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Progress Report

for the period

July 1, 1973 to October 31, 1974

Submitted to the

U. S. Agency for International Development

Contract AID/csd 2490 and AID/ta-c-1104

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; Soil Fertility in the Humid Tropics, AID/ta-c-1104

Principal Investigator: Matthew Drosdoff, Department of Agronomy, Cornell University, Ithaca, New York 14853

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B. Narrative Summary of Accomplishments and Utilization

This is the fifth 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 and soil moisture requirements 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 alternative recommendations for improved soil and crop management practices on those soils which are very extensive in the humid tropics, about 1,500 million acres according to recent estimates. Most of these soils are deep and well drained and have good physical properties, but are largely uncultivated. Those that are cultivated have low production which can be substantially increased with the use of fertilizers, and lime, adapted crop varieties, good water management, and pest control.

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 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. Research was started in Brasilia in the summer of 1972 in cooperation with the Brazilian Ministry of Agriculture and North Carolina State University. Plans have been developed with the Soil Research Institute of Kumasi, Ghana for collaborative soil fertility research on the

acid soils which are extensive in the region. Field research there will be initiated early in 1975.

Puerto Rico: The results of the first three years nitrogen experiments with corn have been summarized in earlier reports and published in the Agronomy Journal in 1974. Subsequent nitrogen experiments with corn at four of the experimental sites were conducted to determine if nitrogen fertilizer requirements could be predicted from a simple laboratory test which has been under study. Also a hybrid corn with a higher yield potential (Funk's G795 W) than the one used in earlier experiments (Pioneer X-306) was tested. This hybrid had yielded about 140 bushels of corn per acre in an earlier experiment, well above the yield potential of 105 bushels per acre of Pioneer X-306. However, in the nitrogen experiments, though the Funk variety had a higher yield potential, it appeared to be more susceptible to insects and diseases. The laboratory test predicted the nitrogen-supplying power of the clayey Ultisol but not the sandy Oxisol which had a much larger nitrogen-supplying power than expected.

Soybeans planted in June, 1973 on clayey Ultisol with a very low phosphorus test value did not respond to applied phosphate. However, a field wide average of 55 bushels per acre was obtained which further demonstrates the potential for high yields of soybeans on acid soils in the humid tropics.

The plantain nitrogen and phosphorus experiment is being continued and the preliminary data from this year's crop indicate that the yield of the first ratoon is as high as the first year's crop with little or no response to applied nitrogen or phosphorus. Close spacing and the use of a chemical nematocide produced a record yield of over 71,000 plantains per acre, the average yield for Puerto Rico being 20,000 to 25,000 plantains per acre.

Field experiments to study the effect of varying lime levels on the growth and nutrient content of several crops on representative acid Oxisols and Ultisols have continued. Yields of corn and green beans increased with rising pH until a pH of 5.2 was reached. Plantains have been found to be one of the most tolerant crops to soil acidity. Other crops in the test have been sorghum, rice, soybeans and sweet potatoes. The latter crop was tolerant to very acid soil conditions and no increase in yield was found when the pH was increased from 4.1 to over 5.0. Rice was also found to be relatively tolerant to soil acidity.

Brazil: As a result of unfavorable climatic conditions, all of the field experiments at the experiment station were adversely affected during the 1974 rainy season. The month of March had over 500 mm of rain. In the previous month a number of plots suffered severe lodging because of strong winds and during the subsequent rainy period the insecticide and fungicide treatments appeared to be relatively ineffective. In the nitrogen experiment a near maximum yield of about 75 bushels of grain per acre was obtained with 60 kg/ha of nitrogen applied as urea. As reported last year this experiment and the ones described below are on an acid Dark Red Latosol or related soil in the Brazilian classification system. These soils are very extensive in the Central Plateau of Brazil.

Four consecutive crops of corn over a two-year period have been harvested in the phosphorus experiments. The highest total yield, over 29 tons/ha, was

obtained with the application of 1280 kg/ha of P_2O_5 without any further additions. The fourth crop under this treatment was at the maximum production, 9 tons/ha (140 bushels per acre). A smaller initial broadcast phosphate application (320 kg/ha of P_2O_5) plus 80 kg/ha banded for each of the four crops resulted in a total yield of almost 85 percent of the maximum or an average of about 100 bushels of corn per acre.

In a phosphorus and nitrogen experiment with dry beans three levels of broadcast phosphate fertilizer were compared with banded phosphate and there were 3 levels of nitrogen applied as urea. In general there were significant responses to all levels of phosphorus and to the level of 60 kg/ha of nitrogen. Over 70 percent of the maximum yield of beans was obtained by the application of 160 kg/ha of P_2O_5 banded. A comparison between the results of this experiment and that with corn suggests the greater ability of beans to use banded phosphorus.

An analysis of long-term climatic data in the Brasilia area indicates that during the rainy season there is a 50 percent chance that there will be a dry spell of 14 days or more which can severely reduce crop production without supplementary irrigation. It is estimated that long-term rainy season yields of corn will only be about one half of the possible yields with supplementary irrigation. A study was made of the possibilities for irrigation during both the wet and dry seasons in the Federal District. It was found that water was plentiful and with the creation of storage facilities the amount of irrigation water may be sufficient to irrigate 5 to 10 percent of the Federal District during the year. Groundwater may be an important irrigation water source. Engineering tests show that the high initial infiltration and permeability of the soils can be reduced by compaction at favorable moisture conditions.

Soil-water properties were determined in the field experimental plots during the growth of a corn crop. It was found that the soils release two-thirds of the available stored water at relatively low tensions, between 1/10 and 1 bar. The unfavorable water-supplying properties of these soils together with the occurrence of dry periods during the rainy season and the limitations of root growth in the subsoil due to aluminum toxicity make water management a critical factor for successful crop production on these soils. Based on crop water use measurements, an estimate was made of the water requirements for dry season irrigated cropping and the potential for dry season cropping was compared with wet season cropping. There was no conclusive evidence that the dry season crop production potential is greater than the wet season because of higher radiation, pan evaporation, or other climatic factors. However, the incidence of uncontrolled variables such as diseases and insects is greater during the wet season and consequently the potential for crop production is less than for the irrigated dry season crops.

A cooperative agreement for soil fertility research in Ghana has been made between the Soil Research Institute at Kumasi and Cornell University. The research effort will focus on identifying those factors which are limiting the yields of food crops in the area. As the project develops, the research will aim at the development of soil and crop management practices suitable for mixed cropping systems as practiced by many small farmers in the region.

ANNUAL RESEARCH REPORT

A. General Background

The world food situation is getting more critical and the future outlook is grim. It is imperative that concerted efforts be made to utilize available soil resources which are potentially arable but not under cultivation. Most of the potentially arable land not under cultivation lies in the tropics and much of it has good potential productivity. Recent estimates indicate that of the 700 million hectares of the land in tropical Africa that is potentially arable less than 15 percent is being cultivated. In tropical South America, of the 600 million hectares of potentially arable land less than 15 percent is under cultivation.

The most extensive soils in the tropics which are not being cultivated but have good potential production for food crops are acid and relatively infertile. But large areas are well drained and have a favorable topography and with adequate soil, crop, and water management practices can be highly productive. The best estimates indicate that there are over 500 million hectares of these soils in the humid and subhumid tropics which are potentially arable and not now under cultivation. Recent research has shown the feasibility for economic utilization of extensive areas of these soils for food production but there are many soil fertility and crop and water management problems which need to be resolved.

Most soils in the tropics which are now under cultivation have low production. The introduction of improved technology including the efficient use of fertilizers and other amendments can increase food

production substantially, especially in the extensive areas under traditional systems of shifting cultivation. The application of improved technology, however, must be geared to the resources available to the farmer within the social and economic constraints under which he operates.

B. Project Objectives

The immediate objective of the project is to determine the most effective and economic amounts of applied nitrogen, phosphorus, potassium, liming materials, and other nutrients to achieve the production potential for food crops on the extensive acid soils of the humid and subhumid tropics. The ultimate objective is to provide recommendations for improved soil, water, and crop management practices 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. Subsequently, 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 North Carolina State University. Following the visit of two Cornell soil scientists to Ghana in the spring of 1974 plans have been developed for the collaborative soil fertility research with the Soil Research Institute at Kumasi on the acid soils which are extensive in the region. In addition to the main

experiments on the land of the Soil Research Institute, it is planned to conduct supplementary trials on farmers' fields where the soils are similar to those at the Institute. A cooperative agreement between Cornell and the Institute has been approved and it is planned to initiate the field work in the spring of 1975. Meanwhile, preliminary laboratory work has been conducted on samples of representative soils on which the field experiments will be carried out.

C. Continued Relevance of Objectives

The objectives as stated in the contract are still relevant but with a shift of emphasis in the research. Increased attention has been given to the water management factor as related to the soil fertility work. Results of the field experiments at Brasilia during the past year show that improved water control is essential if more efficient utilization of applied nutrients is to be realized. The frequent occurrence of dry periods during the rainy season may severely reduce yields unless supplementary irrigation is provided. Long-term predictions based on the research at Brasilia indicate that on the average only about half the potential yield of a crop like corn may be expected without supplementary water. These findings have important implications for many other areas in the humid tropics.

In connection with the studies on the effect of a soil water deficit on corn yields in relation to the soil fertility status, added attention is being given to a study of the crop physiological factors most responsible for reduced growth. This study will relate the characteristics of nutrient and water uptake to root growth and development under the various soil fertility treatments. The ultimate objective of these studies is to

make recommendations for the most appropriate water management practices for cultivated crops on the soils of the Campo Cerrado.

One of the important objectives of the research is to develop ways and means by which food crops can utilize the nutrients in the acid soils more efficiently. One approach to this objective is to develop crop varieties by plant breeding procedures which would utilize more efficiently the nitrogen, phosphorus, and other nutrients in the soil and which would be more tolerant of acid soil conditions especially in the subsoil where high levels of soluble aluminum and/or manganese limit plant root growth and hence crop production. There is now good evidence that genetic materials of corn and other food crops are available which can utilize low levels of inorganic nutrients efficiently. It is proposed to explore these possibilities as another approach to meeting the objectives of the research.

D. Accomplishments to Date

Puerto Rico

Nitrogen Experiments

1. 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 three years work have

been summarized in earlier reports and were published in the Agronomy Journal in 1974.

2. A variety of cassava, Llanera, was found in Colombia with a reported maximum yield of 78 tons/ha in ten months and a protein content three times that of the average sweet cassava variety. An experiment was conducted to determine if similar yields and protein contents could be obtained on the acid soils in Puerto Rico with Llanera and what levels of fertilizer nitrogen would be necessary for maximum yields. Leaves and petioles were sampled in order to determine if their nitrogen content could be correlated with yields and nitrogen uptake.

Llanera appeared to be daylength sensitive and top growth ceased from mid-November to mid-February, when days were shorter than 11 1/2 hours. At Corozal (Humatas clay), the crop was grown from mid-March to mid-December, and top growth responded strongly and root growth moderately to applied nitrogen. High nitrogen rates produced low root/top ratios (.67-.87) but, due to the experience at a second site, it is assumed that root/top ratios would have increased to more normal levels had the crop continued to grow. Apparent recovery of fertilizer nitrogen was high (68 to 69 percent) for the 40 and 80 kg/ha rates. At Cidra (Porres clay), where the crop grew from mid-June until the following May, and was dormant for the three winter months, there was no response to nitrogen. Top yields were lower, but the root/top ratios were higher (average 1.37) and were not affected by nitrogen rates. The lack of response to nitrogen was due to the high nitrogen-supplying power of this soil. The maximum root yields were 22 metric tons/ha at Corozal and 33 metric tons/ha at Cidra. Plants in the highest yielding treatments contained 125 to 175 kg/ha nitrogen. Assuming all nitrogen was protein nitrogen, unpeeled root protein contents averaged 3.4 percent and peeled

2.3 percent on a dry weight basis and were increased only slightly by higher nitrogen rates. These values are only one-third to one-half the protein content reported for Llanera in Colombia. The nitrogen content of the fourth and fifth fully expanded leaves four to five months after planting was very well correlated with final root yield at Corozal (R^2 = .99 for 0-160 kg/ha nitrogen rates). It appears that 5 percent nitrogen in these leaves four to five months after planting is necessary for maximum yields. Sulfur-coated urea appeared to offer no advantage over urea in increasing yields or nitrogen content.

3. Following the cassava harvest, Funk's G-795 W hybrid corn was planted at the four nitrogen experiment sites with varying rates of nitrogen fertilizer to determine if the nitrogen fertilizer requirements could be predicted from 1) the 1N KCl extractable soil organic nitrogen contents or 2) the crop requirement method proposed by W. V. Bartholomew in Technical Bulletin No. 6 of the North Carolina State University International Soil Fertility Evaluation and Improvement Program. An additional objective was to determine the yield potential of this corn hybrid. In a zinc fertilization experiment with this hybrid in Puerto Rico in 1972, the highest yields were over 140 bu/acre, well above the 105 bu/acre maximum obtained with the hybrid Pioneer X-306 used in earlier nitrogen fertilization trials in Puerto Rico. One treatment of an improved Pioneer tropical hybrid (X-306B) was included at each site for comparison.

The two sites with irrigation facilities, Corozal and Manati, were planted in late March and early April, 1974, and were harvested in July. Planting at the other two sites was delayed until the beginning of the spring-summer rains in late May. Growth was excellent at the irrigated

Table 1. Effect of nitrogen fertilizer rate on corn yield, Piña soil, (sandy Oxisol) Manati, 1974

Treatment No.	N applied	Grain yield (15% H_2O)	Stover yield	Grain N	Stover N	Grain plus stover N
	kg/ha	tons/ha	tons/ha	kg/ha	kg/ha	kg/ha
1	0	4.5 a[1/]	5.3 a	53 a	32 a	85 a
2	60	5.1 ab	6.7 ab	64 abc	53 ab	117 b
3	120	4.4 a	6.4 ab	57 ab	51 ab	108 b
4	140	5.0 ab	6.7 ab	70 bc	59 b	129 bc
5	160	5.1 ab	7.2 ab	69 bc	58 b	127 bc
6	180	5.0 ab	4.8 a	69 abc	46 ab	115 b
7	200	5.4 ab	4.7 a	74 cd	46 ab	120 b
8[2/]	180	6.1 b	8.3 a	86 d	58 b	144 c

[1/] Values followed by the same letter in a column are not significantly different at the 5 percent level using Duncan's multiple range test

[2/] Treatment 8 was with Pioneer X-306 B corn hybrid, other treatments with Funk's G-795 W

sites, but reduced by a water deficit at the other two sites due to much less than average rainfall in May, June and July.

Results from the two crops now harvested indicate that:

(1) The nitrogen-supplying power of the Piña sandy oxisol at Manati has risen sharply over that in previous crops. The total nitrogen content of the plants in the no nitrogen added plots was 85 kg/ha (Table 1) compared to 51 kg/ha in the irrigated corn crop in 1973. It is difficult to account for this increased nitrogen-supplying power since soil inorganic nitrogen and extractable organic nitrogen levels were low. Crotalaria was growing in the field and may have fixed some nitrogen but since the field was fallow for less than two months prior to this crop, the amount fixed by Crotalaria should not have been large.

(2) High corn grain yields were obtained at Corozal with Funk's G-795 W (8.4 tons/ha or 134 bu/acre) (Table 1) but, the maximum yield of Funk's at Manati was only 5.4 tons/ha. Since early growth and stover yields at Manati were as large as at Corozal, the lower final yields at Manati are probably due to a moderate Southern leaf blight (Helminthosporium maydis) attack that was first noted at this site when the corn plants were in full silk. This is substantiated by the observation that the grain/stover ratios for the nitrogen fertilized Funk's averaged 1.20 at Corozal and only 0.72 at Manati.

(3) The Pioneer X-306B produced a larger plant with a smaller ear at both sites, resulting in maximum grain yields of only 5.1 and 6.6 tons/ha at Manati and Corozal, respectively. However, Pioneer X-306B was not affected by the Southern leaf blight and its thicker ear husks protected it from ear worm attacks. In a winter crop comparing Funk's and Pioneer X-306 at

Table 2. Effect of nitrogen fertilizer rate on corn yield, Humatas soil (clayey Ultisol) Corozal, 1974

Treatment No.	N Applied	Grain yield (15% H_2O)	Stover yield	Grain N	Stover N	Grain plus Stover N	Apparent fertilizer N recovery[3]
	kg/ha	tons/ha	tons/ha	kg/ha	kg/ha	kg/ha	%
1	0	3.3 a[1]	4.2 a	31 a	16 a	47 a	-
2	60	6.3 b	5.1 ab	66 b	24 ab	90 b	72
3	120	7.6 bc	5.8 b	89 c	30 b	119 c	60
4	140	7.4 bc	5.2 b	93 c	35 bc	128 c	58
5	160	7.6 bc	5.7 b	96 c	41 cd	137 c	56
6	180	7.0 bc	5.1 ab	97 c	35 bc	132 c	47
7	200	8.4 c	5.6 ab	102 c	35 bc	137 c	45
8[2]	180-P	6.6 b	6.3 b	92 c	50 d	142 c	53

[1] Values followed by the same letter in a column are not significantly different at the 5 percent level using Duncan's multiple range test

[2] Treatment 8 was with Pioneer X-306 B corn hybrid, other treatments with Funk's G-795 W

[3] Fertilized plant N minus check plant N/fertilizer N applied

the Manati site, Funk's was very seriously damaged by ear worms while almost no damage occurred in the Pioneer X-306. Thus, it appears that Funk's G-795 W has a considerably higher grain yield potential than Pioneer X-306 or X-306B, but is much more susceptible to insects and disease. Unless these pests are either not present, or are controlled by massive sprayings, grain yield will probably be considerably less on the average for Funk's G-795 W than for Pioneer X-306. Pioneer X-306 or X-306B will be used for all future experimental work in this Puerto Rico project because of their greater reliability.

(4) Because of the higher grain/stover ratios in Funk's than in Pioneer, there was more grain yield per unit nitrogen with Funk's than had been obtained with Pioneer X-306 in previous years. This, coupled with the slightly lower yields than anticipated and the higher nitrogen-supplying power in the Piña soil, resulted in most of the nitrogen fertilizer rates being higher than optimum (Tables 1 and 2). In the Piña soil, 60 kg/ha of fertilizer nitrogen was sufficient to produce a near maximum grain yield of 5.1 tons/ha. The optimum rate for the Humatas soil at Corozal appeared to be between 60 and 120 kg/ha nitrogen.

(5) At Corozal, the apparent nitrogen fertilizer recoveries were 60 to 72 percent for the lower, near optimum rates of fertilizer nitrogen.

(6) The 1N KCl soil extractable organic plus NH_4^+ nitrogen predicted the nitrogen-supplying power of Humatas soil at Corozal quite well when using the prediction equation derived in 1972 with data from these four sites. However, the increased nitrogen-supplying power of the Piña soil was not predicted by this method as the extractable soil nitrogen content was quite low. Also the optimum nitrogen rates for corn on the Piña soil as predicted by the Bartholomew equation were too high.

Phosphorus Experiments

1. Field experiments designed to study the response curves of phosphorus fertilizers, estimate the residual effects of applied phosphate, and measure the relative efficiency of broadcast versus banded phosphorus fertilizer were continued with several test crops. In spite of the low soil test values, only one corn crop responded to applied phosphorus during the first two years of cropping. It was hypothesized that the unanticipated high availability of soil phosphorus in this Ultisol (Terra) was due to mineralization of organic phosphorus.

2. Soybeans planted in June, 1973, did not respond to phosphorus fertilizer. However, a field-wide average of 3.7 tons/ha (55 bu/acre) was obtained. This yield is almost twice as high as the average soybean yield obtained in the continental U.S. and demonstrates the potential for growing soybeans in the tropics.

3. Funk's G-705 W corn was planted at this site in November 1973 and harvested the following April. The plants in most treatments grew quite erratically during the first two months after planting. There was a large variation of plant height within most plots and the smaller plants had phosphorus deficiency symptoms. It was assumed that the plant height variability was a function of whether or not the plant roots had encountered areas of higher phosphorus concentrations in the soil. This variability continued until harvest, so only large differences between treatments were significant.

The results indicated, however, that the phosphrous fertilizer applied in the fall of 1971 had only moderate residual effects on the grain yield

of a crop planted in the fall of 1973. The highest grain yields were obtained in the treatments receiving 90 or 179 kg/ha of band applied phosphorus on each crop (Table 3). The 5.8 tons/ha of corn grain in the 179 kg/ha banded phosphorus treatment was significantly higher than in any other treatment, including the 4.2 tons/ha obtained in the 1,120 kg/ha phosphorus broadcast treatment of 1971. Soil analyses also indicate that the available phosphorus content in the broadcast treatments had dropped sharply during the past three years. Thus, it appears that fertilizer phosphorus is being fixed quite rapidly in these soils and banded applications of moderate quantities of fertilizer phosphorus with each crop are more efficient in increasing yields than large broadcast applications made every few years.

4. The plantain nitrogen and phosphorus fertility experiment has been continued. The preliminary data from this year indicate that yield levels of the first ratoon are as high as those from the first crop, in spite of a prolonged drought this summer. Last year's crop showed very little response to phosphorus and only a slight response to nitrogen. Intensive management, close spacing, and the use of a chemical nematocide produced record yields of over 71,600 plantains/acre, the average yield for Puerto Rico being 20,000 to 25,000 plantains/acre. This experiment has aroused considerable interest among the farmers and extension personnel in Puerto Rico, and it has been estimated that over 2,000 individuals have visited the site during the last year and a half.

5. Experiments to determine if results of phosphorus fertilization experiments in sunken drums could be extrapolated to the field have been terminated. These experiments were established at one location in order

Table 3. Effect of phosphorus fertilizer rate and method of application on corn yield, Torres soil, winter 1973-74

P applied since 1971	Method	Grain yield	Stover yield	Grain P	Stover P	Grain plus stover P
kg/ha		tons/ha	tons/ha	kg/ha	kg/ha	kg/ha
0		3.1 ab[2/]	4.8	13.1 ab	4.9	18.0
90	broadcast, 1971	2.0 a	4.1	10.5 b	5.6	16.1
179	broadcast, 1971	3.6 abc	5.3	12.8 b	6.2	19.0
358	broadcast, 1971	4.0 abc	4.8	17.0 ab	4.0	21.0
1120	broadcast, 1971	4.2 bc	6.1	17.7 ab	5.8	23.5
1120 NL[1/]	broadcast, 1971	3.6 abc	5.2	15.1 ab	7.0	22.[illegible]
112	22, banded each crop	3.9 abc	6.9	14.6 ab	6.6	21.2
224	45, banded each crop	4.0 abc	5.3	16.2 ab	5.2	21.4
448	90, banded each crop	4.5 c	6.0	14.3 abc	7.6	21.9
896	179, banded each crop	5.8 d	5.3	20.6 a	7.8	28.4
470	358, broadcast 1971 plus 22 banded each crop	3.8 abc	4.8	15.0 ab	6.1	21.1

[1/] This treatment received no lime, all other treatments received a total of 13.7 metric tons/ha of ground limestone in 1971 and 1972

[2/] Values followed by the same letter in a column are not significantly different at the 5 percent level

to get information on responses to applied phosphorus on a wide range of soils with much less cost than field experiments. It was thought that the responses in the drums would more closely approximate field results than the pot tests in the greenhouse. However, it was found that plants respond to fertilizer phosphorus in sunken drums when there is no response in the field on the same soil. The results of this work have been submitted for publication.

Liming and Soil Acidity

1. Field experiments studying the effect of varying lime levels on the growth and nutrient content of several crops in representative Oxisols and Ultisols have continued. Results of corn and green beans studies were published during the year. In both crops, yields increased with rising soil pH until a pH of 5.2 was reached. Soil pH's higher than 5.2 (maximum pH 6.5) had no further effect on yields. It was also found that crop yields were negatively correlated with the aluminum saturation of the soils and that the aluminum saturation was near zero at a pH of approximately 5.2.

2. Plantains were planted in the liming experiment plots at all sites and will be harvested this year. Observations on early plant growth indicate that plantains are one of the most acid-soil tolerant crops that have been tested in this experiment. In addition to plantains, corn, and green beans, other crops tested have been sorghum, rice, soybeans and sweet potatoes.

3. An experiment was initiated to determine if deep incorporation of lime would increase crop yields. Enlarging the zone where aluminum sensitive roots can grow would theoretically reduce plant water stress during

periods of limited rainfall and supply a larger reservoir of plant nutrients. Lime was incorporated to depths of 20, 40 and 60 cm by extracting the soil in 20 cm horizons from each plot to a depth of 60 cm and mixing lime into the soil from the desired horizons before replacing it in the plots. The results from the first corn crop planted in the fall of 1973 showed that grain yields increased from 5.5 tons/ha (88 bu/acre) with no lime, to 6.4 tons/ha (102 bu/acre) when the top 20 cm were limed, and to 8.4 tons/ha (126 bu/acre) when the lime was incorporated to a depth of 60 cm (Table 4).

4. Treatments of $Ca(NO_3)_2$ or urea and lime were used in an attempt to raise the subsoil pH without physically altering the soil profile. It has been reported by others that high levels of $Ca(NO_3)_2$ applied to bermuda grass will raise the subsoil pH at least a half unit in sandy soils. The $Ca(NO_3)_2$ treatment produced yields even lower than did the no-lime treatment, presumably due to the salt effect of the high rate of $Ca(NO_3)_2$ applied.

5. Work with several Ultisols and Oxisols in the laboratory has demonstrated that the exchangeable aluminum in these soils can be very accurately predicted if the soil pH, cation exchange capacity (CEC), and soil solution electrical conductivity (EC) are known. Regression analysis gave the following expression:

$$\log\left(\frac{\text{Exch Al}}{\text{CEC}}\right)\left(\sqrt{\text{EC}}\right) = 3.6045 - 0.95587\ \text{pH}$$

with a correlation coefficient (r) of .968.

Table 4. Effect of the depth of incorporation of lime on corn grain yield, Humatas soil, Orocovis, winter 1973-74

Depth of Soil disturbance	Depth of[1] limed soil	N source	Grain yield
cm	cm		tons/ha
20	0	urea[2]	5.4 a[3]
20	20	urea	5.8 a
60	0	urea	5.6 a
60	20	urea	6.4 ab
60	40	urea	6.6 ab
60	60	urea	8.0 b
20	20	$Ca(NO_3)_2$	4.8 a

1/ Each layer of limed soil received 3 meq. of Ca as $Ca(OH)_2$ per meq. of exchangeable Al

2/ Fertilizer rates were [illegible] kg/ha of N and P_2O_5, 168 kg/ha K_2O and 112 kg/ha Mg as $MgSO_4$

3/ Values followed by the same letter are not significantly different at the 5 percent probability level

Brazil

As stated in last year's report, the research was initiated in July 1972 at the Agricultural Experiment Station near Brasilia in cooperation with the Brazilian Ministry of Agriculture and in collaboration with North Carolina State University. During the past year the responsibility for agricultural research in Brazil has been delegated by the Government of Brazil to a new organization, Empresa Brasileira de Pesquisas Agropecuarias (EMBRAPA). A new cooperative agreement between Cornell University, North Carolina State University, and EMBRAPA has been made which is similar to the previous agreement and assures the continuation of the planned research. The following personnel of Cornell and North Carolina State Universities have had major responsibilities for the various segments of the field research summarized below: Dr. George C. Naderman of Cornell (project coordination, nitrogen on corn, and nitrogen and phosphorus on dry beans); Enrique Gonzales of North Carolina State (lime); Russell Yost of North Carolina State (phosphorus); James Wolf, Jan Pruntel, and Dale Bandy of Cornell (soil-water and plant stress).

Nitrogen

The design of the nitrogen experiment, given in last year's report, was slightly altered during the second crop in the 1973-74 rainy season. In treatment 2 the initial banded application was deleted and no more fertilizer was applied. In treatment 1, the application at 30 days was increased to 80 kg N/ha. Treatment 8 with $Ca(NO_3)_2$ as the nitrogen source was repeated, but the level was raised to 20 +120 kg N/ha, all supplied by this source. The sulfur-coated urea (SCU) of treatment 9 was dropped, and

this treatment received a maximum level of 20 + 100 + 100 kg N/ha as ordinary urea for the second crop. Treatment 10 was continued as SCU, but the nitrogen rate was increased to 140 kg/ha all applied as SCU in a band below the seed prior to planting. The SCU material was also different from the first year. This material had a faster rate of nitrogen release, reported by TVA as 43 percent in seven days, and containing 36.8 percent nitrogen. A general application of 150 kg K_2O as KCl was made and the phosphorus level was substantially raised by the broadcast application of 300 kg P_2O_5/ha and a band application of 80 kg P_2O_5/ha, all as simple superphosphate.

The treatment descriptions and yields for the second crop are given in Table 5. These results are notable in that all yields are relatively low with a near maximum yield at the level of only 20 + 40 kg/ha of nitrogen (treatment #3).

The low yields of the nitrogen experiment are typical of the other experiments for the second rainy season crop. An important aspect of this season was the unusually rainy weather during the month of March, 1974 with a total of over 500 mm which is 30 to 40 percent of the normal annual rainfall. In late February, a number of the plots suffered severe lodging (as much as 70 percent of the plants nearly flattened) because of strong winds during a rainstorm. This was followed by the rainy period during which the insecticide applications appeared to be less effective and very severe leaf damage occurred due to corn leaf blight. The symptoms were typical of both Northern and Southern leaf blight caused by species of <u>Helminthosporium</u>. For the nitrogen experiment, this period of unfavorable

Table 5. Grain yields (15.5 percent moisture) of the second corn crop (rainy season 1973-74) of the nitrogen experiment at Brasilia (means of 5 replications)

Treatment No.	Nitrogen applied in kg/ha as urea except where otherwise noted				Yield kg/ha*
	At planting	20 days after planting	40 days after planting	60 days after planting	
4	20	--	80	--	4638 a
3	20	--	40	--	4630 a
9	20	100	--	100	4541 ab
5	20	--	120	--	4504 ab
6	20	40	--	40	3399 ab
7	20	60	--	60	4377 abc
10	140 (SCU)	--	--	--	4242 abc
1	--	--	80	--	3994 abc
8	20	00	120 [$Ca(NO_3)_2$]	--	3903 bc
2	check - No N added				3757 c

*Duncan's multiple range test for significant differences at 0.5 percent is indicated by small letters.

weather and disease damage occurred just after pollination and continued until practically maturity. Measures of solar radiation show that light energy was about 1/4 less during March as compared with the months of November, December, January, February, and April of the same growing period.

Another aspect of the yield response in the nitrogen experiment is shown in Table 6. Comparison of the stover and grain yields from the first two crops shows that the ratio of stover-to-grain was about twice as high in the second crop. The stover yield was considerably greater the second year for all treatments. Furthermore, the grain yield was greater the second year for the first three treatments listed (those with lowest nitrogen level) but less for all of the higher nitrogen treatments. The higher yields at low nitrogen levels may be due in part to the increased phosphorus level the second year. However, it is apparent that the second crop did not respond in grain or stover production to a nitrogen level above 20 + 40 kg N/ha. There was somewhat more stover production with even less grain production in the $Ca(NO_3)_2$ and SCU treatments.

These results suggest the importance of pathological and weather factors often referred to as "a bad year" by farmers. Levels of costly fertilizer application which were expected to produce a maximum crop yield under good growing conditions produced little more than that with a minimum nitrogen application. The limiting factors of climate and disease prevented the crop from utilizing the applied fertilizers effectively.

Table 6. Comparison of dry stover yields, yields of grain at 15.5 percent moisture and the stover/grain ratios for first and second crops in the nitrogen experiment at Brasilia

N applied (kg/ha) (as urea except where otherwise noted)		First Crop			Second Crop		
First year	Second year	Stover	Grain	Ratio	Stover	Grain	Ratio
		kg/ha	kg/ha	s/g	kg/ha	kg/ha	s/g
20+0	0	2843	3246	0.876	5595	3757	1.489
0+40	0+80	3045	3582	0.850	5752	3994	1.440
20+40	20+40	3390	4027	0.842	6584	4630	1.425
20+80	20+80	4075	5285	0.771	6524	4638	1.407
20+120	20+120	4661	6257	0.745	6423	4504	1.426
20+40+40	20+40+40	4205	6179	0.680	6459	[illegible]	1.436
20+60+60	20+60+60	4464	6310	0.719	6715	4377	1.534
$Ca(NO_3)_2$ 20+80	$Ca(NO_3)_2$ 20+120	4087	5423	0.754	6776	3903	1.736
SCU 20+80	SCU 20+100+100	3591	5096	0.705	6508	4541	1.433
SCU 20+80	SCU 140	4268	5677	0.752	7011	4242	1.653

Lime-Phosphorus Experiment on a Red-Yellow Latosol of Medium Texture

As a result of the recommendations of the Cline-Buol study, a second site was selected at the Brasilia station. It was recommended that the usefulness of the results could be considerably increased by testing the more important treatments on a loamy red-yellow latosol as well as on the dark-red clayey latosol on which the first experiments are located. The site selected has no irrigation possibility. The soil profile has somewhat less exchangeable aluminum, about 0.75 me/100 grams of soil, than the dark red clayey latosol but is similarly low in exchangeable calcium and magnesium and in available phosphorus. Studies by Wolf and Buol showed that the available water holding capacity of this soil should be better than that of the dark red clayey latosol having nearly 40 percent more available water storage capacity as indicated in the following table:

Soil-water (tension) (bars)	Amount of Water (percent by volume)	
	Dark red clayey latosol	Red-yellow loamy latosol
0.1	29.3	25.0
15.0	18.0	10.5
Available water	11.3	14.5

The experiment established on this soil has several features common to the earlier experiments with some modifications. Deep and shallow limestone incorporation and a zero limestone rate were included as well as two levels of phosphorus as simple superphosphate, a moderate level and a very high level. The yield response to residual effects of these applications and chemical soil tests will be followed for several crops, as this is one of

the most important aspects of comparison among such soils. Most of the phosphorus treatments were applied as triple superphosphate at the moderate rate of 400 kg P_2O_5 broadcast and 100 kg P_2O_5 banded. All plots are double the standard width of the earlier experiments. These plots will be divided into two plots in future crops. The basic magnesium application was 50 kg/ha of magnesium as magnesium sulfate except for treatments 7 and 8 in which 50 kg/ha was banded. This was done in order to have a specific comparison with another experiment on the Dark Red Clayey Latosol but does not suggest special practical importance of this technique.

The description of the treatments and yield are given in Table 7. This crop was less damaged by leaf blight and insects and was not affected by wind damage as was the nitrogen experiment. Nevertheless, the yields were somewhat lower than expected and the results are considered less than conclusive as a means of comparison between characteristics and requirements of this soil versus the Dark Red Clay Latosol. Preliminary suggestions from these results are:

a) The insignificant yield difference between 2000 kg P_2O_5 broadcast and 400 kg P_2O_5 broadcast + 100 kg banded when the limestone was deeply incorporated was not expected. This could either be due to the inability of the crops during this growing season to respond to higher available phosphorus because of environmental limitations or to the lack of requirement for such a high phosphorus application in the soil. If the latter reason is correct, this could be a very important and favorable characteristic

Table 7. Results of the first wet season crop from experiment conducted on Red-Yellow Medium Texture Latosol at Brasilia (corn grain yields at 15.5 percent moisture--means of three replicates)

Treatment No.	Method and amount of materials applied					Grain yields (kg/ha)*
	Lime	P_2O_5 kg/ha	P_2O_5 kg/ha	Source	Mg Application	
6	4 ton deep	2000 bdcst		Simple super phosphate	50 kg/ha bdcst	6040 a
4	4 ton deep	400 bdcst	100 band	Simple super phosphate	50 kg/ha bdcst	5498 ab
8	4 ton deep	400 bdcst	100 band	Triple super phosphate	50 kg/ha bdcst	5372 ab
5	4 ton deep	400 bdcst		Simple super phosphate	50 kg/ha bdcst	4195 bcd
2	4 ton deep	400 bdcst	100 band	Triple super phosphate	50 kg/ha bdcst	4816 bcde
7	4 ton shallow	400 bdcst	100 band	Triple super phosphate	50 kg/ha band	4714 bcde
1	0	400 bdcst	100 band	Simple super phosphate	50 kg/ha bdcst	4593 de
3	4 ton shallow	400 bdcst	100 band	Triple super phosphate	50 kg/ha bdcst	4181 e

*Results of the Duncan Test at .05 level of probability

of this soil in contrast to the Dark Red Clayey Latosol. Future crops under more favorable environmental conditions are necessary to resolve this matter.

b) There were good indications of response to limestone incorporated to 30 cm versus 15 cm depth. This is similar to the effect noted on the Dark Red Clayey Latosol. The importance of this also should be tested during a year with stronger occurences of dry spells during the rainy season ("veranicos").

c) The response to 4 tons/ha of limestone incorporated to 15 cm depth versus no limestone application was significant. This differs from the Dark Red Clayey Latosol and may be important from the standpoint of a lower lime requirement.

Phosphorus Experiments on Dark Red Clayey Latosol

Four consecutive corn crops have been harvested in this experiment, two wet season crops and two dry season irrigated crops. The results are given in Table 8. The highest total yield for the four crops, over 29 tons/ha, was obtained with the application of 1280 kg/ha of P_2O_5 broadcast initially without any further additions. The fourth crop under this treatment was at the maximum production, over 9000 kg/ha (144 bu/acre). An equivalent amount banded (320 kg/ha for each of the four crops) resulted in about 15 percent less total yield for the four crops than the broadcast. It remains to be determined from subsequent crops how long the strong residual effect of the high initial broadcast phosphate application will persist. A smaller initial broadcast phosphate application (320 kg/ha of P_2O_5) plus

Table 8. Phosphorus experiments with corn at Brasilia; amounts and methods of application of phosphorus and yields of four consecutive crops

Treatment No.	Amount and method of phosphorus application kg/ha of P_2O_5					Grain Yields kg/ha (15.5% moisture)				
	broadcast	banded								
	Nov. 1972	Nov. 1972	May 1973	Dec. 1973	May 1974	1*	2**	3***	4****	Total
1	160	-	-	-	-	[illegible]	3071	[illegible]	1784	11,167
2	320	-	-	-	-	6274	5698	3810	3427	17,602
3	640	-	-	-	-	6794	7462	3977	5459	23,694
4	1280	-	-	-	-	7963	8538	3968	9035	29,400
5	1920 (May 1973)	40	-	-	-	8963	9548	4555	9000	32,366
6	-	80	80	80	80	3414	4079	3080	6032	16,605
7	-	160	160	160	160	3855	6576	3415	8073	21,919
8	-	320	320	320	320	4796	8429	4129	9039	26,456
9	320	80	80	80	80	6659	7321	3335	7224	24,539
10	80	80	80	80	80	4568	6003	2563	6486	19,620

* First crop, wet season 1972-73

** Second crop, dry season 1973--irrigated

*** Third crop, wet season 1973-74

**** Fourth crop, dry season 1974--irrigated

80 kg/ha banded for each crop resulted in a total yield for the four crops of almost 85 percent of the maximum or an average of about 100 bushels of corn per acre for each of the four crops over a two-year period in spite of the poor yields of the second wet season crop which was less than half of the average of the other three crops.

Phosphorus-Nitrogen Experiment with Beans

An experiment was established in January-February 1974 at the Agua Limpa farm owned by the University of Brasilia located near the city. The project was done in conjunction with the Department of Agronomic Engineering of the University, the Fundação Zoobotanica do Distrito Federal, the National Bean Program of EMBRAPA, and five students of agronomy at the University of Brasilia. Each student was assigned principal responsibility for a portion of the data collected, and this work will serve as the "final project" or thesis for the Engineiro Agronomo degree of these students. One of the students was awarded a scholarship from the Brazilian Research Council (CNP) for her participation in the project

The soil on which the experiment is located is classified in the Brazilian system as a Red Yellow Latosol of clay texture. This soil is common in areas of cerrado vegetation and is slightly different from the soils at the Agricultural Experiment Station on which experiments are under way. One important difference is that the quantity of exchangeable aluminum is only about 0.6 me/100 gm at the surface and decreases to 0.3 me/100 gm at 50 cm depth.

The design of the experiment is similar to the original phosphorus experiment at the station. Three levels of phosphorus (simple superphosphate) were broadcast initially and there is one level of phosphorus applied banded with each crop. Three levels of nitrogen were applied as urea, since

previous results suggested the need for fertilizer nitrogen for best yields. The experiment is a randomized complete block with split plots. There are nine fertilizer treatments with four varieties as subplots, and four replications. The treatments and yields of the first crop are shown in Table 9. In addition to yield, data were collected on root weight, foliage weight, pod weight, and bean weight.

In general, there were significant responses to all levels of phosphorus and to the level of 60 kg/ha of nitrogen. Perhaps the most important result is the relatively good yield attained by the application of 160 kg/ha of P_2O_5 banded. Root studies indicate that the weight of roots extracted from the banded treatments was at least double of the highest broadcast treatment. Considerable root proliferation was apparent around the phosphorus band. A comparison between the results of this experiment with beans and others with corn suggests the greater ability of beans to utilize banded phosphorus although the maximum yield was obtained with 3060 kg/ha of P_2O_5 broadcast. Over 70 percent of the maximum yield was obtained with only 160 kg/ha of P_2O_5 banded. This suggests the importance of crops with a tap root system in the rotation as a means of utilizing banded phosphorus more effectively.

Liming Experiment on Dark Red Clayey Latosol

Three consecutive corn crops have been harvested in this experiment and the data are shown in Table 10. A significant increase in yield due to an initial deep incorporation of lime in comparison with shallow incorporation has been maintained for all three crops. Yields for the second crop were substantially higher than the first crop due primarily to a higher level of

Table 9. Treatments and yields of dry beans (Phaseolus vulgare) in an experiment conducted on the Agua Limpa farm (means of four replications)

Treatment				Varieties			
	kg/ha	kg/ha of P_2O_5					
No.	Nitrogen	Broadcast	Banded	Rico 23	Corisca	Rosinba	Roxinbo
1	0	160	-	658	523	547	460
2	0	400	-	950	950	1034	531
3	0	2060	-	1561	1667	1474	815
4	60	400	-	1273	1431	1175	1052
5	60	-	160	1334	1517	1379	966
6	120	160	-	693	667	860	600
7	120	400	-	1298	1516	1362	1138
8	120	2060	-	2062	2248	1939	1459
9	120	-	160	1425	1581	1522	1167

lsd .05 - for differences between fertilizer treatments and within the same variety or between varieties - 252 kg/ha.

lsd .05 - for differences between varieties but within the same fertilizer treatment - 241 kg/ha.

Table 10. Liming experiment with corn at Brasilia; amount and depth of lime incorporation and yields of three consecutive crops.

No.	Initial lime treatments tons/ha	Depth incorp.	Grain yields, kg/ha (15.5% moisture) 1st Crop*	2nd Crop**	3rd Crop***
1	0	-	2115	4569	880
2	1	0-15	3423	5281	1474
3	2	0-15	3531	5689	1863
4	4	0-15	4004	5903	2265
5	8	0-15	3723	5960	2052
6	0 (1 ton/ha $MgSO_4 \cdot 7H_2O$)	0-30	3572	5875	1653
7	1	0-30	4019	5684	2086
8	2	0-30	4341	5858	2573
9	4	0-30	4797	6682	3058
10	8	0-30	4792	7266	3601
	Duncan test at .05		574 (2 means)	553 (2 means)	not
			604 (3 means)	582 (3 means)	yet
			622 (4 means)	599 (4 means)	avail.

* First crop, wet season 1972-73

** Second crop, dry season 1973-irrigated

*** Third crop, wet season 1973-74

phosphorus applied. The relatively low yields of the third crop was due to the unfavorable climatic conditions and disease and insect damage which affected all the experiments in the 1973-1974 wet season. Nevertheless the initial deep incorporation of lime resulted in yields 50 percent or more higher than the same amount incorporated at a shallow depth. The question is how long this residual effect will persist and this will be determined by subsequent cropping.

Soil-Water Studies

1. As it has been found that crop production on extensive areas in the Carpo Cerrado may be severely limited by dry periods during the rainy season, an analysis was made of the likelihood of occurrence of the dry periods or "veranicos" as they are called locally. This analysis dealt with the questions of how long do they last and how are the chances of a dry spell of x number of days. An attempt was also made to answer the question of when the "veranicos" are likely to occur during the rainy season. Data were collected from several sources and combined to give a precipitation record of over 40 years for the area. Long-term temperature, radiation, and evaporation data were obtained from a station about 40 km northeast of the site of the field experiments.

The results of the analysis of the climatic data can be summarized as follows:

(1) There is only an 8 percent chance that in any year the longest dry spell will be limited to eight days or less. In other words, only one year in thirteen will rainfall be well distributed during the rainy season;

(2) There is a 50 percent chance that the longest dry spell will be fourteen days or more and a 15 percent chance that the longest dry spell will exceed three weeks;

(3) The 20-day period from December 27 to January 15 has a larger number of dry days than periods either before or after;

(4) The occurrence of wet season dry spells is hidden in the means of montly precipitation data. That they occur and their extent are only shown when the monthly data are divided into shorter time periods and analyzed by appropriate methods.

2. Soil-water properties were determined in the field experimental plots at the experiment station during the period of growth of the corn crop. This was done by instrumentation of the soil with tensiometers and electrical resistance blocks and taking instrument readings on a regular basis. In order to relate soil-water tension or resistance block readings to soil-water content, gravimetric soil samples were taken in the vicinity of the instruments. More than 600 samples were collected from three experimental sites and these provided a wide range of soil-water conditions. The results are summarized as follows:

(1) Although the soils at the main experimental plots have almost 50 percent clay they are very strongly aggregated and their physical properties are like sands. Water infiltration and capillary conductivity are very high;

(2) The soils release two-thirds of the available stored water at relatively low tensions, between 1/10 and 1 bar;

(3) Available stored water is limited to approximately 34-44 mm per 30 cm

of soil on the clayey soil. On a medium textured soil about 30 percent more water is available than on the clayey soil;

(4) The unfavorable water-supplying properties of these soils together with the occurence of dry periods during the rainy season and the limitations of root growth in the subsoil due to aluminum toxicity make water management a critical factor for successful crop production on these soils.

3. A dry season experiment with corn planted in June 1973 and grown with different irrigation schedules and wet season experiments with corn planted in September, October, and November, 1973 were conducted to determine:

(a) Crop response to various water environments;

(b) Crop water use in relation to meteorological factors;

(c) effects of differential depths of limestone incorporation in relation to water treatments.

The results of these experiments can be summarized as follows:

(1) In the dry season experiments, although recovery from visual wilting was almost immediate following an irrigation, treatments undergoing severe moisture stress failed to use water in a normal manner for three days after the irrigation. Evapotranspiration rates for those treatments were only 66 percent of treatments not stressed prior to the irrigation. Water extraction patterns with depth indicated root inactivation in the top part of the root zone;

(2) Yield was well correlated with soil-water stress in the dry season, less so in the wet season. Correlations were as high as -.98 in the dry season and -.77 in the wet season;

(3) A critical level was found of one-half bar of soil-water tension or 60 percent soil-water depletion above which corn yields are increasingly reduced;

(4) It is estimated that a day of soil-water stress will result in corn yield decreases of 32-55 kg/ha/day for the range in water stress in the dry season experiment;

(5) Dry season yields were well correlated with irrigation interval and amount of water applied;

(6) Wet season yields were only weakly affected by dry periods of up to eight days.

4. Functional relationships were established to relate evapotranspiration to the various climatic parameters measured during the growing season. Based on crop water use measurements, an estimate was made of the water requirements for dry season irrigated cropping and the potential for dry season cropping was compared with wet season cropping. The results of these analyses are summarized below:

(1) The dry season field water requirement to be supplied by irrigation is estimated at 630 mm. This estimate includes losses by evapotranspiration (510 mm) and drainage (300 mm) and additions of rainfall (180 mm). It does not include conveyance and application losses which may be considerable. The requirement of an estimated 630 mm to be supplied to the field is based on a gravity irrigation system which is grossly inefficient for this type of soil. A sprinkler type of irrigation system would be an alternative to keeping losses to a minimum. Proper management of that system would be accomplished by frequent wettings of the shallow root zone, minimizing the losses due to drainage;

(2) There was no conclusive evidence that the dry season crop production potential is greater than the wet season because of higher radiation, pan evaporation, or other climatic factors. However, the incidence of

uncontrolled variables such as diseases and insects is greater during the wet season and consequently the potential for crop production is less than for the irrigated dry season crops.

5. It has been postulated that the beneficial effects of deep incorporation of lime on crop yields on the highly acid soils of the Campo Cerrado were due to greater water and/or nutrient exploitation of the subsoil because of the more extensive root system developed. The experimental results relating the effect of differential depths of lime incorporation to the soil-water utilization lead to the following conclusions:

(1) Although a 30 percent increase in corn yields was obtained by incorporating lime to a depth of 30 cm in comparison with incorporation to a depth of 15 cm, no evidence was found that there was greater water utilization with the deeper incorporation of lime;

(2) There is evidence that the deep liming had a beneficial nutritional effect as yet not completely understood which resulted in the higher yields;

(3) Soil-water extraction was confined to the upper 60 cm of the soil profile, with about 80 percent of the crop water use from the upper 45 cm. The soil-water extraction appeared to be independent of percentage aluminum saturation.

It is estimated that long-term rainy season yields of corn will only be about 54 percent of possible yields with supplementary irrigation during the wet season. Improved wet season water management is required for intensive cropping in the region if yields are to be stabilized and costly inputs repaid.

6. A study was made during the summer of 1974 of the possibilities for irrigation during both the wet season and dry season in the Federal District of Brazil which is representative of a large part of the Central

Plateau. Data on climate, hydrology, geology, and soils were collected from all available sources. At representative sites physical soil tests were made and soils collected for further study. Part of the soil tests were done by locally trained technicians at the Experiment Station near Brasilia. Other soil properties were determined at Cornell's engineering laboratory in Ithaca. As a result of this study the following conclusions may be drawn:

(1) Water is plentiful and with the creation of storage facilities the amount of irrigation water may be sufficient to irrigate 5 to 10 percent of the Federal District during the year;

(2) For a year of average rainfall about one third of the precipitation goes to deep percolation. This water is released from the subsoil and subsequently is gradually discharged by the rivers and streams. The quality of this water is excellent.

(3) Groundwater may be an important irrigation water source, especially at high elevations. Water from springs is readily available and can be used for irrigation to some extent.

(4) Engineering tests show that the high initial infiltration and permeability of the soils can be reduced by compaction at favorable moisture conditions. In properly compacted canals and farm ponds, seepage and percolation losses will be at an acceptable low level. The costs of compaction as a method to prevent water losses is one tenth of the cost of plastic linings.

Soil-Plant-Water Relationships

Studies were initiated during the 1974 dry season to determine some of the physiological responses of corn to the soil fertility and management practices under investigation at the experiment station near Brasilia. Two sets of interrelated experiments are planned and will be related to the soil fertility experiments. One set will focus on the above ground portion of the corn plant and detailed growth analysis studies will be made with particular emphasis on the effects of water stress as related to soil treatments and weather patterns 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 soil fertility and management practices.

Ghana

In late April and early May, 1974, Cornell soil scientists, Drs. M. G. Cline and D. J. Lathwell visited Ghana to consult with Ghanaian officials and soil scientists and USAID Mission personnel regarding a proposed cooperative soil fertility research project. On the basis of the consultations and the information assembled, it was concluded that prospects were very good for successful collaboration on soil fertility research between Cornell University and the Soil Research Institute at Kumasi. A tentative cooperative agreement was drafted and reviewed by Director Henry Obeng and his associates of the Soil Research Institute, the Executive Director of the Council for Scientific and Industrial Research, the Agriculture and Program officers of USAID/Accra,

and Dr. Kang, soil scientist of the International Institute of Tropical Agriculture at Ibadan, Nigeria. Subsequently, the agreement was approved with minor modifications.

The research effort would focus on identifying those factors which are limiting the yields of food crops on the acid soils in the area. This may include work on nitrogen, phosphorus, and lime rates and methods of application, subsoil acidity, micronutrients, soil moisture relationships, and adaptation of crop varieties. As the project develops, the research will aim at the development of soil and crop management practices suitable for mixed cropping systems as practiced by many small farmers in the region.

As the main rainy season begins in March and April, it is planned to initiate the field experiments early in 197[illegible]. This schedule would provide more lead time in completing plans for the research, recruiting personnel, and obtaining the necessary clearances. Meanwhile, soil samples collected from potential experimental sites by Drs. Cline and Lathwell are being analyzed for their physical, chemical and mineralogical properties. Arrangements have been made for Dr. Charles Ofori, head of the soil fertility division at the Soil Research Institute, to visit Cornell University and the on-going soil fertility research projects in Puerto Rico and Brazil in November. This would provide additional opportunity for discussion of the detailed plans for the work in Ghana and how the research would relate to the similar projects in Puerto Rico and Brazil.

Ithaca

Soil Chemical and Mineralogical Investigations

During the past year, chemical and mineralogical investigations were carried out as a counterpart to the field study of the soils of the Brazilian Central Plateau conducted by Professor M. G. Cline of Cornell University, Professor S. W. Buol of North Carolina State University and four senior Brazilian soil scientists in June 1973. The objective of the field study was to appraise 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. Six soil profiles, clayey and loamy textural phases of Dark Red or Red Yellow Latosols, were examined, described, and sampled. The conclusions of the field study 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.

The results of the laboratory investigations on the chemical and mineralogical properties of the soils generally substantiated the conclusions of the field studies inasmuch as the gross mineralogical composition of the soils was not greatly different from that of the soils at the experiment station, and indeed the results of the fertility research should apply in principle to large areas of the Central Plateau.

There were, however, some interesting and novel findings. One of these was that the clay size fractions of the soils were found to have a reactive surface phase, extractable in acid calcium chloride solution, that apparently

is depleted in silica or enriched in aluminum oxide, relative to the bulk of the clay fraction. This reactive surface phase is extremely small in amount and does not constitute more than one percent of the soil clay fractions. It was found, however, to have an influential effect on the surface charge properties (anion and cation retention) and soluble aluminum levels of the soils.

The composition of the reactive surface phase as given by the SiO_2/Al_2O_3 ratios was highly correlated with the sand content of the soils. The most abundant mineral in the sand fractions was quartz and apparently over long periods of time this sand size quartz has functioned as a source of a small amount of soluble monosilicic acid, $Si(OH)_4$, of which a portion has been specifically adsorbed by aluminum surfaces in the clay fractions. This occurrence may be a common phenomenon in highly weathered soils developed from acidic rocks that have an appreciable quartz content. Indeed, a relationship between the sand content (quartz) and the composition of the surface reactive phase has also been found for some highly weathered acid soils from Malawi.

Although the observed textural relationship to the composition of the surface reactive phaser may be of limited immediate significance in regard to recommended management practices, it is of significance in aiding an understanding of the more important compositional differences that may exist within highly weathered soils which are important in determining their chemical properties.

The results of the laboratory investigations were presented at a recent annual meeting of the Clay Minerals Society and a manuscript is being prepared for publication in CLAYS AND CLAY MINERALS.

E. Dissemination and Utilization of Research Results

The results of the research as in previous years have been disseminated in a number of different ways: (1) seminars, conferences, and workshops; (2) publications; (3) experimental site visits by farmers, extension agents, scientists, teachers, and students; (4) graduate and undergraduate student participation; and (5) consultation.

Seminars, conferences, and workshops: Results of the research in Puerto Rico and Brazil were presented in February, 1974 at a seminar in Cali, Colombia on Tropical Soil Management and the Development Process sponsored by AID, CIAT, and the University Consortium on Soils of the Tropics. There were about 200 participants at the week long seminar including researchers, teachers, extension agents, administrators, and students. Most of them were from Latin American countries and of particular interest was the participation of a large number of young soil scientists from a number of different research and educational institutions.

A report on the "Relationship of aluminum toxicity with root growth, water uptake, and yield of corn in an Oxisol of the Federal District" was presented in Portuguese in Recife, Brazil in July, 1974 at a symposium on Breeding of Plants for Tolerance to Toxic Conditions of Aluminum and Manganese in the Soil. This symposium was sponsored by the Brazilian Society for Progress in Science. As a result of this symposium, stimulus has been given to more intensive research efforts to develop crop varieties which are more tolerant to soil toxicities and deficiencies as an important part of an overall objective of minimum input technology for

small farmers.

As part of a seminar held at Campina Grande, Paraiba, Brazil in July, 1974 under the auspices of EMBRAPA, two 90-minute presentations were made by Dr. Naderman to 35 participants on the principal concepts and methodology involved in the research program at the experiment station near Brasilia.

A presentation in Portuguese was given in Brasilia by Dr. Naderman to 100 participants including agricultural specialists, university staff and students on research in soils and plant nutrition for the Central Plateau of Brazil. This program was sponsored by the University of Brasilia as one of ten conferences on recent developments in crop and soil technology.

Periodic seminars in Portuguese for the staff at the experiment station at Brasilia have been held throughout the year to discuss the results of the various studies including the liming experiments, soil-water investigations, and studies on the physiological effects of water stress in relation to lime and phosphorus applications.

Publications: Reports are prepared for publication in technical and nontechnical journals and other media as phases of the research are completed. Copies are distributed to interested research workers, extension agents, teachers, and students. Abstracts of the more important publications are prepared for inclusion in the quarterly A.I.D. Research and Development Abstracts. As an outgrowth of the research on soil acidity and liming, a comprehensive review of this subject as it relates to the humid tropics is now in press as a bulletin which will be given wide distribution. A list and abstract of publications, articles submitted for

publication, theses, and reports prepared for conferences during the past year are given in the Appendix.

Experimental Site Visits: The experimental sites in Puerto Rico and Brasilia continue to have periodic visits of a substantial number of farmers, extension agents, scientists, teachers, and students to keep informed of the progress of the research. The very high production of plantains in the experiment in Puerto Rico continue to draw large numbers of farmers and extension agents. It is estimated that some 2,000 persons have now visited the plots which have demonstrated the potential for high production with relatively modest inputs on the acid soils.

Student Participation: During the past year twelve graduate students, foreign and U.S., were involved in the project or research related to it. Of these, eight were involved in thesis research in developing countries overseas.

As reported in the section on Research Accomplishments, five agronomy students from the University of Brasilia participated in the research project. Each student under the supervision of the project coordinator was assigned responsibility for a phase of the work and this served as the basis for a thesis for the degree of Engineiro Agronomo. One of the students was awarded a scholarship from the Brazilian Research Council (CNP) for participation in the project.

Consultation: During the past year several of the Cornell faculty involved in the research were requested by AID to serve as consultants. Dr. Fox spent two weeks in South Vietnam in the fall of 1973 for the purpose of consulting with AID personnel on soils problems in refugee relocation sites and on soils research in the country. Dr. Lathwell spent

a month from mid-January to mid-February, 1974 with an AID team in Central and South America to review the soil testing and soil fertility projects conducted by North Carolina State University. Drs. Prosdoff and Cady took part in a workshop on "Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs," sponsored by AID and the Universities of Hawaii and Puerto Rico. This was held in Hawaii in May, 1974. Dr. Arnold participated in an AID seminar in Washington, D.C. on the interpretation and management of development resource data with special reference to Central-West Africa. Dr. Prosdoff participated in an AID Workshop in Washington, D.C. in October, 1974 on research information networking.

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. Soil scientists of the U. S. Department of Agriculture stationed in Puerto Rico have collaborated in some phases of the research.

2. The research in Brazil is carried on cooperatively with the Brazilian Agricultural Research Organization (EMBRAPA) and North Carolina State University. During the course of the work at Brasilia, research linkages were established with the University of Brasilia, the Federal District Agricultural Research Agency, the Sao Paulo Agricultural Research Institute and the International Atomic Energy Office at Campinas, Sao Paulo.

3. The proposed research in Ghana has provided a linkage with the Soil Research Institute at Kumasi. As the work gets under way, it is

anticipated that cooperation will be established with the Crop Research Institute at Kumasi and the University of Accra at Legon.

4. Continuing contact and research linkages are being maintained with the International Research Institutes: (1) Dr. Kang of the International Institute of Tropical Agriculture (IITA) at Ibadan, Nigeria has participated in the discussions of the proposed research project in Ghana and it is anticipated that there will be collaboration with IITA in certain phases of this project; (2) at the seminar in Cali, Colombia in February 1974 on Tropical Soil Management and the Development Process, an opportunity was provided to interact with the soil and crop scientists of the Centro International de Agricultura Tropical (CIAT). A Cornell Ph.D. candidate from Cameroon is now doing his thesis research at CIAT on cassava and a Ph.D. candidate from Ghana completed his thesis research during the year at CIAT on legume Rhizobia; (3) the Cornell graduate student interdisciplinary research team of six Ph.D. candidates in the agricultural sciences, one of whom is majoring in soil science, is continuing the collaborative arrangement with the International Center for Improvement of Corn and Wheat (CMMYT). The research team is under the guidance of Cornell faculty and CMMYT research scientists. The program is now in its second year of a four-year program.

5. Through the U.S. University Consortium on Soils of the Tropics (Cornell, Hawaii, North Carolina State, Prairie View A&M, Texas, and Puerto Rico) information and ideas are exchanged on tropical soils research activities through periodic meetings, seminars, and workshops.

6. During the past year visiting professors and scientists with extensive research experience on soils of the tropics have broadened the opportunities for research linkages with their institutions. Dr. Claude Charreau, soil scientist with the Institut de Recherches d'Agronomie Tropicale (IRAT) was at Cornell for the 1974 spring term to give a series of lectures on The Use and Management of the Soils of Dry and Wet-Dry Tropics of West Africa. One result of his presence is that arrangements are now being made for a Cornell Ph.D. candidate to do his thesis research in the Ivory Coast in collaboration with IRAT. Dr. Peter Nye of Oxford University, England, co-author of the classic treatise on "The Soil Under Shifting Cultivation" is giving a series of lectures during the 1974 fall term and consulting with students and staff on soil management problems in the humid and subhumid tropics with special reference to his work in Africa.

7. Through his graduate students from Venezuela, Dr. Arnold has maintained continuing contact with the Division of Soils of the Ministry of Public Works. He is periodically called upon by Venezuelan government officials for advice and counsel in connection with their research and training program in soil classification and soil survey.

8. Periodic contact is maintained with FAO soil scientists in Rome and at field stations. There has been a regular exchange of soils research publications as in the past year. There is an FAO soil scientist working on a soil testing project at the Soil Research Institute in Ghana, and it is anticipated that there will be some collaboration with him relating to the soil fertility research proposed for Ghana.

G. Expenditures--April 1, 1973 to March 31, 1974--csd-2490 (Research Contract csd-2490 terminated on March 31, 1974 and all obligations under this contract have been paid. A new contract ta-c-1104 became effective on April 1, 1974)

	Cornell	Puerto Rico Subcontract	Total
Salaries and Wages	$ 81,686.16	$ 86,729.78	$168,415.94
Overhead	29,304.92	44,319.13	73,624.05
Travel and Transportation	22,087.75	2,321.41	24,409.16
Allowances	8,673.87	---	8,673.87
Equipment, Vehicles and Supplies	8,021.11	7,402.73	15,423.84
Other Direct Costs	14,884.95	4,281.86	19,166.81
TOTAL	$164,658.76	$145,054.91	$309,713.67

Expenditures--April 1, 1974 to September 30, 1974--ta-c-1104

	Cornell	Puerto Rico Subcontract	Total
Salaries and Wages	$ 37,730.44	$ 32,656.71	$ 70,387.15
Overhead	493.00	15,100.46	15,593.46
Travel and Transportation	14,764.23	869.98	15,634.21
Allowances	910.00	---	910.00
Equipment, Vehicles and Supplies	6,110.87	3,599.74	9,710.61
Other Direct Costs	1,118.81	1,414.95	2,533.76
TOTAL	$ 61,127.35	$ 53,641.84	$114,769.19

H. Work Plan (April 1, 1975 to March 31, 1976)

The plan of work for 1975-1976 described below follows the general plan which was outlined in the contract with modifications based on previous results and new approaches to meet the objectives. As planned, the level of effort will be somewhat reduced in Puerto Rico but with more attention given to legumes such as soybeans and perennial crops such as plantains. The work in Ghana will be given greater attention and it is planned to initiate simple experiments on farmers' fields to supplement the main experimental work to be conducted at the Soil Research Institute at Kumasi. The level of effort in Brasilia will be about the same as last year as will the on-campus chemical, physical, and mineralogical studies and staff support.

One important objective of the research is to develop ways and means by which crops can utilize the nutrients in the soil more efficiently. Although a large part of the population in the tropics will continue to rely on large inputs of fertilizers for food production, a substantial population will continue to depend on food produced with little or no inputs because of economic, geographic, social, and political constraints. One approach to improve food production with minimum inputs is to develop crop varieties by plant breeding procedures which would utilize more efficiently the nitrogen, phosphorus, and other nutrients in the soil and which would be more tolerant of acid soil conditions especially in the subsoil where high levels of soluble aluminum and/or manganese limit plant root growth and hence crop production. There is now good evidence that genetic materials of corn and other food crops are available which can utilize low levels of inorganic

nutrients efficiently. It is proposed to explore the possibilities within the budgetary constraints of the present contract. A work plant and budget for an expanded effort in this work was supplemented as a proposed amendment to the present contract.

A detailed description of the research activities under the present contract follows.

Puerto Rico

Experiments with corn and soybeans: In a continuing effort to find ways and means to utilize nitrogen sources more efficiently for corn production, the four nitrogen field experiment sites were redivided in the fall of 1974 into three main plots. These were planted with soybeans, corn, or left fallow. The soybeans and corn will be harvested and the soybean stalks and pods left on the ground. In the spring of 1975, corn, with and without nitrogen fertilizer will then be grown on each of these three pretreatments (corn, soybeans, fallow) in order to determine the effect of the residual nitrogen. It has been shown in the continental U.S. that the residual fixed nitrogen from a soybean crop is enough to raise the grain yield on a subsequent non-nitrogen fertilized corn crop by 10 to 15 bushels per acre. In Puerto Rico and in other tropical regions high yields of soybeans have been obtained and the time between crops is less than in temperate regions. Consequently, substantial residual nitrogen may be available to reduce the applied nitrogen required for high yields of a subsequent crop.

Experiments with plantains: The nitrogen and phospherus fertility experiments with plantains will be continued. The preliminary data from this year's crop indicate that yield levels of the first ratoon are as high as the record yields of the first crop with little or no response to applied nitrogen

and phosphorus. It is planned to continue the experiment to determine if the yields of subsequent ratoon crops will be sustained and if pronounced responses to applied nitrogen and phosphorus will eventually be obtained.

Liming Experiments: The subsoil liming experiment with corn as the test crop initiated last year will be continued to determine the long-term effect of deep placement of lime in providing for greater root growth in the highly acid subsoils with consequent higher yields. The results from the first corn crop planted in the fall of 1973 showed that the grain yields increased from 5.6 tons/ha (88 bushels/acre) with no lime, to 6.4 tons/ha (102 bushels/acre) when the top 20 cm was limed, to 8.4 tons/ha (126 bushels/acre) when the lime was incorporated to a depth of 60 cm.

Phosphorus experiment with corn: The field study will be continued comparing the residual effects of initial high levels of applied phosphorus broadcast with annual applications of smaller amounts applied in a band. Results of the last crop year indicate that small banded annual applications are more efficient in increasing yields than large broadcast applications made every few years.

Brazil

Soil fertility studies: These studies on the soils of the Campo Cerrado in collaboration with the Brazilian Agricultural Research Organization (EMBRAPA) and North Carolina State University will continue to focus on the responses of corn and other food crops to different levels and methods of application of nitrogen, phosphorus, and lime in order to determine the most efficient ways in which the applied nutrients may be utilized by the crop. Nitrogen field experiments with corn were begun last year at a second site

on a medium textured acid soil which is representative of extensive areas in the region. These experiments will continue for at least two more crop years in order to determine the nitrogen utilization efficiency.

The phosphorus and liming experiments with corn will continue in order to determine the residual effects of the treatments on subsequent crops. It appears now that a combination of broadcast and banded phosphorus applications is most efficient but additional trials in the field are required to confirm the present tentative results.

Preliminary trials with soybeans have indicated a high production potential of this crop on the soils under study. Methods will be explored on how to attain good production with minimum fertilizer input.

The experiments on these infertile soils of the Campo Cerrado have concentrated thus far on supplying nitrogen, phosphorus, and lime most effectively. As potassium and magnesium are very low in these soils more attention will be given to methods of supplying these nutrients more efficiently so that they are not limiting.

Soil-Plant-Water Relationships: Experiments were initiated in the spring of 1974 to study the effect of certain soil management practices on water stress of the corn crop during moisture deficit periods. This study has involved the measurement of growth responses to water stress for both the above and below ground portions of the corn plant and an investigation of the physiological factors most responsible for reduced growth and yield as influenced by plant water stress. The study also will relate the characteristics of nutrient and water uptake to root growth and development to the various soil fertility treatments. The ultimate objective of these

studies is to make recommendations for the most appropriate water management practices for cultivated crops on the soils of the Campo Cerrado. These studies are planned to continue for another year.

Ghana

Following the visit of two Cornell soil scientists to Ghana in the spring of 1974, plans have been developed for collaborative soil fertility research with the Soil Research Institute at Kumasi on the acid soils which are extensive in the region. A cooperative agreement between Cornell and the Institute has been approved, and it is planned to initiate the field experiments in the spring of 1975. In addition to the main experiments on the land of the Soil Research Institute, it is planned to conduct supplementary trials on farmers' fields where the soils are similar to those at the Institute. It has been agreed that priority in the research be given to develop (1) efficient methods for supplying the nitrogen requirements of the major food crops for good production, (2) methods for correcting soil acidity most effectively, (3) methods for economically supplying phosphorus for sustained crop production, and (4) methods for more efficient use of soil moisture in relation to nutrient uptake.

Cornell-Ithaca

Soil and plant samples from the field experiments in Puerto Rico, Brazil, and Ghana will be analyzed to help interpret the results of the field experiments and provide a basis for the application of the data to similar soils in other areas of the tropics.

Mineralogical analyses of the clay and other size factions of the soils from the experimental plots and similar soils from other areas will be made to

assist in the interpretaton of the field results and the other laboratory analyses.

A search will be made of corn and sorghum germplasms which show some degree of tolerance to unfavorable soil conditions such as high levels of soluble aluminum and/or manganese and which indicate a capacity to utilize efficiently low levels or nitrogen, phosphorus, and other nutrients in the soil. The collection of promising germplasms will then be tested in a range of artificial media solutions to simulate soil solution concentrations. After this preliminary screening the best of the materials in each of the soil problem categories will be subject to more critical tests to determine the tolerance limits.

Work Plan; Abstract and Time Table

Location	Starting Date	Expected Completion
PUERTO RICO		
1. Nitrogen experiments with corn and soybeans at 4 field locations	October '74	October '76
2. Nitrogen and phosphorus experiment with plantains on a representative Ultisol	April '74	June '76
3. Subsoil liming on high aluminum soil with corn and sorghum as test crops	April '74	October '75
4. Phosphorus experiment with corn to test residual effects	April '74	October '76
BRASILIA, BRAZIL		
1. Nitrogen, phosphorus, and liming experiments. Rates and methods of application of nitrogen and phosphorus fertilizers and lime on corn and other food crops	April '74	June '77
2. Potassium and magnesium levels required on the soils of the Campo Cerrado for corn and other food crops	April '74	June '77
3. Soil-plant-water relationships; effect of soil management practices on water stress of corn crop during moisture deficit periods	April '74	January '76
GHANA		
1. Rates and methods of application of nitrogen and phosphorus fertilizers on corn and other food crops at the Soil Research Institute in Kumasi on representative acid soils of the region	January '75	June '77

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

Location (Ghana-cont'd)	Starting Date	Expected Completion
2. Experiments on rates and placement of lime on corn and other food crops on representative acid soils at the Research Institute	January '75	June '77
3. Simple trials on farmers' fields to supplement the experiments at the Research Institute	January '75	June '77
CORNELL-ITHACA		
1. Laboratory analyses of soil and plant samples from the field experiments in Puerto Rico, Brazil, and Ghana	April '74	June '77
2. Mineralogical studies of soils from the experimental plots and similar soils from other areas to provide a basis for interpretation of field results and laboratory analyses	April '74	June '77
3. Staff supp . . and backstopping of field and laboratory work	April '74	June '77
4. Collection and screening of corn and sorghum germplasms which show tolerance to acid soil infertility	April '75	June '77

Budget--April 1, 1975 to March 31, 1976

Salaries and Wages	$ 158,000
Overhead	63,000
Travel and Transportation	21,000
Allowances	18,000
Equipment, Vehicles, and Supplies	12,000
Other Direct Costs	5,000
TOTAL	$ 277,000

Personnel

Professional personnel with full or part-time involvement in the project during the year.

Cornell Staff

Dr. Matthew Drosdoff - Professor of Soil Science, Principal Investigator
Dr. Richard H. Fox - Assistant Professor of Soil Science, Project Leader in Puerto Rico
Dr. George C. Naderman - Research Associate, Project Leader in Brasilia
Dr. Robert M. Weaver - Assistant Professor of Soil Science
Dr. Thomas W. Scott - Associate Professor of Soil Science
Dr. David R. Bouldin - Professor of Soil Science
Dr. Douglas J. Lathwell - Professor of Soil Science
Dr. Robert B. Musgrave - Professor of Crop Science
Mr. James M. Wolf - Research Assistant
Mr. H. Talleyrand - Research Assistant
Mr. Dale Bandy - Research Assistant
Mr. Jan Brunted - Research Assistant

Puerto Rico Staff

Dr. Ferdinand Sanchez Nieva - Director, Puerto Rico Agricultural Experiment Station
Dr. Mario E. Perez Escolar - Associate Director, Puerto Rico Agricultural Experiment Station
Dr. Raúl Pérez - Associate Soil Scientist
Dr. José Badillo - Assistant Agronomist
Mr. Reinaldo del Valle - Assistant Agronomist
Mr. Abdul Wahab - Assistant Biochemist
Ms. Josefina Rivera Muñoz - Associate Chemist
Mr. José Rodriguez Garcia - Research Assistant
Ms. Yvonne Fraticelli - Chemist

U. S. Department of Agriculture

Mr. José Vicente-Chandler - Soil Scientist
Mr. Fernando Abruña - Soil Scientist
Dr. Robert W. Pearson - Soil Scientist

Brazil - Ministry of Agriculture and EMBRAPA

Mr. Wilson W. Soares - Soil Scientist
Mr. Enéas M. Galvão - Research Assistant
Mr. Elcios Martins - Technical Assistant

Appendix

Bibliographic List and Abstracts

Published Articles and Theses

Response of Green Beans to Acidity Factors in Six Tropical Soils and Response of Corn to Acidity Factors in Eight Tropical Soils. Two articles by: Fernando Abruna, Raul Perez-Escolar, Jose Vicente-Chandler, Robert W. Pearson, and Servando Silva. Jour. Agric. of the Univ. of Puerto Rico. 58:44-77. 1974.

The effect of soil acidity factors on yields and foliar composition of intensively managed green beans was determined in Ultisols and an Oxisol typical of the humid tropics. Beans responded very strongly to liming on all six soils. Calcium content of the bean leaves increased and manganese content decreased with increasing lime rates and with yields. Bean yields increased with increasing soil pH to about 5.2 at which level these soils contained essentially no exchangeable aluminum. Bean yields increased with increasing exchangeable soil base content to about 70-percent saturation based on cation exchange capacities as determined with ammonium acetate at pH 7. Bean yields increased with decreasing exchangeable soil aluminum to essentially 0. Soil pH and exchangeable base and aluminum contents were effective criteria for liming these soils.

The effect of soil acidity factors was determined on yields and foliar composition of corn grown on Ultisols and Oxisols typical of the humid tropics. Soil pH values increased from about 3.8 with a base saturation of around 20 percent to about pH 5 with a base saturation of around 70 percent based on cation exchange capacities determined with neutral ammonium acetate. The low pH values in relation to exchangeable base contents are explained by the presence of free salts. The level of aluminum saturation of the soil based on exchange capacities as determined with ammonium acetate decreased from 40 percent at about pH 3.9 to 0 at about pH 5.2. The Ultisols had a high content of exchangeable aluminum when acid but the more weathered Oxisols contained little aluminum. A very close relationship exists between exchangeable base (Ca + Mg) and aluminum values based on total exchange capacities determined either with ammonium acetate at pH 7.0 or by the sum of cations at a given pH permitting conversion of one value to another. Corn responded strongly to liming particularly on the Ultisols which had high exchangeable aluminum content when acid. Calcium content of the corn leaves increased with soil base content and with yields but foliar composition was not otherwise affected by liming. Corn yields increased with pH to about 5.2 at which pH level these soils contained essentially no exchangeable aluminum, with exchangeable base content as determined with ammonium acetate to about the 70-percent saturation level, and with decreasing exchangeable aluminum in the soil to essentially 0. Soil pH, exchangeable base, and exchangeable aluminum content were effective criteria for liming these soils.

Soils of the Central Plateau of Brazil: Chemical and Mineralogical Properties. R. M. Weaver. Agronomy Mimeo 74-9, Department of Agronomy, Cornell University. 1974.

Six soils representing extensive areas of the Central Plateau of Brazil were analyzed for their mineralogical and chemical properties with the objective of relating these properties to implications for soil management practices.

The gross mineralogical composition of the soil clay fractions in this area are predominantly iron oxides, gibbsite, amorphous materials (alkali extractable), and traces of 2:1 layer silicates and titanium oxides. The wide differences among the soils in the amounts of the predominant minerals is not related to soil texture or to soil color (Dark Red vs Red-Yellow). Exceptions to this would be the iron oxides which show a tendency to increase as clay content decreased and the presence of hematite in the Dark Red Latosols but not in the Red-Yellow Latosols.

From an agronomic standpoint, soil texture will probably be the most outstanding property that may necessitate different management systems for the soils of the area. This is first a consequence of increased physical and chemical activity associated with increased specific surface area of the finer textured soils. Secondly, for these soils, texture has an important influence on the nature of the more active oxidic surfaces of the clay fractions, which may in part explain differences in gross mineralogical composition. This will cause the degree of expression of some soil properties to be the resultant of two opposing trends. For example, phosphorus retention by these soils should be expected to decrease with decreasing clay content. The decrease in P retention, however, should be proportionally greater than the decrease in clay content, because of an increased degree of silication of active oxidic surfaces associated with an increased sand (quartz) content.

Soil-Water Studies on Oxisols and Ultisols of Puerto Rico. James M. Wolf and Matthew Prosdoff. Agronomy Mimeo 74-22, Department of Agronomy, Cornell University. 1974.

The purpose of the soil-water experiments conducted in Puerto Rico during the summer of 1971 was to determine the water-supplying characteristics of four soils on which fertility experimentation was in progress, or planned. An auxiliary objective was to compare several possible techniques for obtaining this information for these types of soils. The four soils on which the experiments were conducted were Carreras, Catalina, Torres, and Piña.

Results of the soil-water experiments included: (1) Water <u>infiltration</u> into all soils was very rapid; (2) on the clay soils, lateral water movement, downslope, was a significant factor in observed high rates of water infiltration; (3) field capacity was established to be 1/15 bar for the sandy soil and 1/20 bar for the clayey soils; (4) two avenues for soil-water movement were postulated: Capillary pores (between soil particles) and non-capillary pores (between soil aggregates); (5) the two Oxisols, one very sandy (Piña) and the other high in clay (Catalina) tended to dewater at low tensions, whereas

soil-water release in the Ultisols extended over a wide range of tensions; (6) for the two Oxisols, the bulk of the water is released between field capacity and one bar and a high proportion of the water in the Ultisols is only available at tensions above 1 bar. The Catalina soil is by far the best in terms of water supply characteristics while Carrera and Pifa may be considered the worst; (7) values of capillary conductivity were calculated for the Carrera and Pifa soils--these were found to be highly water content dependent; (8) undisturbed core samples should be used to measure water retention in the wet range (0-3/4 bar) and disturbed samples should be used to measure water retention in the dry range (1-15 bars); and (9) it was suggested that values of soil-water tension be directly related to water contents through extensive gravimetric sampling.

A Simplified Determination of Reductant-Soluble Phosphate in Soil Phosphate Fractionation Schemes. R. M. Weaver. Soil Sci. Soc. Amer. Proc. 38:153-154. 1974.

A simplified and more rapid procedure for the determination of reductant-soluble phosphorus (P) was developed by a modification of the Murphy and Riley (1962) ascorbic acid method. The procedure which eliminated the interference of sodium dithionite by air oxidation and that of sodium citrate by addition of ammonium molybdate, was suitable for the determination of 0.1 to 0.7 µg P/ml in the presence of up to 3000 µg Fe/ml and 4.0 µg Si/ml.

Liming of Highly Weathered Soils of the Humid Tropics. Gaston Amedee. Ph.D. Thesis. Department of Agronomy, Cornell University. 1974.

The objective of this research was to evaluate two commonly used laboratory methods for determining the "lime-requirement" of highly weathered acid soils of the humid tropics and to study the fate of $CaCO_3$ applied to these soils. The standard of comparison for the lime-requirement was the maximum amount of $CaCO_3$ decomposed by the soils upon equilibration of the soils with an excess of $CaCO_3$ and the partial pressure of CO_2 of the air. The two common laboratory methods for determining the lime-requirement of soils examined in the study were the salt (1N KCl) extractable acidity and the exchange acidity as determined by the $BaCl_2$-triethanolamine (TEA) method. The soils tested were the Ap and B2 horizons of highly weathered soils from seven different locations in Brazil, Colombia and Puerto Rico, known to represent extensive areas of potentially productive soils.

It was found that the salt (1N KCl) extractable acidity method greatly underestimated the amount of $CaCO_3$ that was found to react with the soils. On the other hand, the exchange acidity as determined by the $BaCl_2$-TEA method agreed closely with the maximum amount of $CaCO_3$ that was found to react with the soils especially in those that were known to contain aluminum chlorite.

With respect to the fate of $CaCO_3$ applied to the soils, it was found that the cumulative amounts of calcium removed by leaching after saturating with appropriate amounts of $CaCO_3$ were smaller in the highly weathered soils of the tropics than a New York soil, indicating that the pH-dependent charge was just as effective as the permanent charge of soils in adsorbing and preventing the loss of calcium by leaching. There was little indication of fixation of calcium into nonexchangeable forms.

Articles Submitted for Publication

Soil Acidity and Liming in the Humid Tropics. Robert W. Pearson. Bulletin of the College of Agriculture and Life Sciences, Cornell University. In press.

This is a review of the available results of liming trials from the humid tropical regions in an attempt to determine what general conclusions may be possible that would be useful in the synthesis of soil management systems for tropical areas. The review is divided into four main topics with a number of subtopics under each: (1) Effect of lime on soil properties; (2) crop response to lime; (3) residual effects of lime; (4) prediction of lime requirements of tropical soils. There is a final section of summary and conclusions. The literature cited contains about 150 references.

Características de Umidade de um Latosol Vermelho Escuro do Distrito Federal. James M. Wolf e Wilson V. Soares. Submitted to Pesquisa Agropecuaria Brasileira.

Data are presented which characterize the water holding properties of a Latosol Vermelho Escuro of the Federal District. These data were obtained by relating in situ measurements of soil-water content. Use of this information has been applied to determine water availability for cropping on this soil.

The soils of the Federal Experiment Station at Planaltina may be characterized by rapid infiltration and extensive internal drainage. Like a sand, this clayey Oxisol releases two-thirds of the stored water between 1/10 and 1 bar. Water availability is limited to approximately 30-40 mm per 30 cm of soil.

The unfavorable soil-water relations of this soil, together with less than ideal rainfall conditions and cropping regimes which may be limited by aluminum toxicity makes water related agricultural cropping risky. Since management of this soil for cropping will require costly inputs, it may be difficult to repay investments when yields vary greatly in the absence of controlled water management.