluminum toxicity and that, in general, much lower levels of lime need to be applied to the very acid soils of the humid tropics than has been previously thought for the optimum production of many crops. The importance of counteracting subsoil acidity to

increase root penetration and reduce moisture stress during dry periods has been demonstrated and methods for practical application to field situations are being tested.

Phosphorus Experiments: Field experiments on two representative Ultisols with corn, sorghum, and plantains have been conducted during the past three years to: (1) Define response curves of phosphorus fertilizers; (2) estimate the residual effects of applied phosphate; (3) measure the relative efficiency of broadcast versus banded phosphate fertilizers. As reported last year there was no response to applied phosphorus of sorghum or corn at one site even though chemical soil tests and a greenhouse assay had indicated that this soil should respond.

In January, 1972, plantains were planted at this site and the design modified to study the responses to both phosphorus and nitrogen fertilizer applications. Earlier work had indicated that plantains were responsive to applied phosphorus on this soil and as plantain in one of the most important food crops in the tropics, it was decided to initiate soil fertility studies with this crop. The first crop of plantains has just been harvested and the data have not yet been analyzed. However, the yield on all plots are very high and an average of 12 tons per acre of edible fruit is estimated. This is several times the average production in Puerto Rico. In the past nematode infestation has severely limited plantain production, especially the ratoon crops. The availability of a new nematocide, Dasanit, has made it possible to reach very high levels of production especially if the ratoon crops will have high production as anticipated.

At another site on a clayey Ultisol, chemical soil tests indicated a severe deficiency in phosphorus. Corn was planted at this site in the fall of 1971 to test the response to different levels of applied phosphate with

two methods of application, broadcast and banded. During the early months of growth there was a large response to applied phosphate and the banded applications were considerably more effective than the broadcast applications. Near maximum growth was obtained with 80 lbs per acre of banded phosphorus whereas 320 lbs per acre of broadcast phosphorus was necessary for near maximum growth. Unfortunately a little known disease, Phyllachora maydis (tar spot), attacked the corn and caused premature leaf death, grain yield reduction, and large variability. Nevertheless, there was a substantial yield response to applied phosphate with the maximum grain yield obtained with 160 lbs per acre of applied phosphorus. It was somewhat surprising to find that there was not much difference in yield response between the 1000 lbs per acre of applied phosphorus and 80 and 160 lbs per acre as it was found by chemical analysis that the lower applications of phosphate resulted in soil solution phosphorus far below the levels necessary for maximum yields on related soils in the tropics as reported in the literature.

A second crop was planted on this site in May, 1972 and differences in the early growth were observed with the different phosphorus treatments. By the time the grain matured there were little or no visual differences due to treatment. The crop was harvested in September and no significant yield differences were found between treatments. Actually the highest grain yield (92 bushels per acre) was in the zero phosphorus treatment. Chemical analysis showed that the soil in the zero phosphorus plots contained only 0.0027 parts per million of phosphorus in solution which is far below the level considered adequate for near maximum yields.

One obvious explanation is that there was enough mineralization of organic phosphorus to supply the needs of the crop once the root system had become extensive enough to utilize the immobile, mineralized phosphorus. This

hypothesis is supported by the fact that at least 250 lbs per acre of nitrogen was mineralized in the last two crops in an adjacent nitrogen experiment.

It should be noted that the first crop of corn grown in the winter months showed a significant response to applied phosphate whereas in contrast, the second crop grown in the summer did not respond to phosphate applications. This suggests that the warmer summer temperatures resulted in a greater mineralization of organic matter than in the cooler winter months with a consequent release of larger amounts of phosphorus available to the plants.

A considerable amount of research done in the temperate regions indicates that the release of organic phosphorus under field conditions contributes a significant share of the phosphorus to the crop. Because a study of the release of organic phosphorus under tropical conditions might contribute to a more efficient and economical use of phosphorus fertilizer in the humid tropics, investigations have been initiated on the factors involved in the release of organic phosphorus and the relationship to the inorganic phosphorus fraction. These studies should help explain some of the variability in effectiveness of fertilizer phosphorus response predictions when these predictions are based only on some fraction of soil inorganic phosphorus.

Soil Moisture Studies: As indicated in last year's report, water stress of the growing crop commonly occurs in the humid tropics during short periods of drought during the rainy season. It was found that this can seriously limit the response of crops to applied fertilizer nutrients. This is especially so in acid soils where a high content of soluble aluminum in the subsoil creates a hostile environment which limits the rooting depth of many crops, particularly aluminum sensitive crops such as sorghum. In order to assess the effect of the soil moisture factor it is necessary not only to get

detailed information on the climatic conditions but also data on depth of rooting in relation to the soil physical and chemical properties which affect the water supplying characteristics of the soil.

To get additional information on rooting depth and water extraction in relation to crop growth, corn and sorghum were grown at two sites adjacent to the soil fertility experiments (clayey Ultisol and clayey Oxisol). The effective rooting depth was determined by the maximum depth of water extraction by the two crops during the drought period. Water availability was determined by examining the relationship between plant water saturation deficit and soil water tension in the soil profile as the water supply diminished.

The results indicate that on the Ultisol the corn plants were not able to utilize soil water beyond a depth of 12 inches although during the drought period the soil profile below this depth was at field capacity. Studies of the root distribution showed that about 7[illegible] percent of the roots were found in the surface 5 inches. The high aluminum content and compaction of the subsoil undoubtedly were the main factors restricting root development in this soil.

In contrast the roots of corn on the clayey Oxisol were able to utilize soil moisture to a depth of three feet or more and 75 percent of the roots were found in the upper 20 inches. The subsoil of this soil has no appreciable amounts of aluminum and is not compacted.

The results with sorghum on the two soils were generally similar to those with corn although it appeared that the sorghum plants were better able to utilize the available soil moisture of the surface layer than corn. The studies are still in progress and a more complete interpretation of the data

will be made on completion of the experiments.

Brazil

Introduction: The research in Brazil was started in July, 1972 at the Brasilia Experiment Station under an agreement developed in 1971 by the Brazilian Ministry of Agriculture, Cornell University, North Carolina State University, and USAID/Brazil. Cornell and North Carolina State Universities are contributing jointly to a single research effort at Brasilia under their respective contracts. Dr. George C. Naderman of Cornell has the main responsibility for coordination of the project at Brasilia. Three junior scientists joined the project in Brasilia during the first year of operation: Mr. Enrique Gonzalez E. and Mr. Russell S. Yost of North Carolina State University and Mr. James M. Wolf of Cornell University. Although each of the individuals based in Brasilia has major responsibility for the specific segment of research most closely related to his interest and training, all members of the team have been involved in the planning and implementation of all parts of the project. Part of the work of the junior scientists will be used for their respective doctoral dissertations.

Faculty members of both Cornell and North Carolina State Universities have provided short-term on-site consultation. Professor E. J. Kamprath of North Carolina and Professor Gilbert Levine of Cornell have spent about two weeks at Brasilia to advise on the phosphorus, lime, and soil moisture studies. Professor F. R. Cox of North Carolina worked with the group for about a month in establishing the zinc experiments. Professor M. G. Cline of Cornell and Professor S. W. Buol of North Carolina in collaboration with four Brazilian scientists spent about three weeks in the region to investigate the extent to which the results of the research at

the experiment station could be applied to other areas in the Central Plateau of Brazil. They suggested modifications in the program to increase the usefulness of the findings.

The project is based at the Brasilia Experiment Station in the Federal District. Offices, laboratory facilities, field labor, field equipment, fertilizers, insecticides, and land area at the station have been provided by the Brazilian government. Mr. Eneas Z. Galrać, staff member, and Mr. Wilson V. Soares, Director of the station and soil specialist, have been closely associated with the planning and implementation of the project. The services of one full-time Brazilian technical assistant, Mr. Elcios Martins, have been obtained through a contract between Cornell University and a Brazilian employment agency. Under this arrangement, Mr. Martins has operational responsibility for much of the experimental work and manages the field labor staff.

USAID/Brazil has been most cooperative in providing two vehicles and their maintenance for the project. These vehicles are used almost entirely for daily trips to the experimental site which is located about 25 miles from Brasilia. The USAID Mission has also provided other services to the project personnel at Brasilia such as language training, health, communications, household furnishings, and other services.

Objectives: Experimental work had been initiated at the station in 1966 and the results through 1971 have provided valuable guidelines for initiating project operations. As a result of a review of the previous research with the Director of the Experiment Station and his staff and with the Director of Agricultural Research of the Ministry of Agriculture and his associates, the initial objectives of the research were to establish

the following experiments on a soil (Dark Red Latosol in the Brazilian classification and probably Typic Haplustox, fine, isohyperthermic, kaolinitic in the U.S. Soil Taxonomy) representative of extensive areas in the Campo Cerrado with corn as the test crop to:

1. Measure growth and yield responses to different levels, frequency of application and sources of nitrogen fertilizers;

2. Determine growth and yield responses to levels and methods of application of phosphorus fertilizers and their residual effects;

3. Measure growth and yield responses to levels of incorporation of lime and determine the soil moisture relationships to depth of incorporation of lime;

4. Evaluate soil characteristics related to moisture supply under different levels of water applied by natural rainfall and by controlled irrigation;

5. Determine suitable rates and residual effect of zinc fertilization and relationship to different levels of lime applications on growth and yield response.

Experiments and Results: The details of the field experiments and the data obtained are given in Appendix I. Following are the conclusions from the first crop of corn which was planted in November and December, 1972 during the rainy season and harvested in March and April, 1973.

Nitrogen: (1) The average yield of corn ranged from about 50 bushels per acre with only about 18 pounds per acre of nitrogen applied as urea to over 100 bushels of corn per acre with the application of about 125 pounds per acre of nitrogen; (2) there was a high variability in the responses to the different nitrogen treatments which could be accounted for by the variation in the amount of nitrogen released from the mineralization of the organic matter; (3) the addition of 36 pounds per acre of nitrogen 28 days after planting gave a substantial increase in yield over that obtained with 18 pounds per acre applied preplant; (4) the highest yields (100 bushels per acre) were obtained with 36 to 54 pounds of nitrogen per acre applied

20 days after planting plus 36 or 54 pounds applied 52 days after planting; (5) the application of nitrogen as calcium nitrate gave about the same results as that applied as urea; (6) generally the response to sulfur-coated urea was about the same as that of regular urea; (7) undoubtedly the response to nitrogen applications would have been greater if more phosphate had been applied in the basic treatment. Only about 350 pounds of P_2O_5 per acre were applied and the phosphorus experiments summarized below indicate that this amount was not adequate for maximum yields.

Phosphorus: (1) The soil was extremely deficient in phosphorus and large applications of phosphate fertilizer were necessary to obtain good yields; (2) the maximum grain yield (130 bushels per acre) was obtained with 1280 kg/ha (1150 lb/acre) of P_2O_5 applied broadcast as simple superphosphate; (3) applications of 40 and 80 kg/ha (35 and 70 lb/acre) of P_2O_5 banded resulted in only 30 percent of the maximum yield with no significant difference between the two treatments; (4) broadcast applications of superphosphate were significantly better than the same amounts applied in bands; for example, 320 kg/ha (280 lb/acre) of P_2O_5 applied broadcast resulted in yields of almost 80 percent (100 bushels per acre) of the maximum while the same amount applied in bands yielded only 60 percent of the maximum; (5) a split application of 80 kg/ha (70 lb/acre) banded and 80 kg/ha broadcast was equally as effective as 320 kg/ha of P_2O_5 applied in the band; (6) increasing the amounts of phosphate applied broadcast increased yields proportionally, from 160 kg/ha of P_2O_5 resulting in a yield of about 66 percent of maximum to 1280 kg/ha resulting in the maximum yield of about 8000 kg/ha (130 bushels per acre). The complete data are given in Appendix I.

As indicated above one of most interesting results with the first rainy season corn crop was the greater effectiveness in grain yield response

to simple superphosphate applied broadcast in comparison with that banded although in the early weeks of growth the banded applications were more effective. This is contrary to what was expected. Usually cereal crops are more responsive to banded applications than the same amounts broadcast on phosphorus deficient soils. The high capacity of this soil to fix phosphorus in a form not readily available to the plants is indicated by the large amount required (1250 kg/ha) to obtain maximum yields. The response curve indicates that even higher applications would probably result in higher yields. It is obvious that an important problem to resolve is how to effect a more efficient use of the applied phosphate. Preliminary laboratory studies have indicated that the application of liming materials such as calcium carbonate and calcium silicate can increase the effectiveness of applied phosphate on this soil. Also, it is planned to determine the residual effects of the large amounts of applied phosphate on subsequent crops.

Lime: This experiment compared different levels of lime, 0, 1, 2, 4, and 8 tons per hectare. Each level of lime was incorporated at two depths, 0 to 15 cm (6 inches) and 0 to 30 cm (12 inches). In addition to determining the effects of levels of lime applied, an important objective was to determine if the deeper incorporation of lime increased the rooting depth sufficiently to permit exploitation of subsoil moisture during the short dry period which usually occurs during the rainy season when the crop was grown. It was observed that during the short dry period wilting occurred on the shallow lime treatments generally about three days before it occurred on the deeper lime treatments. This was reflected in the yields which were 20 percent less for the shallow incorporated lime. This beneficial effect of deep lime incorporation was obtained regardless of the level of lime used. Root measurements show that the roots in the unlimed subsoil were much coarser

and distorted and less extensive than those in the limed subsoil although there was little difference in the weight of the dry roots. This indicates that root weight measurements are not adequate for determining root behavior. More complete data are given in Appendix I.

There were no significant differences in grain yield between the plots with 1, 2, 4, or 8 tons of lime per hectare incorporated at the shallow depth. The average yield of grain was about 3650 kg/ha (about 60 bushels per acre) in comparison with the check plots which averaged about 34 bushels per acre. For the plots with incorporation of lime to 40 cm, there were no significant differences between the 2, 4, and 8 tons applications which averaged about 4600 kg/ha (about 83 bushels per acre) which was somewhat higher than the one ton treatment. The yields were less than maximum probably because the basic phosphate application to all plots was only 300 kg/ha of P_2O_5 which is not adequate for maximum yields as indicated by the data from the phosphorus experiments.

Soil Moisture: Preliminary soil moisture studies made during the summer of 1972 at the soil fertility experimental site confirmed that water management is an essential component of the soil fertility investigations. The main objective of the preliminary studies was to establish the soil-water characteristics at the site. Relationships were established between soil-water content and soil moisture tension measurements. Determinations were made of rates of infiltration, bulk densities and field capacities. Details of these studies are given in Appendix I.

The rate of water infiltration was usually rapid and ranged from 16 to 24 cm/hr. There was little diminution in the rate of infiltration after two successive floodings, the first with 55 cm of water and the second with 23 cm of water about four weeks later. This infiltration rate is similar to

that observed earlier on a closely related soil in the Puerto Rico soil moisture studies. The bulk densities of the soil ranged from 1.05 gm/cc at the 7.5 cm depth to 0.95 gm/cc at the 60 cm depth.

Soil-water characteristics were obtained at depths of 7.5, 30, 60, and 90 cm. Data in the tension range 0-0.5 bar were obtained by correlating corrected soil tensiometer readings with corresponding results of gravimetric sampling. In the range 1 to 15 bars, disturbed soil samples were run using conventional pressure plate apparatus techniques. The following table summarizes the data for two depths:

Soil-Water Tension Bars	Soil-Water Content (%) 0-45 cm	45-105 cm
1/13-1/10*	35.6	34.0
1/9-1/7 (Field Capacity)**	33.4	32.4
1	24.5	22.0
15	19.0	19.0

* One day after a heavy irrigation or rainfall which saturated the profile, soil-water tensions ranged from 1/13 to 1/10 bar.

** Field capacity has been defined as the water content of the soil after the profile has been saturated and allowed to drain for two to three days. In this study the soil continued to drain and the water content never reached equilibrium. Thus, the concept of field capacity may not be very useful for assigning an upper limit to water availability in this soil. The fact that substantial percolation occurs in these soils under unsaturated conditions has important management implications. For example, continued leaching and loss of applied fertilizer material may occur many days following a rainfall or irrigation.

The use of soil-water release curves allows calculation of water storage. The maximum amount of water which can be stored in this soil to a depth of 30 cm is about 50 mm. When one considers that evapotranspiration can be 7 mm or more per day, water stress is likely after about a week without rain

or irrigation if the rooting depth is no more than 30 cm. Actual field observations on shallow rooted corn during the 1972-1973 rainy season indicated wilting after six days of a dry spell. Rainfall records indicate that ten days without rain may occur one year in two and two weeks or more without rain one year in five. This points up the importance of either providing supplementary irrigation for the crop during stress periods, extending the rooting depth by deep lime incorporation, or using crops or varieties which are tolerant of aluminum toxicity and very low levels of calcium and magnesium.

Zinc: Without some application of zinc, corn makes very poor growth on this soil and produces very little grain. Field experiments were established to compare zinc levels of 1, 3, 9, and 27 kg/ha. Near maximum yields were obtained with 3 kg/ha.

E. Dissemination and Utilization of Research Results

The results of the research have been disseminated in a number of ways: (1) Conferences, workshops, and seminars; (2) visits to the experimental sites by farmers, extension agents, students, teachers, and scientists; (3) graduate student participation; and (4) publications.

Conferences, workshops, and seminars: Though the work in Brazil has been under way for only about a year, the results of the initial experiments are getting wide dissemination. A preliminary paper was presented at the Brazilian Congress of Soil Science in Santa Maria in July 1973 and several popular articles have been printed in the "Supplemento Agropecuario" of the Diario de Brasil in February and March of 1973. A summary of the results to date was presented at the University of Brasilia in July 1973.

Two meetings during the year of the University Consortium on Soils of the Tropics, sponsored by an AID 211(d) grant, have provided an important

way to disseminate the findings of the project. Each of the five-member universities is building both its research and teaching competence in tropical soils. The research on this project is immediately available for related research activities of the other institutions. The Consortium institutions have a large number of students from the developing countries in the tropics, and they are made aware of the latest research findings through formal seminars and informal discussions. Three seminars have been presented at the Agronomy Department during the past year on the findings of the project.

Visits to experimental sites in Puerto Rico and Brazil: The experimental sites have had continual visits from substantial number of farmers, extension agents, students, teachers, and scientists. Following are some examples:

During the past year some 500 to 1000 farmers and extension agents have visited the intensively managed soil fertility experiment with plantains in Puerto Rico. The yield of approximately 65,000 plantains per acre in this experiment is about three times that attained by the average farmer. Many farmers have indicated their intention to adopt the improved practices which do not require a very substantial departure from current practices. As there is considerable interest in many of the Caribbean and Central American countries to increase the production of plantains, thought is being given to invite representative farmers and extension agents from these countries during the coming year to demonstrate the improved technology.

At the Brasilia experimental site there have been a number of visits by various groups. One was a group of about 40 farmers organized by the extension service of the Federal District. On several occasions administrative officials of the Ministry of Agriculture have visited the experimental plots. These included officials concerned with fertilizer promotion, plant

protection, planning and economic development. The staff of ten from the vocational agricultural school near Brasilia spent a day at the experimental site. An agronomy class of 15 students from the University of Brasilia visited the field plots. Several students from the University have worked on the project on their own time at the station laboratory to gain experience. A frequent visitor to the experimental site is a Brazilian farmer who has purchased land in the area which he is developing for seed production of wheat, soybeans and other crops. He is drawing on the experimental results in the plots for guidance for his management practices.

Graduate student participation: About 20 graduate students, foreign and U.S., have been or are now either directly involved in the project or research related to it. During the past year a student from the Dominican Republic, Mr. Rafael [illegible], completed his M.S. degree thesis research on the project in Puerto Rico. He has been appointed head of the Soils Department at a University in the Dominican Republic and is interested in developing a soil fertility research program at his institution in collaboration with Cornell and Puerto Rico. This possibility is now being explored. Dr. Ritchey of the U.S. completed his Ph.D. thesis research in Puerto Rico on work directly related to the project and now has a position in northeast Brazil under contract with the University of Wisconsin. Mr. Mughacho of Malawi is doing his M.S. degree thesis research in laboratory studies related to the Puerto Rico field studies. Mr. James Wolf of the U.S. is doing his Ph.D. thesis research on the project in Brasilia.

Publications: Upon completion of phases of the project, the data are analyzed and interpreted. Reports are prepared for publication in appropriate technical and non-technical journals. A list and abstracts of publications, articles submitted for publication, theses, and reports prepared for

conferences during the past year are given in Appendix II.

F. Research Linkages

1. The research in Puerto Rico is in cooperation with the University of Puerto Rico Agricultural Experiment Station under a subcontract. Staff members of the Experiment Station are assigned to the project. Some phases of the research project have been in collaboration with soil scientists of the U.S. Department of Agriculture stationed in Puerto Rico.

2. The research activities in Brazil are being carried on cooperatively with the Brazilian Ministry of Agriculture and North Carolina State University. Frequent contact is maintained in other phases of the project with North Carolina State University which has a related research project, "Agronomic-Economic Research on Tropical Soils."

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

4. Continuing contact and collaborative arrangements for research are being maintained with the International Research Institutes:

(a) At a Seminar on Shifting Cultivation and Soil Conservation in Ibadan, Nigeria in July, 1973, Dr. Lathwell had the opportunity to discuss soil fertility research work with soil scientists of the International Institute of Tropical Agriculture (IITA). Rearranged with Dr. Kang of IITA to have soil samples sent to Ithaca from their nitrogen experiments to determine the applicability of a simple procedure developed by Dr. Lathwell for determining the nitrogen supplying power of soils of the tropics.

Arrangements have been made with IITA for a cooperative research project entitled, "Agricultural Land Use and Potential in Relation to the Genesis and Classification of Soils of a Climatic Sequence on Early Pleistocene and Late Tertiary Sediments in West Africa." Dr. Frank Moormann of IITA, Dr. M. G. Cline, Dr. K. A. A. Ad, and Mr. Terry Forbes of Cornell have responsiblity for the project. Mr. Forbes will be the main investigator. In addition to IITA, AID, and Cornell, other cooperators are West African research institutions that cooperate with IITA. This study would appraise the potential performance of different kinds of soils in the area where data are available. It would determine soil properties at benchmark sites from Togo to southeastern Nigeria where IITA, IRAT (French Research Institute of Tropical Agriculture), and West African research institutions have data on soil performance. Based on this information, the soils would be classified as bases for extending the information to other tropical regions.

(b) Collaborative arrangements for research have established with the Centro International de Agricultura Tropical (CIAT) on problems of mutual interest related to the objectives of the project. Dr. Eduardo Alvarez, Associate Director of CIAT, has recently visited Cornell and offered his cooperation in our research efforts, particularly in connection with soil fertility experiments on cassava.

Arrangements have been made for a Cornell Ph.D. candidate from Cameroon to do his thesis research at CIAT on cassava which will include soil fertility studies. Another Ph.D. candidate from Ghana at Cornell is now doing his thesis research at CIAT on legume Rhizobium. This work has important implications for the nitrogen economy in crop production in the tropics.

(c) An arrangement has recently been formalized between Cornell and CIMMYT (Centro Internacional de Mogoramiento de Maiz y Trigo) for a graduate

training and research program to involve a team of five Ph.D. candidates from different disciplines (Soil Science, Plant Protection, Plant Breeding, and Agricultural Economics) to work on a project problem which would involve a multi-disciplinary approach. The research team would be under the guidance of Cornell faculty and CIMMYT research scientists. This is a four-year program and will provide continuing contact and association with CIMMYT.

5. Regular communications have been carried on with FAO soil scientists in Rome and other stations, and there has been a periodic exchange of publications. Dr. Lathwell participated in the FAO sponsored Regional Seminar--Shifting Cultivation in Africa at the University of Ibadan in Nigeria. At this seminar he had the opportunity to discuss with FAO representatives problems of mutual interest in tropical soils research. Dr. Olson spent several months as a consultant to soil scientists in the FAO Office in Rome on soil survey interpretations.

6. Soil scientists from abroad with extensive experience in the tropics are invited to Cornell for formal lectures and seminars and consulting with faculty and students on their research activities on soils of the tropics. During the past year Dr. E. W. Russell, for a number of years Director of the East African Agriculture and Forestry Research Organization, spent about six months on the campus; Mr. Carlos Zamora, Director of Natural Resource Surveys (Soils, Water, Forests) for the Peruvian government, was at Cornell for about three weeks; Dr. A. VanWambeke, University of Ghent and frequent FAO consultant on soils of the tropics, was on the campus for several days.

7. Participation of Cornell soil scientists in research conferences and seminars on soils of the tropics provide opportunities for interaction with colleagues from tropical countries. During the past year Dr. Arnold

participated in a meeting of the IV Latin American Soil Congress at Maracay, Venezuela; Dr. Lathwell attended the Caribbean and Tropical America Soils Conference at Trinidad sponsored by the University of the West Indies.

8. Important research linkages are developed and maintained through graduate students from tropical countries who return to their home countries to positions which involve a substantial research component. During the past year 16 students from the developing nations, most of them from the tropics, did graduate work with a major in soil science. Five have returned to their home countries and periodic contact is maintained with them.

G. Expenditures--July 1, 1972 to June 30, 1973

	Cornell	Puerto Rico Subcontract	Total
Salaries and Wages	$ 61,659.83	$ 90,107.28	$151,767.11
Overhead	21,823.36	41,665.60	63,488.96
Travel and Transportation	10,307.11	4,854.24	15,161.35
Allowances	6,712.30	---	6,712.30
Equipment, Vehicles, and Supplies	2,166.20	11,441.36	13,607.56
Other Direct Costs	1,505.45	2,850.19	4,355.64
TOTAL	$104,174.25	$149,918.67	$254,092.92

H. Work Plan (April 1, 1974 to March 31, 1975)

It is planned to reduce substantially the effort in Puerto Rico during the next three years and expand the work in Brazil and develop collaborative programs in other developing countries in the tropics. Investigations in the new areas will be similar to those in Puerto Rico with the necessary modifications for on-site testing of the validity of the earlier findings under somewhat different soil and climatic conditions. Collaboration with

the Soils Research Institute at Kumasi, Ghana is being negotiated, and it is planned to initiate project activities there during the coming year. The soil scientists at Kumasi were very much interested in participating in a cooperative research program. A request for collaboration with a University in the Dominican Republic is being explored and a modest program there may be developed in the coming year closely related to the work in Puerto Rico. The following program focuses on research activities for the coming year noting those which will continue beyond March 1975.

Puerto Rico

Experiments with cassava and plantains: Following the work on cereal food crops, a large part of the work in Puerto Rico is being concentrated on responses to applied nitrogen and phosphorus of such important food crops in the tropics as cassava and plantains. Cassava was planted at the four experimental sites in the spring and summer of 1973 and will be harvested during the coming year. A new high protein variety is being used on which there is little information on response to various rates and methods of application of nitrogen fertilizers. In addition to the yield data, soil and plant analyses will be made to help in the interpretation of the data on the efficiency of utilization of the applied nutrients.

The first crop of plantains planted on a representative clayey Ultisol in January, 1973 was harvested during the summer of 1973, and it is planned to determine the yield response to nitrogen and phosphorus on at least two ratoon crops. It is expected that the first ratoon will produce a crop between seven and nine months after the first crop. At another location an extensive field trial with plantains is being conducted in cooperation with the U.S. Department of Agriculture soil scientists to

determine nitrogen responses in various combinations with phosphorus, potassium, lime, and micronutrients. This experiment will run for at least three years in order to measure the responses of the ratoon crops to the various treatments. In all of the experiments with plantains, soil and plant analyses and observations on root growth will be made to supplement the yield data.

Liming experiments: A field trial has been initiated on a clayey Ultisol to determine the effect of incorporating lime in both the subsoil and surface soil in comparison with liming only the surface soil. A surface application only of a neutral salt, calcium nitrate, is included in the treatments as previous research on related soils in southeastern United States has indicated that the downward movement of the calcium ion has been effective over a period of time in neutralizing somewhat the aluminum toxicity of the subsoil. Two test crops, corn and sorghum, are being used in this experiment which will continue for about two years. This work is being done in cooperation with U.S. Department of Agriculture soil scientists.

Brazil

Soil fertility studies: A series of field experiments was initiated in 1972 in collaboration with the Brazilian Ministry of Agriculture and North Carolina State University on a clayey Oxisol at the experiment station near Brasilia which is representative of extensive areas of the deep, well-drained highly acid soils of the Campo Cerrado. Similar to the work in Puerto Rico these experiments are designed to measure the responses of corn and subsequently other crops to different levels and methods of application of nitrogen, phosphorus, and lime. The first wet season crop of corn has been harvested, the dry season irrigated crop has been planted, and the

second wet season crop will be planted in the fall of 1973. The results of the yield data of the first three corn crops and supplementary soil and plant analyses will help determine whether corn or some other test crop will be planted subsequently.

Similar experiments are contemplated on a medium textured Oxisol which is also very extensive in the area and which may respond somewhat differently to fertilizer and lime applications. A search is being made to locate a suitable site which meets the necessary criteria for the experiments.

Preliminary work on soil fertility studies with forage crops has been initiated. The initial experiments will involve responses to different sources of phosphate by a legume, Stylosanthus, and a grass, Brachiaria, which are two of the more promising pasture crops for the region. The field plots will be established in the fall of 1973 and is expected to continue for several years.

As an integral part of the soil fertility studies, research will be initiated in the early part of 1974 to determine some of the physiological responses of corn under different soil management practices. Two sets of interrelated experiments will be superimposed on the soil fertility treatments. One set of experiments will focus on the above ground portion of the corn plant. Detailed growth analysis studies and an in-depth look at the effects of water stress will be made on the plant as related to soil treatments in both wet and dry seasons. The second set of experiments will focus on the below ground portion of the plant. The effects of water stress on some physiological aspects of root growth and development and on nutrient and water uptake will be studied as they relate to the soil fertility and management practices.

Soil Moisture Studies: These studies initiated in the summer of 1973 are directly related to the soil fertility research as water management is a critical factor in determining suitable soil and crop management practices on the Campo Cerrado. Preliminary studies on soil-water characteristics and crop water use for the wet and dry season corn crops in 1973 have provided basic information for the experiments on the subsequent corn crops to be grown during the rainy season of fall and winter 1973-1974 and the summer dry season of 1974. Actual crop water use will be correlated with a model to predict evapotranspiration from available climatic data which has been assembled and analyzed. The meteorological information which will be collected include pan evaporation, insolation, precipitation, temperature and wind speed. The ultimate objective in these studies is to determine the relationship between crop yield and soil-water stress and between yield and amount of water applied as related to certain soil fertility management practices.

Ghana

It is planned to initiate field, greenhouse, and laboratory soil fertility research during the coming year in collaboration with the Soils Research Institute at Kumasi and the University of Ghana near Accra. Cooperation with the International Institute of Tropical Agriculture at Ibadan is planned. Preliminary discussions with scientists of these institutions indicated a definite interest in a joint research effort. The priority areas for the suggested research on representative acid soils of the area may include: (a) Methods of supplying the nitrogen requirements of important food crops; (b) methods of economically correcting soil acidity as a factor limiting crop production; (c) methods of economically supplying phosphorus for sustained crop production; (d) determination of micronutrient deficiencies

through observations, soil analysis, plant analysis, and yield response experiments; (e) soil moisture studies to determine water utilization patterns and to develop methods for more efficient use of water in relation to nutrient uptake.

Two soil scientists from Cornell will visit Ghana in the spring of 1974 to work with the Ghanian soil scientists and officials in developing the details of a mutually acceptable research plan and a memorandum of agreement on the commitments of the institutions involved in the project.

Work Plan; Abstract and Time Table

Location	Starting Date	Expected Completion
PUERTO RICO		
1. Nitrogen and phosphorus experiments with cassava on Oxisols and Ultisols at 4 locations.	April '73	April '75
2. Nitrogen and phosphorus experiment with plantains on a representative Ultisol.	Jan. '72	June '76
3. Nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrient experiment with plantains.	April '73	June '76
4. Subsoil liming on high aluminum soil with corn and sorghum as test crops.	May '73	June '75
BRASILIA, BRAZIL		
1. Nitrogen and phosphorus experiments: Rates and methods of application of nitrogen and phosphorus fertilizers for determining their most effective utilization by corn and other food crops on soils representative of extensive areas in the Campo Cerrado.	Oct. '72	June '77
2. Liming experiments: Effect of deep placement of lime in comparison with surface applications on yields of corn and other food crops.	Oct. '72	June '77
3. Soil moisture studies to determine the relationship between crop yield and soil fertility as affected by water availability under natural rainfall and irrigation.	Jan. '73	June '76

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

Location	Starting Date	Expected Completion
GHANA		
1. Nitrogen and phosphorus experiments: Rates and methods of applicaton of nitrogen and phosphorus fertilizers for determing their most effective utilization by corn and other food crops on representative acid soils of the area.	July '74	June '77
2. Liming experiments: Effect of rates and placement of lime on yields of corn and other food crops on representative acid soils of the area.	July '74	June '77
3. Soil moisture studies: Development of improved water management practices in relation to soil fertility requirements.	July '74	June '77
ITHACA		
1. Chemical studies on soil samples from field experiments in Puerto Rico, Brazil, Ghana, and other countries to help interpret the field experiments and provide a basis for the application of the data to similar soils in other areas of the tropics.	April '73	June '77
2. Clay mineralogical analyses of soils from the experimental plots and similar soils from other areas to assist in the interpretation of the field and laboratory data.	April '73	June '77

Budget Plan - April 1, 1974 to March 31, 1975

Salaries	$ 160,000
Overhead	55,000
Travel & Transportation	18,000
Allowances	15,000
Other Direct Costs	5,000
Equipment, Vehicles, & Supplies	22,000
TOTAL	$ 275,000

Personnel - April 1, 1974 to March 31, 1975

Location		Man Months
PUERTO RICO		
Professional		
R. H. Fox	- Soil Scientist	12
E. J. Brenes	- Soil Chemist	6
R. deValle	- Agronomist	6
Y. Fraticelli	- Chemist	6
H. Talleyrand	- Research Assistant	12
Nonprofessional		
V. Santiago	- Lab. Technician	12
M. Malave de Garcia	- Secretary	12
Laborers (Field)		48
Laborers (Lab and Greenhouse)		12
BRASILIA, BRAZIL		
Professional		
G. C. Naderman	- Soil Scientist	12
J. Wolf	- Res. Assistant	3
D. Bandy	- Res. Assistant	12
J. Pruntel	- Res. Assistant	3
Nonprofessional		
Eleios Martins	- Field Assistant	12
--	- Lab. Assistant	12
Laborers (Field and Lab.)		15
GHANA		
Professional		
--	- Soil Scientist	9
--	- Res. Assistant	5
--	- Field and Lab. Technician	9
Laborers (Field and Lab.)		15
ITHACA		
Professional		
M. Drosdoff	- Soil Scientist	3
R. M. Weaver	- Soil Scientist	6

Personnel

Location		Man Months
ITHACA		
Professional (cont'd)		
D. R. Bouldin	- Soil Scientist	1
D. J. Lathwell	- Soil Scientist	2
T. W. Scott	- Soil Scientist	2
R. B. Musgrave	- Crop Scientist	2
Nonprofessional		
M. Buyukcolak	- Secretary	12

Appendix I

Details of the Soil Fertility Experiments with Corn at the Experiment Station near Brasilia, Brazil

SOIL

The soil on which the experiments were conducted is classified in the Brazilian system as a Dark Red Latosol, dystrophic, clayey, cerradão phase. In the U. S. Soil Taxonomy this soil would fall in either the Haplustox or Acrustox great group.

The surface 10 cm is a dusky red (10R 3/4, moist) that grades through a transitional horizon 25 cm thick to a dark red (10R 3/6 to 10R 4/6) subsoil. The solum extends to a depth of more than 2 meters and is a clay throughout. The clay is aggregated in very fine granules so that the soil is very friable when moist and is very porous. The bulk density is 1.05 g/ml at 7.5 cm and 0.95 g/ml at 60 cm depth.

The soil is a clay throughout but it feels like a loam or fine sandy loam because of the predominance of strong ultrafine granules less than 0.5 mm in diameter which require vigorous rubbing for several minutes while wet to be destroyed.

Selected analytical data of the soil from the soil are given in the following table and is taken from Boletim Tecnico No. 8 of Division of Pedology and Fertility of the Brazilian Ministry of Agriculture:

Horizon	Depth	Sand[1/]	Silt[1/]	Clay[1/]	Water Dispersible Clay	pH H_2O	pH KCl
	cm	%	%	%	%		
Ap	0-10	36	19	45	14	4.9	4.2
A3	10-35	33	18	48	6	4.8	4.3
B1	35-70	35	18	47	1	4.9	4.2
B21	70-150	35	18	47	0	5.0	4.2
B22	150-260	39	19	42	0	4.6	4.4

Depth	C	N	Exchangeable Cations - me/100 g Ca + Mg	K	Al
cm	%	%			
0-10	1.8	0.21	0.4	0.10	1.9
10-35	1.2	0.08	0.2	0.05	2.0
35-70	0.9	0.05	0.2	0.03	1.6
70-150	0.7	0.05	0.2	0.01	1.5
150-260	0.3	0.03	0.2	0.02	0.7

[1/] Unpublished data from reanalysis of samples in July, 1973, courtesy of M. N. Camargo of the Division of Pedology and Soil Fertility of the Ministry of Agriculture.

NITROGEN EXPERIMENT

Plot Size, Planting Distance, and Design

5 x 10 meters. Rows 80 cm apart (6 rows). Plants 20 cm apart in the row giving about 50,000 plants/ha.

5 replications in randomized blocks.

Variety

Cargill 111.

Basic Treatments

Phosphorus: 200 kg/ha of P_2O_5 as single superphosphate broadcast, plowed down, and rotovated to a depth of about 20 cm one week before planting;

200 kg/ha of P_2O_5 as triple superphosphate banded at planting.

Potassium: 100 kg/ha of K_2O broadcast with the single superphosphate.

Lime: 4 tons/ha of $CaCO_3$ equivalent lime containing 10 percent Mg; 60 percent was finer than 60 mesh and 40 percent finer than 100 mesh; plowed down and rotovated to a depth of about 20 cm before planting.

Magnesium and Micronutrients: 50 kg/ha of $MgSO_4 \cdot 7H_2O$, 50 kg/ha of sodium molybdate. These were plowed down with the lime.

Planting and Harvest Dates

Planted November 17, 1972 and harvested on March 25, 1973.

Irrigation

The plots received a complete wetting once in mid-January.

The following table lists the nitrogen treatments and the corn yield responses.

Source	Time and Amount of Applied N: Pre-plant	After Planting: 20 days	After Planting: 28 days	After Planting: 56 days	Yield * (shelled corn 15.5% moisture average of 5 repl.)
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
Urea	20	---	---	---	3246
Urea	0	---	40	---	3582
Urea	20	---	40	---	4027
Urea	20	---	80	---	5285
Urea	20	40	---	40	6179
Urea	20	---	120	---	6257
Urea	20	60	---	60	6310
$Ca(NO_3)_2$	20	---	80	---	5423
Urea sulfur coated #1	20	---	80	---	5096
Urea sulfur coated #2	20	---	80	---	5677

PHOSPHORUS EXPERIMENT

Plot Size, Planting Distance, Design and Variety

The same as the nitrogen experiment.

Basic Treatments

Nitrogen: 30 kg/ha of N as urea banded at planting, 40 kg/ha after 30 days and 40 kg/ha after 62 days.

Potassium, Lime, Mg, and Micronutrients: The same as in the nitrogen experiment.

Planting and Harvest Dates

About the same as in the nitrogen experiment.

The following table gives the data on responses of corn to the method and amount of P_2O_5 applied as simple superphosphate:

P Treatment					
Broadcast kg/P_2O_5/ha	Band kg/P_2O_5/ha	Leaf area index	Grain yield shelled corn 15.5% moisture	Proportion of maximum yield	P in ear leaf
			kg/ha *	%	%
---	40	2.10	2263 a	28.0	.089
---	80	2.16	2414	30.0	.085
---	160	2.66	3855 b	48.4	.106
80	80	2.88	4568 c	57.3	.149
---	320	3.12	4796	60.2	.106
160	---	2.56	5233 d	65.7	.142
320	---	3.08	6277 e	78.8	.172
320	80	3.32	6659	83.6	.153
640	---	3.37	6796 f	85.3	.176
1280	---	4.14	7961 g	100.0	.212

* Duncan's multiple range test for significant differences at .05 percent is indicated by the small letters.

LIMING EXPERIMENT

Plot Size, Planting Distance, Design, and Variety

The same as the nitrogen experiment.

Basic Treatments

Nitrogen: 20 kg/ha of N as ammonium sulfate banded at planting, 40 kg/ha applied as urea after 30 days and 40 kg/ha after 60 days.

Phosphorus: 200 kg/ha of P_2O_5 as triple superphosphate broadcast and 100 kg/ha applied in the band.

Potassium, Magnesium, and Micronutrients: The same as in the nitrogen experiment.

Planting and Harvest Dates

The corn was planted on December 11, 1972 and harvested on May 10, 1973.

Irrigation

The plots were not irrigated.

The following table gives the data on responses of corn to amount and depth of incorporation of lime:

Lime tons/ha	Depth of Incorporation cm	Grain yield at 15.5% moisture kg/ha*				Leaf area index
4	0-30	4797	a			2.65
8	0-30	4792				3.15
2	0-30	4341		b		2.41
1	0-30	4019				2.54
4	0-15	4004				2.25
8	0-15	3723				2.83
0 + 1 ton of $MgSO_4 \cdot 7H_2O$	0-30	3572		c		2.40
2	0-15	3531				2.28
1	0-15	3423			d	2.35
0		2115			e	2.04

* Duncan's multiple range test for significant differences is indicated by the small letters.

The following table gives the effects of the amount and depth of incorporation of lime on Al saturation of the soil and root development.

Lime Rate	Depth of lime incorporation	Depth increment of sample	Al sat'n	Dry wt. of roots	Root length/ soil volume*
T/ha	cm	cm	%	g	cm/100 cm^3 soil
2	0-15	0-15	24	13.9	1007
	"	15-30	60	9.4	236
	"	30-45	69	1.8	56
4	0-15	0-15	6	12.5	912
	"	15-30	55	9.3	342
	"	30-45	65	3.0	108
4	0-30	0-15	8	14.1	930
	"	15-30	20	8.2	650
	"	30-45	65	3.5	137

* The line intersection method used here for the determination of root length was reported by E. I. Newman, 1966, Appl. Ecology 3:139-145.

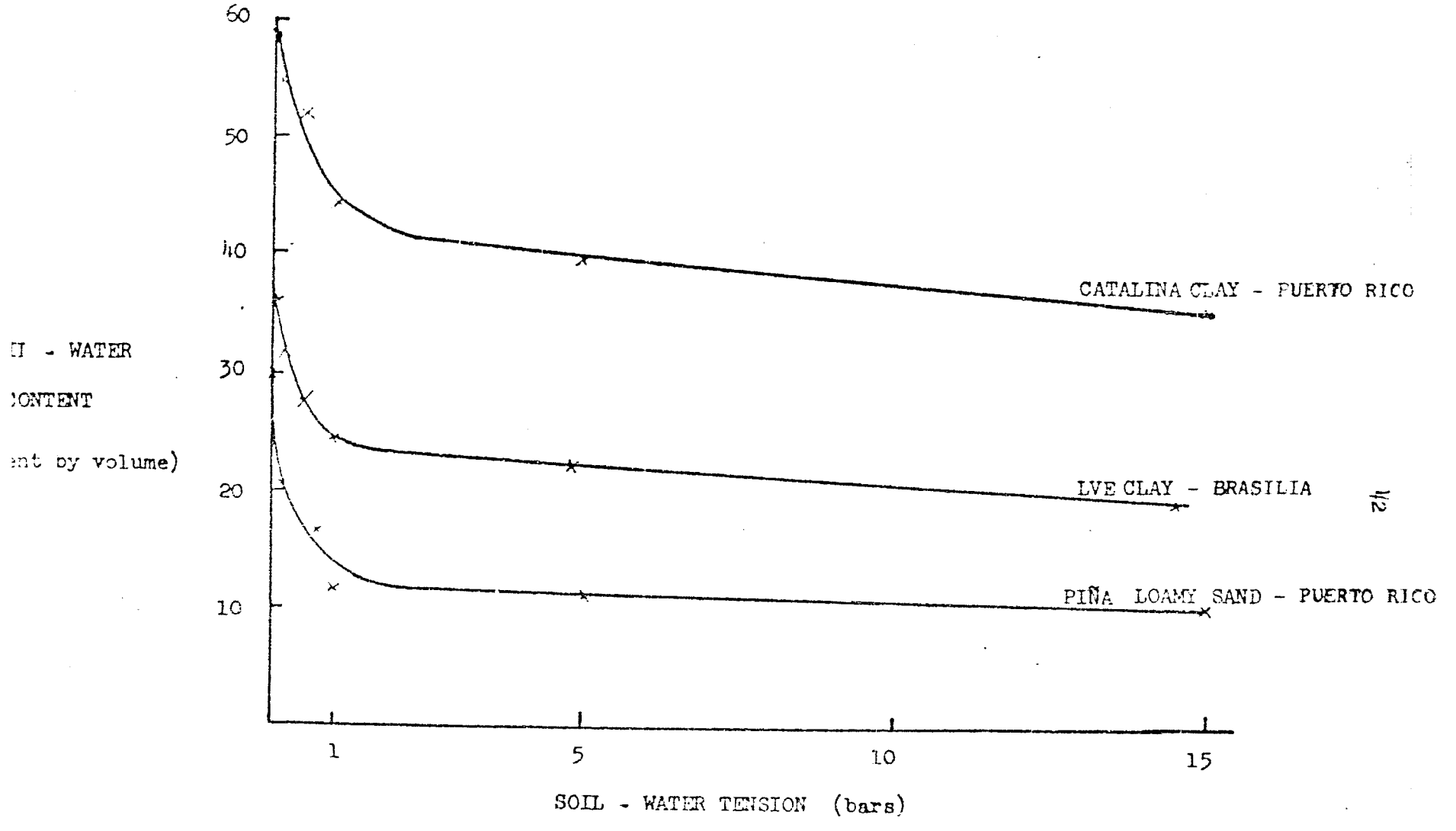
SOIL MOISTURE

Techniques for running soil-water contents were compared and it was concluded that "undisturbed" soil core samples can be used to determine water retention in the wet range (0-3/4 bar) and that disturbed samples should be used to measure water retention in the dry range (1-15 bars). An overestimation of soil-water content will be made by using disturbed samples on the pressure plate in the wet range, or by running "undisturbed" core samples on the pressure plate apparatus in the dry range.

Tensiometers and gypsum blocks were installed in the field plots and the tension or resistance readings were correlated with soil-water contents as determined gravimetrically. In the tension range 1-15 bars, disturbed samples were run on the pressure plate apparatus. The percent soil-water by weight was converted to percent by volume by using the bulk density measurements as determined in the field.

For soils (Oxisols) similar to those at the experimental site it is essential to determine the relationships of soil-water content versus tension *in situ* rather than in the laboratory. These soils, though clayey in texture, have very fine stable aggregates which result in physical properties usually associated with sandy soils. The bulk of the available water is held at low tensions and it is the soil structure and not the texture which appears to be the overriding consideration in determining soil-water properties.

Figure 1 shows the soil-water release curves for the soil at the experimental site (IVF CLAY) in comparison with two Oxisols from Puerto Rico. Curves were developed for various depths but for simplicity only the 30 cm depth is shown. In general, curves for the other depths in a profile are similar in Oxisols where horizonation is not pronounced. It is interesting to note from Figure 1 the similarity in shape of the curves in spite of the fact that two of the soils are clays and one a loamy sand. It appears that the clayey Oxisols simulate a sand in their water release characteristics, although the actual amount in storage between a clay and a sand may differ considerably. Thus, with regard to water movement in Oxisols soil structure, stability, type of structure, and type of clay are more useful parameters for characterizing water relations than the amount of clay present.



L. Soil-water release characteristics for three Oxisols at the 30-centimeter depth.

The curves in Figure 2 show the effect of water loss by percolation on soil-water tensions. These data are for the 30 cm depth and are from plots covered to prevent evaporation. Soil-water tensions after two to three days of free drainage but no evaporation are in the range of 1/15 to 1/10 bar. It took more than 80 days to reach 1/3 bar. During this time, tensions continued to change reflecting slow drainage.

Figure 3 is a graph of the deep percolation with time occurring from a 60 cm profile of the soil at the experimental site (IVE-Brasilia). Percolation at two days is as large as probable crop evapotranspiration. Even after two weeks, percolation from the covered soil may be as large as 20 percent of crop ET. Continued drainage of significant amounts of water will void the applicability of the field capacity concept to these Oxisols. If it should become necessary to fix an upper limit to available soil water (as being done here for comparative purposes), one should never rely on 1/3 bar percentage or moisture equivalent. Instead, one should determine soil-water contents in the field after two to three days of free drainage, but no evaporation. If changes in soil-water contents are to be the basis for determining crop water use, it will then be necessary to establish relationships between deep percolation and soil-water content and to subtract this internal drainage component from other soil-water changes which occur in the profile.

The fact that substantial percolation occurs in these soils under unsaturated conditions may have other important management implications. Miller et al.[1], and others, have shown that ion movement is tremendously more efficient under unsaturated flow conditions. Since unsaturated flow is substantial in these Oxisols we may expect large amounts of ionic

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[1] Miller, R. J., J. W. Biggar, and D. R. Nielsen. 1965. Chloride displacement in relation to water movement and distribution. Water Resources Research, 1:1-7.

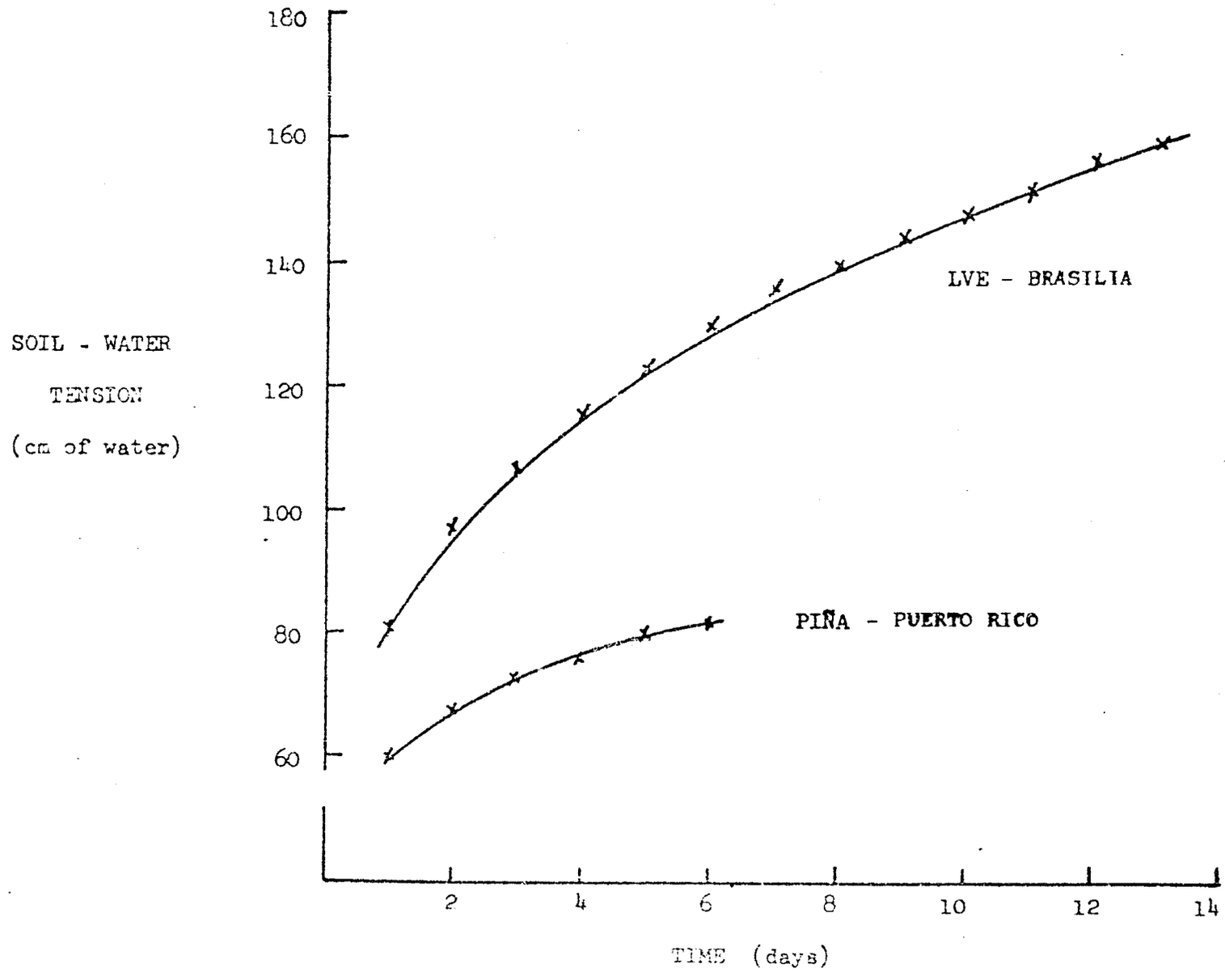

Figure 2. The effect of water loss by percolation upon soil-water tension with time. (Measurements made in the field at a depth of 30 centimeters in a plot covered to prevent evaporation.)

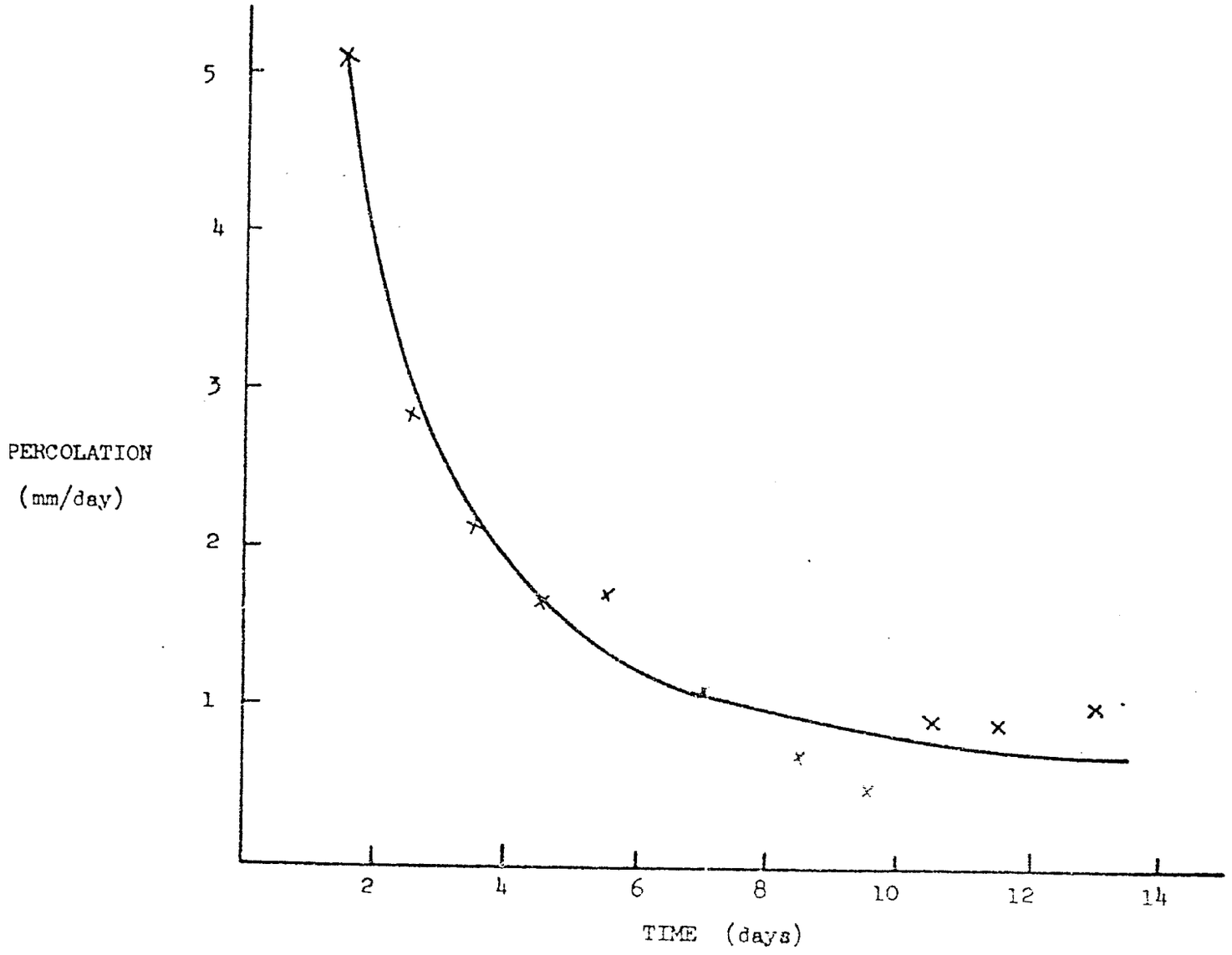

Figure 3. The relationship of the percolation rate with time from a 60-centimeter profile of LVE-Brasilia. (Determinations made in a covered plot under field conditions.)

transport and redistribution with time. For example, this can mean continued leaching and loss of fertilizer material many days after a rainfall or irrigation. Equally important, it suggests that liming materials may continue to redistribute with time. In these soils, deep lime movement may be a possibility without deep placement of the material. This possibility merits further study.

Appendix II

Bibliographic List and Abstracts

Nitrogen Fertilization of Corn and Sorghum Grown in Oxisols and Ultisols in Puerto Rico. R. H. Fox, H. Talleyrand, and D. R. Bouldin. 1973. Submitted for publication to the Agronomy Journal.

Three rates and two times of application of fertilizer N were applied to 15 corn and three sorghum crops on two Ultisols and three Oxisols during five successive growing seasons in Puerto Rico to determine the most effective means of applying fertilizer N to these crops. Additional objectives were to determine the apparent recovery of fertilizer N by the crops, the interrelationships between crop yield, N fertilization and soil inorganic N content; and the effectiveness of slow release sulfur-coated urea as a source of fertilizer N for corn and sorghum. The results indicated that: (1) Postplant sidedress applications of fertilizer N resulted on the average in higher yields and plant recovery of fertilizer N than preplant applications; (2) when there were no limiting factors of climate or disease, and there was a response to N, the recovery of postplant applied N was comparable to that observed in temperate areas; (3) maximum corn grain yields were approximately 6.3 tons/ha; (4) near maximum corn grain yields were obtained with 67 kg/ha of postplant applied N; (5) preplant applied sulfur-coated urea is no more effective than preplant urea in increasing yields or N recovery; (6) soil inorganic N content was generally not a good index of soil N supplying power in these soils; (7) drought and disease frequently reduced yields; (8) there was very little residual effect of the fertilizer N applied in this experiment; and (9) the clayey Oxisols and Ultisols in Puerto Rico had a relatively high N supplying power.

Denitrification Losses from Humid Tropical Soils of Puerto Rico. H. D. Dubey and R. H. Fox. 1973. Submitted for publication to the Proceedings of the Soil Science Society of America.

Profile samples from five depths (0-25, 25-50, 50-75, 75-100, and 100-125 cm) from three soil types (two Oxisols: Piña sandy loam and Catalina clay, and an Ultisol: Humatas clay) were incubated at 23±1C under field capacity and waterlogged conditions in an oxygen-helium atmosphere. Evolved N_2 and N_2O were determined after one and two weeks by gas chromatography. Denitrification was related to moisture level, organic matter content, pH, and denitrifying population. Gaseous nitrogen losses occurred almost exclusively under waterlogged conditions and from the surface soil (0-25 cm) and ranged from 8 to 31 percent of the applied NO_3^- -N. Some loss (7 percent) also occurred at field capacity from the surface horizon of the Oxisol having the highest organic matter content, Catalina clay. Losses were directly related to organic matter content. Raising the pH of the subsoil had only slight effect on enhancing denitrification. Addition of a denitrifying population to a subsoil with a raised pH and organic matter content increased denitrification significantly. Losses by denitrification were important in the surface soil, and the lack of denitrification at lower depths was due to an inadequate supply of rapidly available energy material, low pH, and

consequent lack of a denitrifying population. Since the surface soil, where denitrification is important, under normal conditions does not generally get waterlogged, there is little possibility of N losses by denitrification in these humid tropical soils.

Limitations to Productivity of Some Ultisol and Oxisol Subsoils. K. Dale Ritchey and Richard H. Fox. 1973. Submitted for publication to the Journal of Agriculture of the University of Puerto Rico.

Greenhouse experiments with maize were carried out to see if the reported infertility of some subsoils could be improved with mineral fertilization and efficient waterings. It was shown that the Nipe soil series (Typic Acrorthox; clayey, oxidic, isohyperthermic) exposed subsoil was as productive as the Carreras series (Aquic Tropohumult; clayey, kaolinitic, isohyperthermic) surface soil when N, K, micronutrients and 600 ppm P were added and the pots were watered by means of wicks. Carreras subsoil, when limed and fertilized with N, K, 300 ppm P, 100 ppm Mg and 36 ppm Zn produced as well as Carreras surface soil, even though it contained only about one-third as much organic matter. A comparison among eight surface and subsoils showed that yields on limed, liberally fertilized, well-watered Los Guineos series (Epiaquic Humoxic Tropohumult; clayey, kaolinitic, isothermic) surface soil, Carreras surface soil, Piña series (Psammentic Haplorthox; sandy, isohyperthermic) surface soil, Los Guineos subsoil, Piña subsoil and Catalina series (Tropeptic Haplorthox; clayey, oxidic, isohyperthermic) surface soil were not significantly different. However, the yield on the least productive of two Catalina subsoils was only 64 percent of the yield on the Los Guineos surface soil. But with the addition of Zn and slightly over 1000 ppm P, greenhouse pot yields on the two soils were essentially the same. Field experiments will be necessary to determine optimum P rates under field conditions. It was concluded that the productivity in greenhouse pots of surface and subsoils of the Ultisols and Oxisols studied can all be brought to the same high level, provided adequate mineral fertilization (including Zn and high P rates), lime and water management are used.

Use of Wick-Watering for Greenhouse Pots in the Tropics. K. Dale Ritchey and Richard H. Fox. 1973. Submitted for publication to Tropical Agriculture (Trinidad).

The use of a simplified modification of the wick-watering method of Dolar and Keeney (Agronomy J. 63:334-335. 1971) was shown to increase yields in greenhouse pots over those obtained with conventional watering, presumably by increasing the supply of available water. Water contents in various parts of the pots ranged from 70 percent of field capacity to 141 percent. Oxygen diffusion rate current measurements indicated that sufficient oxygen was available to the plant roots. The method permitted a considerable reduction in the time necessary for watering.

Potential of the Soils of the Humid Tropics for the Production of Food Crops. Matthew Drosdoff. Prepared for the section on Soils for the McGraw-Hill 1974 Yearbook of Science and Technology.

This is a short review article on recent developments in knowledge of soils of the humid tropics including soil surveys and nitrogen and phosphorus fertilization.

Soils of the Central Plateau of Brazil. M. C. Cline and S. W. Buol. 1973. Agronomy Mimeo 73-13, Department of Agronomy, Cornell University.

This is a report of a two-weeks' field study of the soils of the Campo Cerrado with the objective of appraising the extent to which the experimental results being obtained at the experimental station near Brasilia could be applied to broad areas of the Central Plateau. Four senior Brazilian soil scientists accompanied Drs. Cline and Buol in this investigation. They traveled approximately 2[illegible] km, reaching points [illegible] km SSE, 330 km WSW, and 160 km NNE of Brasilia. The conclusions were that the results of the cooperative research at the Experiment Station should apply in principle to an immense area of the Central Plateau of Brazil but the applications of the results may vary in detail on the different kinds of soil. One important conclusion is that the capacity of the soils to supply water for crops during the relatively short dry periods in the rainy season appears to be one of the very critical factors in the use and management of the soils. It is suggested that the Brazilian authorities may wish to investigate the feasibility of constructing small ponds or reservoirs on typical land forms to supply water for supplemental irrigation during the rainy season.

Clay Minerals--A Dynamic Component of Soils. R. M. Weaver. 1973. Presented at the Third Soil Microcommunities Conference, New York State University College of Environmental Science and Forestry, Syracuse, New York. October 15, 1973.

This is a review article which discusses the dynamic character of the clay fraction of the soil in its relation to nutrient availability, water retention, and aeration of soils. The composition and structure of clay minerals and their charge properties, clay mineral-water interactions, clay minerals and soil chemical properties, clay minerals and soil physical properties, and clay mineral-organic matter interactions are the topics discussed. Examples are given from soils of the tropics. There are 45 references.

Organic Phosphorus in Soils with Special Interest in Soils of the Tropics. K. J. Roberts and R. M. Weaver. 1973. Agronomy Mimeo 73-1. Department of Agronomy, Cornell University.

This is a review article which covers the following topics: (1) Forms of soil organic phosphorus including inositol phosphates, phospholipids, and nucleic acids; (2) forms of organic phosphorus in soils of the tropics; (3) mineralization of organic phosphorus including correlation with organic

nitrogen and carbon, effects of cultivation and the presence of plants, effects of soil organic phosphorus-clay mineral interactions; (4) determination of total organic phosphorus including extraction methods, ignition methods, and comparative studies of extraction versus ignition methods. There are 100 references to the literature.

Inorganic and Organic Phosphorus Occurrence in Some Highly Weathered Soils of Puerto Rico. R. M. Weaver, R. H. Fox, and M. Drosdoff. 1973. Submitted to Tropical Agriculture (Trinidad).

The results of this study suggest two aspects that may help explain the lack of field response to phosphorus on these soils. The first is the origin and significance of the adsorbed or bicarbonate extractable phosphorus associated with aluminum and iron oxides and ordinarily determined as aluminum-phosphate or iron-phosphate. The second is the possible mineralization of the organic phosphorus which comprises a significant proportion of the total soil phosphorus. The mineralization of some portion of the soil organic phosphorus would seem likely in considering the results obtained in other tropical areas. It would seem that one of the results of organic phosphorus mineralization would be an increase in the absorbed phosphorus fraction. This would be a dynamic process with portions of the adsorbed phosphorus being converted to forms non-extractable with bicarbonate while at the same time mineralization processes could replenish or increase the adsorbed phosphorus fraction.

Chemical and Clay Mineral Properties of a Highly Weathered Soil from the Colombian Llanos Orientales. R. M. Weaver. Department of Agronomy Mimeo 73-19. Cornell University 1972.

This is a report of the results obtained from a quantitative clay mineralogical investigation on a representative Oxisol from the Eastern Plains of Colombia (Llanos Orientales) and a discussion of the agronomic implications of the presence of significant amounts of Al-chlorite in this and related soils in the humid tropics.

Cultural Systems on Tropical Soils. M. Drosdoff. In Proceedings of the Tropical Soils Workshop, Prairie View A&M College, October 1972.

This is a review article of systems of soil and crop management in the tropics including traditional systems, transitional systems, and modern systems.