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SOIL FERTILITY IN THE HUMID TROPICS

Progress Report
for the period
November 1, 1975 to October 31, 1976

Submitted to the
U. S. Agency for International Development
Contract AID/ta-c-1104

New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University
Ithaca, New York 14853

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REPORT SUMMARY

Soil Fertility in the Humid Tropics ta-c-1104
Project Title and Contract Number

Douglas J. Lathwell
Principal Investigator

Cornell University
Contractor

Office of Academic Funding, Cornell University, Ithaca, N.Y. 14853
Contractor's Address

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NARRATIVE SUMMARY OF ACCOMPLISHMENTS

This research project is concerned primarily with determining the most effective means of utilizing the well-drained, relatively infertile arid soils of the humid tropics for increased food production. These soils are very extensive in tropical Africa, Latin America, and Southeast Asia and many are either not under cultivation or underutilized. The project is thus designed so that the results obtained are applicable to these extensive areas of soils. The field research is being carried on in Puerto Rico, the central plateau of Brazil, and south-central Ghana in cooperation with host institutions, the University of Puerto Rico, EMBRAPA, and the Soil Research Institute of Ghana. Supplementary laboratory and greenhouse studies are carried out in Ithaca by staff members of the Department of Agronomy.

Puerto Rico: Crop rotation experiments were continued to measure the amount of nitrogen supplied to maize from mineralization of crop residues with and without nitrogen fertilizer. There were no significant differences among maize yields without nitrogen following soybeans, maize, or fallow. Nitrogen applications to maize resulted in substantial yield increases regardless of previous crop. Although soybean stover contributed about 40 kg/ha the release of this nitrogen through mineralization was insufficient to contribute substantially to maize yields compared to the fallow treatments. Modest increases in yields of Phaseolus vulgarus (field bean) were obtained from nitrogen applications up to 160 kg N/ha. The potential for respectable yields of this important food crop was demonstrated and further efforts towards increased production appear justified. Irish potatoes likewise appear to have potential and an experiment to measure nigrogen response of Irish potatoes was made. Modest rates of nitrogen resulted in increased yields. The results were sufficiently promising that these experiments are worth continuing.

The phosphorus experiment begun in 1971 was continued through an eighth and ninth crop of maize and beans, respectively. The results obtained on this experiment were consistent with those obtained previously, namely that small amounts of phosphorus banded was generally superior to larger amounts of phosphorus applied broadcast.

The plantain experiment was continued through a second ratoon crop but wind and banana stem borer damage affected yields. This study has shown, however, that high fruit production can be obtained by following a proper technological package of production practices including plant spacing and nematode and stem borer control. Fertilizer inputs other than nitrogen are minimal for optimum production.

In other experiments the interval of time between lime application and cropping had no influence on yield of beans. Zinc treatment had no effect on the yield of sweet potatoe on a potentially zinc deficient Oxisol soil. In a third experiment sunflower oilseed yields comparable to those in the temperate regions of the United States were obtained.

Brazil (Cerrado Center): Again for the fourth year maize grain production without added nitrogen was near the 4 ton level on the clayey Dark Red Latosol. The maximum production of 6350 kg/ha of grain was obtained with 200 kg N/ha while 80 kg N/ha was sufficient to produce 88 percent of maximum.

New experiments were established in a virgin clayey Dark Red Latosol to study the response to potassium and magnesium. This soil which is typical of many of the highly weathered soils was extremely low in both exchangeable potassium and magnesium. Significantly, highly economical responses by maize to potassium were obtained. Little magnesium response was observed although plants showed symptoms of magnesium deficiency during dry periods.

A zinc experiment was continued for a fourth year and showed that 9 kg of zinc applied four years previously continued to be adequate for maize. Soybeans, however, gave a more marked response to zinc than did maize. A supplementary experiment established on newly cleared land to check zinc response at lower lime levels substantiated the original observations that high lime levels on these soils increases the zinc requirement of crops grown on these soils.

Short term droughts (veranicos) during the rainy season, highly acidic soils with root-growth-inhibiting concentrations of aluminum, and the low water-holding capacity of these soils severely limit yields of most crops in the Central Cerrado of Brazil. Incorporating lime, 8T/ha, in these soils to 15 and 30 cm depths improved the growth of corn before tasseling only in those seasons experiencing drought. From silking to maturity the plants on the deep-limed plots always maintained a longer period of active growth.

Soil and plant measurements taken during a veranico showed that deep liming allowed deeper root penetration and water extraction. Direct evidence that deep liming reduced moisture stress appeared in the leaf-water-potential, the relative leaf-water content, the leaf-stomatal resistance and in the soil moisture data.

Black plastic and grass mulches reduced soil surface evaporation of soil water by 4-7 mm from the top 20 cm depth of soil during stress periods. Plant water stress was greatly reduced by liming, mulching and their combinations. Yield benefits from mulching were greater from the black plastic than from the grass mulch apparently due to the higher and more favorable root temperatures beneath the black plastic.

Transpiration suppressants (chemical) reduced internal water stress by over 30% but one antitranspirant was toxic and caused premature leaf senescence. Beneficial effects were short lived. The indicated frequent applications would be costly and likely to result in reduced photosynthesis accompanying stomatal closure.

Two upland rice varieties derived benefits from liming 15 and 30 cm depths. However, unlike corn, rice gave a better response to the shallow than to the deep incorporation.

Ghana: Eight major field experiments were established in Ghana in April-May 1976. Three of these experiments were at the main farm of the Soil Research Institute at Kwadaso, three at Crops Research Institute farm at Aiyinasi, and two at the Soil Research Institute sub-station at Huhunya.

Two experiments on variety-nitrogen interaction at Kwadaso and Aiyinasi to compare grain yield response of improved and unimproved maize varieties to nitrogen resulted in significant responses to 60 to 90 kg N/ha. The improved varieties did not significantly outyield the local unimproved varieties this particular year. In the high rainfall area (Aiyinasi) yields were low (less than 2000 kg/ha)and yield was lost due to wet weather during the harvest season. Yields approaching 4000 kg grain/ha were obtained at Kwadaso under more nearly favorable weather conditions.

Two lime-phosphorus interaction experiments were established at Kwadaso and at Aiyinasi to study the influence of lime on the yield response of food crops to phosphorus application on the Ultisols of Ghana. Grain yield of maize was significantly increased by both lime and phosphorus at Kwadaso. Response to applied phosphorus was greatest at zero lime and lowest at 4 tons of lime/ha.

The two rates and methods of application of phosphorus experiments started in 1975 at Kwadaso and Hukunya were continued in 1976 with maize as the test crop. At Kwadaso although yields were increased from 4.7 tons/ha without phosphorus to 5.8 tons/ha with phosphorus the increase was not statistically significant. At Hukunya the control resulted in a grain yield of 1.2 tons/ha while 400 kg phosphorus broadcast/ha resulted in a yield of 3.9 tons/ha.

In a study of liming the acid Ultisols of the forest region of Ghana it was concluded that the lime required for optimum growth on these soils was small. Aluminum in these soils, in contrast to those from both Puerto Rico and Brazil, does not appear to be a significant problem. From the limited results obtained thus far, liming should be restricted to those situations where calcium is likely to be limiting as a nutrient.

Ithaca-Cornell: The studies to develop crop varieties tolerant to mineral stress conditions of the highly weathered soils of the tropics have continued. Using the screening procedures developed it is possible to select varieties of maize tolerant to aluminum. About 200 inbred and hybrid varieties of maize have been screened by the techniques developed and a wide range of tolerance to aluminum toxicity has been found. It now appears feasible through plant breeding techniques to develop aluminum tolerant varieties.

The applicability of the adsorption isotherm approach to characterizing reactivity of highly weathered soils to phosphorus was assessed for incubation periods up to 3 months. Relations between final concentrations of phosphorus and phosphorus removed from solution by soil conformed to the Langmuir and Freundlich isotherm treatment of the data for all incubation periods. Significant correlations were found between phosphorus reactivity indices and clay or organic matter content. These latter two factors were correlated strongly with aluminum extracted from these soils.

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 effectively improving soil, water, and crop management practices within the capability and resources of farmers in developing countries. The project is designed so that the results would be applicable to extensive areas in Latin America, Africa, and Asia.

Field research was initiated in Puerto Rico in cooperation with the Agricultural Experiment Station of Puerto Rico and in collaboration with research personnel of the U.S. Department of Agriculture. 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 agricultural research agency, EMBRAPA, and in collaboration with the North Carolina State University. In 1974 a cooperative agreement was developed between Cornell University and the Soil Research Institute of Ghana for collaborative soil fertility research on the acid soils in Ghana. Field experiments were initiated in the spring of 1975 supplemented by laboratory and greenhouse studies.

ACCOMPLISHMENTS TO DATE

1. Findings:

PUERTO RICO

Cooperative research is conducted in Puerto Rico through the University of Puerto Rico at the Agricultural Experiment Station. Dr. Miguel Lugo-Lopez, Soil Scientist, is in charge of the projects experimental work in Puerto Rico and Dr. Raul Perez, Associate Soil Scientist; Dr. Jose Badillo, Associate Agronomist; and Ing. Reinaldo del Valle, Assistant Agronomist, have major responsibilities for the field research.

Utilization of Nitrogen from Crop Residues

Nitrogen is probably the most important plant nutrient affecting crop yields in the humid tropics. The high cost of nitrogen fertilizer and its unavailability to most farmers in LDC's, expecially the small farmer, necessitates a research effort aimed at obtaining more nitrogen from natural supply processes. A critical evaluation must be made of nitrogen availability supplied from mineralization of crop residues under acid soil conditions in the humid tropics.

To determine the nitrogen supplied by crop residues, crop rotation experiments were conducted on a clayey Oxisol (Catalina), clayey Ultisol (Humatas) and sandy Oxisol (Bayamon). Three rotations were compared: soybeans-maize-maize, fallow-maize-maize, and maize-maize-maize. After harvesting the first maize and soybean grain crops, the maize roots, soybean stover, and weed fallow were plowed under about two weeks before planting maize. The two maize crops following maize, soybeans, or fallow had two treatments: with and without 110 kg N/ha applied as urea.

The critical soybean and maize yields were reported in 1975. Grain yields from the two maize crops following the initial maize crop, soybean crop, and fallow were reported in 1975 for the Bayamon and Humatas sites. Grain yields for one maize crop from the Catalina site are reported in Table 1.

Table 1. The effect of maize roots, soybean stover, and fallow plowed under on yields of subsequent corn crops.

Plowed Under	N Applied kg/ha	Yield kg/ha
Maize roots	0	4870
" "	110	5976
Soybean stover	0	4782
" "	110	6769
Weed fallow	0	4461
" "	110	5734

There were no significant differences among maize yields without nitrogen following soybeans, maize, or fallow. However, yields were higher following maize and soybeans than yields after fallow.

Nitrogen applications to maize resulted in substantial yield increases regardless of the previous crop. Response to nitrogen was greatest following soybean stover.

The total amount of organic nitrogen contributed by soybean stover and weed fallow was determined. Apparently there was no relationship between the amount of nitrogen returned to the soil from these residues and yields of the following maize crop. Soybean stover contributed an average of 40 kg/ha and weed fallow, 30 kg/ha of nitrogen to the following maize crops. The release of this nitrogen through mineralization apparently occurred over a period of time and supplied quantities of nitrogen that were not sufficiently different to be measured in terms of maize yield response.

During 1976 an experiment was established on a clayey Ultisol (Humatas) and sandy Oxisol (Bayamon) to determine the effect of residues from several edible legumes on subsequent maize yields. The following crops were grown, harvested, and the residues plowed under: continuous maize, soybeans, winged bean, and mungbean. Yield data are not completed and will be included in the next annual report. Maize will be planted at the two experimental sites using 0 and 110 kg N/ha.

Pattern of Nodulation of Winged Beans, Pigeon Peas, Cowpeas, and Fieldbeans

Biological nitrogen fixation could be an important source of nitrogen for food crops in the developing countries of the tropics. It is not well understood how food crops grown in rotation or in association with grain legumes might maximize the benefits from biologically fixed nitrogen. Winged beans are of interest because of their ability to fix nitrogen plus furnishing edible seeds, pods, and leaves with high protein content and edible tuberous roots also exceptionally high in protein.

A study has been initiated with the above mentioned legumes on a clayey Oxisol to determine size and number of nodules at different time intervals and quantities of nitrogen fixed. Data are currently being summarized and will be reported at a later date.

Nitrogen Response and Row Spacing Experiments with Fieldbeans (Phaseolus vulgaris)

Experiments were conducted on a clayey Oxisol (Coto) to determine appropriate fertilizer nitrogen levels for fieldbeans (Bonita variety) and proper row spacing for red kidney beans and fieldbeans. The six nitrogen levels for fieldbeans were 0, 20, 40, 80, 160, and 320 kg/ha. The row spacing experiment was separate from the nitrogen level experiment and consisted of row widths of 30, 45, and 10 cm. Fieldbean varieties used were 27R, a red kidney type and Bonita, a native white bean.

Table 2. The effect of nitrogen level on yields of fieldbeans

kg/ha N applied at planting	marketable yields kg/ha
0	1313
20	1342
40	1367
80	1412
160	1460
320	1369

As shown in Table 2, beans responded to increasing nitrogen applications up to 160 kg/ha. It was also recorded that plant weight, number of pods, and weight of pods per plant were significantly higher at the 160 kg/ha nitrogen level when compared with 0 and 40 levels. Number of seeds per pod were significantly lower in the 0 nitrogen as compared with 80 kg/ha of nitrogen level. The possible contribution of rhizobium to nitrogen needs of the plants was not determined.

Varying the row width apparently had no significant effect on yields of red kidney beans or white field beans. There were no significant differences in mean yields between both varieties and among the three planting distances. Both yielded approximately 2200 kg/ha of beans regardless of row width. With both varieties, plant weight was significantly higher at the 60 cm row spacing. There were no obvious insect or disease problems with either variety.

Since Phaseolus vulgarus is an important ingredient in the diet of many tropical countries, especially tropical Latin America, a great potential exists for local production of the crop. These experiments demonstrate that respectable yields can be obtained under local conditions and commercial production should be explored. Further refinements in research should be undertaken to complete a technological package of recommendations.

Nitrogen Experiment with Irish Potatoes

A potential exists for increasing the production of Irish potatoes in certain cool temperature areas of developing countries. It might also be possible to select varieties that can tolerate warm temperatures. Because of the high energy value of potatoes and their short growing season, they could serve as a substitute energy source for other longer season root crops such as cassava. An additional advantage of potatoes is the higher protein content when compared to crops such as cassava.

An experiment was conducted on a clayey Ultisol (Torres) to determine the most appropriate rate and time of nitrogen application to Irish potatoes. Yield results are presented in Table 3.

Mean yields from plots of Irish potatoes receiving 56 kg/ha of N preplant (6,659 kg/ha) were significantly higher than those from plots receiving 0, 112, or 448 kg/ha N.

Yields were likely affected due to serious infestations of disease caused by Rhizortomia and Fusarium spp. which affected some of the top growth and caused some tuber decay. Lack of uniformity of seed also probably contributed to a poor stand. The high rate of preplant N, 448 kg/ha caused a yield depression.

Table 3. Effects of N levels and time of application on the yield of Irish Potatoes on a clayey Ultisol (Torres) grown at 450 meters above sea level

Rate and time of nitrogen applications, kg/ha	Yield, kg/ha
1) 0	3,598 bc 1/
2) 56 preplant	6,659 a
3) 112 "	4,148 bc 2/
4) 224 "	5,302 ab
5) 448 "	2,590 c
6) 28 preplant + 28 post-plant	5,560 ab
7) 56 " + 56 " "	5,706 ab 3/
8) 112 " + 112 " "	5,953 ab
9) 224 " + 224 " "	5,784 ab
Mean	5,033

1/ Treatments with different letters are significantly different at the 5% level

2/ Average yield of preplant treatments

3/ Average yield of preplant plus post-plant treatments

Phosphorus Experiments

Phosphorus field experiments have been conducted on a clayey Ultisol (Torres) using various test crops since 1971. The objectives of this study are 1) measure the response to applied phosphorus fertilizer, 2) compare the efficiency of broadcast versus banded phosphorus fertilizer, and 3) estimate the residual effects of applied phosphorus. The sequence of crops were 1) maize (Pioneer X-306), 2) maize (Pioneer X-306) 3) rice (Sinaloa), 4) soybeans (Hardee), 5) maize (Funk G-795W), 6) maize (Funk G-795W), 7) maize (Pioneer X-306B), 8) maize (Pioneer X-306B, and 9) dry beans (Bonita).

Yield results from the eighth crop (maize) and ninth crop (beans) are presented in Table 4.

The results for maize are consistant with results from previous years. Small amounts of P banded at planting result in higher yields than large amounts of broadcast P applied every few years. Banded P applied at the rate of 22 kg/ha outyielded all broadcast treatments.

Table 4. Yields of maize (Pioneer X-306B) and beans (Bonita) as influenced by method and rate of phosphorus application

Treatment	Lime	Broadcast P kg/ha	Banded P ea yr kg/ha	Grain yields kg/ha maize	beans
1.	0	1121	0	2997 b	1182 c 1/
2.	limed to pH 5.5-6.0	0	0	3629 b	1489 abc
3.	"	90	0	3891 ab	1229 bc
4.	"	179	0	3429 b	1121 c
5.	"	359	0	3061 b	1229 bc
6.	"	1121	0	3524 b	1653 ab
7.	"	0	22	4679 a	1854 a
8.	"	0	45	3789 ab	1754 a
9.	"	0	90	3663 b	1536 abc
10.	"	0	179	3903 ab	1667 ab
11.	"	359	22	3964 ab	1675 ab

1/ Treatments with different letters are significantly different at the 5% level

Yields from the bean crop show that banded P applications are superior to broadcast P applications. Highest bean yields were obtained with 22 kg/ha banded. Banded rates of 22 and 45 kg/ha were significantly greater than 4 out of 6 broadcast treatments.

Soil samples were taken after the maize and bean crops were harvested. The P tests by the Bray 2 method indicate a low soil test value in all treatments except the two receiving the highest broadcast P rate. pH values have declined to pH 4.8 to 5.0.

Although soil test values indicate a low level of available P on most plots, small amounts of banded P resulted in the greatest yields. It is possible that the Bray P test is not measuring all of the soil P that becomes available to the crops and that both maize and bean roots are efficient in utilizing P that is present in the soil.

Plaintain Nitrogen and Phosphorus Experiment

Results of harvest yields from the seed crop and first ratoon have been reported in previous years. Yield data from the second ratoon crop was not analyzed statistically because of damage to a number of plants from wind and banana stem borer. However, analysis of various fruit characters from the seed crop was made during the year and provide some interesting data.

The third hand in each of the three middle plants per plot was examined and the following characteristics determined: number of fingers, weight of fingers (pounds), external length (inches), and percent of pulp.

The influence of N fertilization can be summarized as follows:

1) There was a significant increase in the number of fingers as N was increased from 0 to 224 kg N/ha banded. No further benefits were obtained with higher rates of N banded or broadcast.

2) There was an increase in fruit weight when fertilizer N was increased from 0 to 224 kg N/ha banded.

3) No effect of fertilizer N was observed on percent pulp content.

The effect of phosphorus fertilization can be summarized as follows:

1) There was no significant effect of residual P or P applied at planting on the number of fingers in a bunch.

2) Lack of applied P significantly reduced fruit weight. Even residual P outyielded the control plots.

3) There was no effect of P on length of fingers.

4) Lack of P significantly reduced the pulp content.

This study has shown that considerable fruit production can be obtained by following a proper technological package of production practices. Factors such as proper plant spacing, nematode, and stem borer control are essential. Fertilizer inputs other than N are minimal for top yields.

Cassava Yield as Influenced by Potassium and Magnesium

Cassava is an important food crop in many tropical countries. Good growth occurs even on extremely acid and low fertility soils. It is not considered an export crop and little research has been done in the past in an attempt to increase yields. For many people it is an important source of carbohydrates but has a low protein content of about one percent. Experiments by Ngongi in Columbia suggested that increased root yield might be obtained from potassium and magnesium.

An experiment was established on a sandy Oxisol (Bayamon) to determine the influence of potassium and magnesium on cassava root yields. The experiment was planted in August 1976 and consists of four levels of potassium and four levels of magnesium. Harvesting will be accomplished 10-12 months after planting. A potassium-magnesium interaction, if any, will be determined.

The Movement of Soil Water and Solutes in Some Oxisols and Ultisols

In recent years, interest has increased in the use of drip irrigation in tropical areas for crop production. A potential exists not only for supplying water to crops during the dry season but also to supply water during temporary dry periods of the wet season. This method of water supply also offers the possibility of varying the method of fertilizer application to crops. Drip irrigation systems could be especially useful on soils with low available water and low nutrient holding capacity such as Oxisols.

The proper use of drip irrigation requires a knowledge of soil hydraulic properties and solute movement which determines row spacing and nutrient supply. Lacking this knowledge, the systems are established by trial and error. Different soil series could require quite different spacings because of a difference in hydraulic properties. This study was undertaken to quantitatively describe the movement of soil water and solutes in some well drained Oxisols and Ultisols. The objectives of the study are:

1) To present the functional relationship of moisture movement patterns under different water discharge rates and the nutrient distribution through the soil profile.

2) To develop a combined fertilization and irrigation field technique which would meet the requirements of simple operation, low energy input, no pollution hazard, and economically feasible for tropical countries.

Both field and laboratory investigations are being conducted.

A field study is being conducted on a clay Oxisol (Coto) to determine the best fertilization technique for use with drip irrigation. Three different methods were used to apply the same amount of fertilizer throughout the growing season with drip irrigation. A crop will be grown in both the rainy and dry season. Sweet peppers are the test crop.

The first crop has just been harvested and a second crop planted. Yield data are not available for this report; preliminary evidence, however, has indicated that fertilizer supplied through the drip irrigation system is a satisfactory method for fertilizing the crop. When compared with broadcast and banded fertilizer, yields from the first few pickings are somewhat lower but soon reach and even surpass yields from conventional fertilization methods at the later pickings.

The Effect of Calcium Levels on Yam Yields

The behavior of lime applied to soils of the humid tropics has been intriguing and the subject of much study. Little information seems to be available about the timing of the lime application prior to the planting of crops sensitive to low soil pH conditions. The objective of this study was to determine the proper interval between time of lime application and cropping.

Lime at the rate of 2,242 kg/ha was applied in July, September, November 1975, and January, March, and May 1976. Two varieties of beans, red kidney (27 R) and white field beans (Bonita) were planted in May 1976 and harvested in August. There were no significant mean differences in yields attributable to intervals between liming and planting date. However, mean differences between varieties were significant: 920 for the Bonita white beans and 595 kg/ha for the red kidney beans.

Two maize varieties have been planted over the experimental site but yield data are not yet available.

Soil samples were taken following the bean crop and are being analyzed for pH and available nutrients.

The Effect of Zinc on Sweet Potato Production

Crop response to zinc has occurred on some of the highly weathered tropical soils. Some maize response to zinc was observed on the Coto Oxisol using maize variety Pioneer X-306 B. This study was conducted on the Coto Oxisol to determine if sweet potato roots and tops were affected by applications of zinc.

Six zinc levels were used; 0, 0.56, 1.12, 2, 2.4, 4.48, and 8.99 kg/ha. Zinc treatments were mixed with the fertilizer which was applied at the rate of 1345 kg/ha of 6-6-12 two weeks after planting.

The crop was harvested after five months. Total yields of sweet potatoes ranged from 20 to 25 metric tons/ha. Mean differences attributable to zinc treatment were not significant.

Performance of Oilseed Sunflowers

Although sunflowers are commonly grown in temperate regions, there is some interest in them as a tropical crop. The seeds contain about 50 percent oil, are high in protein and can be processed for oil extraction or eaten as whole seeds or dehulled roasted nuts. The oil is used for cooking, fuel, and for margarine and other foods. Byproducts are excellent feed for ruminants.

A study was conducted to evaluate the performance of five high yielding oilseed sunflowers in tropical environments. The soil used was the Coto Oxisol.

The cultivars tested were Hybrid 894, Hybrid 896, and Hybrid 891 supplied by ARS, USDA, and the Russian varieties Sputnik and Peredcvik.

Mean seed yields were not significantly different among varieties. A field wide average of 1,616 kg/ha was obtained. These yields were considered quite good for a tropical environment.

There were no apparent insect or disease problems.

It was concluded that the proper variety with adequate fertility and rainfall can produce sunflower oilseed yields comparable to those obtained in temperate regions of the United States.

BRAZIL

The research in Brazil is carried out at an agricultural experiment station near Brasilia in cooperation with EMBRAPA, the Brazilian agricultural research agency, and in collaboration with North Carolina State University. The following professional personnel of Cornell and North Carolina State Universities have been involved with their Brazilian Associates in various aspects of the field research during the past year:

Cornell - Dr. K. Dale Ritchey, Research Associate, and Joint Cornell-NCSU Project Coordinator, and Mr. Dale E. Bandy, Research Assistant.

NCSU - José G. Salinas, Research Assistant and Mr. Jot Smyth, Research Assistant.

Leadership of the project for EMBRAPA has been provided by Dr. Elmar Wagner, Director of CPAC Center, Dr. Wenceslau Goedert, and Mr. Edison Labato.

Zinc

The results of the first three years of cropping as reported in the respective North Carolina State University annual reports showed a very marked response to zinc for maize, but a lesser response in sorghum. In the fourth year of the study Cargill 111 maize and IAC-2 soybeans were planted. No additional zinc, boron or Mo were added but applications of 160 kg/ha P205 as simple superphosphate, 160kg/ha N as urea and 150 kg/ha K20 as KCl were made. The pH resulting from the original high lime rate remained at about 6.5. The incorrect use of a surfactant in the pest control program for maize resulted in an uneven stand and high coefficient of variation.

As shown in Table 5 the residual effect of 9 kg zinc applied four years ago continued to be adequate for maize. The soybeans gave a more marked response to zinc than did the maize, showing 140% increase in yield on the 9 kg Zn treatment.

Table 5. Cargill 111 maize grain production (15.5% moisture) and IAC-2 soybean grain production (13T moisture) for various levels of zinc applied in 1972 on clayey Dark Red Latosol at CPAC 1975-1976.

Zinc Applied in 1972	Grain Production	
	maize *	soybeans *
	-kg/ha-	
0	3282 a	1083 a
1	4985 b	1569 b
3	6902 c	2126 c
9	6293 bc	2596 d
9 minus B	6215 bc	2623 d
27	6248 bc	2813 d

* Values followed by the same letter are not significantly different at the 5% level (Duncan).

A supplementary experiment was installed on newly-cleared land to check the zinc response at lower lime levels. The area received an application of dolomitic limestone equivalent to 3000 kg/ha calcium carbonate two weeks before the planting date of November 15 which was sufficient to increase the surface soil pH initially at 4.6 to 5.1 by December 17. The yield increase due to the application of 9 kg Zn was 29%. Without added zinc 3840 kg/ha of corn grain was obtained. This substantiates the original observations made in earlier annual reports that high lime levels tend to increase the zinc requirement on these soils.

Nitrogen

The fourth consecutive rainy-season maize crop on the clayey Dark Red Latosol was planted November 22, 1975. The use of lime-coated ammonium nitrate and sulfur-coated-urea as sources in treatments 8 and 10 was discontinued this year. Treatment 10 did not receive any N in order to evaluate the residual effect of three years of sulfur-coated-urea applications. Treatments 8 and 9 were modified to study the effect of two versus three sidedressings for the 200 kg N rate.

Again for the fourth year, grain production without added nitrogen was near the four ton level (Table 6). Analysis of the grain and stover indicates that the soil is supplying approximately 60 kg/ha of nitrogen annually. As shown in Table 6, maximum production of 6350 kg/ha maize grain was obtained with the application of 200 kg nitrogen. The application of 80 kg/ha N was sufficient to produce 88% of the maximum. Varying the number of sidedressings from one to three had no effect on yield. There was no difference in grain production between the treatment receiving sulfur-coated-urea for the previous three years and the treatment which had never received nitrogen.

Table 6. Cargill 111 maize grain production (15.5% moisture) for various levels of nitrogen applied as urea on clayey Dark Red Latosol at CPAC 1975-1976.

Treatment Number	Nitrogen Applied, Days after planting: 0	20	30	40	60	Total N Applied	Grain Production **
	-kg/ha-						
2	-	-	-	-	-	0	3885 a
10 *	-	-	-	-	-	0	4173 a
3	20	-	40	-	-	60	5115 b
1	-	-	80	-	-	80	5452 bc
6	20	40	-	-	40	100	5680 bc
4	20	-	80	-	-	100	5784 cd
7	20	60	-	-	60	140	5812 cd
5	20	-	120	-	-	140	5812 cd
8	20	60	-	60	60	200	5987 cd
9	20	90	-	-	90	200	6350 d

* The previous year this treatment received 140 kg/ha N as sulfur-coated urea.

** Values followed by the same letter are not significantly different at the 5% level (Duncan).

Potassium and Magnesium

This year a new experiment was begun in a virgin clayey Dark Red Latosol to study the response to potassium and magnesium. Five potassium and four magnesium rates were applied. The desired magnesium rates were obtained by varying the concentration of calcitic and dolomitic lime used to correct the soil acidity.

Initially the soil pH was 4.6 (1:2.5 soil:water) and the soil had 1.1 meq/100 gm soil exchangeable Al, 0.34 meq/100 cc Ca + Mg, and 0.0092 meq/100 gm exchangeable K (36 ppm).

Just before planting broadcast fertilizers consisting of the appropriate level of K_2O as KCl, 320 kg/ha P205 as simple superphosphate, 9 kg/ha zinc as zinc sulfate, 1.1 kg/ha B as borax and 0.2 kg/ha Mo as ammonium molybdate were incorporated by rotovator to a depth of about 15 cm two weeks after the incorporation of ground limestone equivalent to 3000 kg/ha calcium carbonate. Cargill 111 maize was planted November 15 at which time 20 kg/ha N as urea and 80 kg/ha P_2O_5 as simple superphosphate were applied in the furrow along with 150 kg K20/ha for treatment 6. Sidedressings of urea sufficient to supply 60 kg N each were applied at 24, 44 and 62 days.

There was a good response to potassium as shown in Table 7 and Figure 1. Maximum production was obtained with 300 kg D20. The result of applying 75 kg/ha K_2O was particularly impressive, increasing grain yields by 1748 kg/ha, worth 9.3 times as much as the cost of the potasssium applied.

There was no deleterious effect from the application of KCl in the furrow at planting. No differences in yield between the calcitic and dolomitic limestone treatments were observed this first year although the plants showed symptoms of Mg deficiency during dry periods.

Table 7. Cargill 111 maize grain production (15.5% moisture) for various levels of potassium and magnesium applied on a virgin clayey Dark Red Latosol at CPAC 1975-1976.

Treatment Number	Potassium Applied (K_2O)	Magnesium Applied (Mg)	Grain Production	1)
	kg/ha			
1	0	345	2,328	a
2	75	345	4,076	b
3	150	345	4,372	b c
4	300	345	4,890	c
5	600	345	4,712	c
6	150 2/	345	4,453	b c
8	150	7,5	4,362	b c
9	150	27	4,301	b c
10	150	97	4,017	b

1) Values followed by the same letter are significantly different at the 5% level (Duncan).
2) Potassium chloride was applied in the furrow at planting.

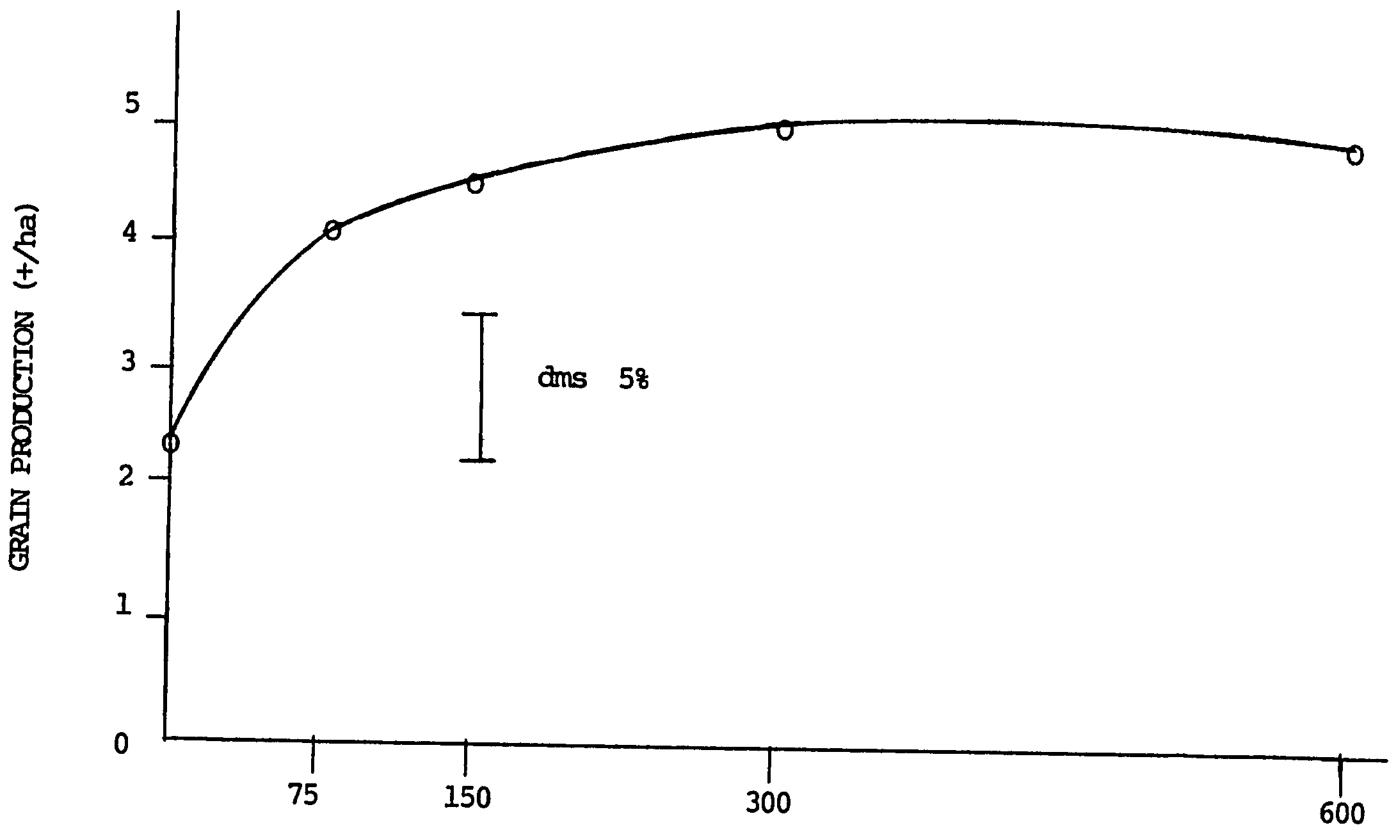

Figure 1. Cargill 111 maize grain production as a function of potassium fertilizer added to virgin clayey Dark Red Latosol at CPAC 1975-1976.

The exchangeable Mg content in the low Mg treatment is about 5% of the total exchangeable bases and usually this is just adequate to avoid yield depressions. However, the total Mg removed in the grain and stover was 30% of the total exchangeable Mg in the top 15 cm of soils. Note in Tables 8 and 9 that the removal of 18 kg of K in the grain and stover from treatment 1 has reduced the soil level of exchangeable K to one-half of its original value. This year the potassium rate plots have been split and one-half of each is receiving 100 kg/ha K20 as a maintenance application while the other is receiving no additional potassium. In treatment 7 the stover was returned to the field and incorporated, and the maintenance application for the split plot was reduced to correspond to the K removed in the grain.

Table 8. Soil content of exchangeable K at three dates, K uptake by Cargill 111 maize, and ear-leaf K content as a function of K added to clayey Dark Red Latosol, CPAC, 1975-1976.

K_2O Applied	Exchangeable K in soil			Total Plant K Uptake	Ear Leaf K Content
	12 Nov	14 Jan	27 May		
-kg/ha-	- - - - - -ppm- - - - - -			- - -kg/ha- - -	- - % - - -
0	40	20	17	18	0.48
75	35	26	23	35	1.06
150	33	32	29	56	1.56
300	30	58	52	90	2.38
600	33	137	80	102	2.46

Table 9. Soil content of exchangeable magnesium, Mg uptake by Cargill 111 maize plants, and ear-leaf Mg content as a function of Mg added to clayey Dark Red Latosol, CPAC 1975-1976.

Mg Applied	Exchangeable Mg in Soil 14 Jan	Total Mg Uptake	Ear Leaf Mg Content
- -kg/ha- -	- - -meq/100cc- - - -	- kg/ha -	- - -%- - -
7.5	.135	7.3	.09
27	.13	7.8	.10
97	.195	8.2	.14
345	.52	11.3	.32

Soil-Plant-Water-Relationships

The experiments begun in 1974 to test soil and crop management techniques for conserving soil water were concluded this past year. Much of the original data collected was reported in the year previous annual report. The material that follows is a summary of those results.

Short term drought periods during the rainy season, low soil water storage capacity, and highly acidic soils with 80% Al saturation which inhibit root growth all give a combined effect of limiting yields for most crops in the Central Cerrado of Brazil.

With those problems in mind, experiments were conducted in Brazil for two years to study the effect of a veranico (drought) on corn (Zea mays L.) growth and yield. In one experiment, soil management techniques were used to allow a crop to tap a greater quantity of the soil water stored in the soil. A second experiment used crop management techniques to increase water use efficiency by decreasing water loss from the soil surface and from the corn leaf.

The soil management experiment consisted basically of lime rates and depths of lime incorporation, i.e. 0-lime, 8T/ha lime incorporated to a 15 cm depth and 8T/ha lime incorporated to a 30 cm depth, and a broadcast versus banding application of phosphorus.

Without plant water stress, no depth of lime effect was noted on plant growth before the tasseling stage. From silking to grain maturity, the deep limed plants maintained a longer period of active plant growth by delaying leaf senescence. The unlimed corn plants were always inferior to the limed plants with the dry-cool season crop showing a more pronounced decrease in plant growth.

Measurements taken during an actual veranico or a simulated veranico showed that deep liming had a large effect in eliminating water stress in the corn plants. Corn roots were able to penetrate to deeper soil depths to extract water which in turn reduced the plant's internal water stress, i.e. leaf water potential and relative water content, and reduced stomatal resistance thus allowing the plant to continue to transpire and take up CO_2.

At final grain harvest, deep lime incorporation plots outyielded shallow limed plots in both water stressed and non-water stressed treatments. A 10-15 day water stress period during the vegetative growth stage (Hanway stages 2.5-3.0) permanently reduced plant size but it did not significantly reduce grain yield. A 10-15 day stress period during the grain formation stage (Hanway stage 5) decreased yields by 100-150 kg/ha per day. On a three season average, stress during the grain formation stage reduced yields by 19% for deep limed treatments, 27% for shallow limed treatments, and 31% for unlimed soils. Broadcast application of phosphorus gave less reduction in yield in relation to plant water stress for two of the three seasons when compared to the banded application of phosphorus.

The second experiment used two types of mulches, two antitranspirants, two corn varieties, and two lime depth incorporations. Mulching was shown to influence corn growth and development. Grass mulch decreased plant growth and development due to cooler soil temperatures (2-3°C) while black plastic mulch increased plant growth and development due to warmer soil temperatures (3-4°C) in relation to the non-mulched plots.

Both mulches reduced soil surface evaporation of soil water by 4-7 mm in the top 20 cm of the soil during the stress periods. During a veranico, plant water stress was greatly reduced by depth of liming, mulching, and their combinations. Deep liming with mulch reduced leaf water potential and showed no loss in cell turgidity. Transpiration suppressants reduced internal plant water stress by over 30% but one of the antitranspirants caused a serious reduction in plant growth and yield by causing severe premature leaf senescence.

Mulching had a significant effect on grain yield. Plastic mulch increased yields by 1000 kg/ha. Grass mulch increased grain yield by 400-500 kg/ha despite its negative effect on plant growth during the vegetative stage. The phenyl mercuric acetate antitranspirant reduced yields by 4000 kg/ha while Wilt Pruf had no significant effect on yield.

An upland rice (Oriza sativa L.) experiment was conducted to study depth of lime incorporation and row spacing on the rice plant's internal water balance and final grain yield with two rice varieties.

An analysis of growth and yield parameters showed that Pratao Precoce was more influenced by row spacing than lime depth incorporation. The 15 cm row spacing showed more grain sterility and lighter grain weights which resulted in a lower grain: straw ratio and lower grain yield/plant. Final yield results showed that narrow row spacing (15 cm) produced 400 kg/ha less than the 45 cm row spacing.

IAC-1246 growth and yield parameters were not influenced by row spacing. Lime depth did have a significant effect. Shallow lime treatments outyielded deep lime treatments by 440 kg/ha because they produced greater panicle weights which in turn produced more grain/plant.

IAC-1246 significantly outyielded Pratao Precoce because it produced fewer unproductive tillers, produced heavier grain weights, and had a lower percentage of flower sterility. Those factors contributed to a 660 kg/ha yield difference.

Lime and Phosphorus Experiments

The long term lime and phosphorus experiments reported on in earlier annual reports have been taken over by the staff of the CPAC. The management and collection of data and its reporting is now being done by the CPAC staff. The results being obtained are providing a base for future development of the Cerrado region of Brazil.

GHANA

The research in Ghana is carried out in Ghana in cooperation with the Soil Research Institute of the Council for Scientific and Industrial Research at Kumasi. The following professional people of Cornell University have been involved with the Soil Research staff as follows:

Cornell - Dr. Amos G. Ngongi, Research Associate and Cornell project coordinator; and Mr. Spider Mughogho, Research Assistant.

SRI - Dr. Henry Obeng, Director; Dr. Peter Kwayhe, Senior Research Officer; Mr. Ambrose Nyamayke, Research Assistant.

Eight major field experiments were established in April-May 1976, three at the Soil Research Institute's main farm in Kumasi-Kwadaso, three at the Crops Research Institute's farm at Aiyinasi, and two at the Soil Research Institute's sub-station at Huhunya. Two phosphorus experiments established in 1975 at Kumasi-Kwadaso and Huhunya were continued in 1976. The 1975 minor season crop at Kwadaso was a failure owing to bird damage. Good yields were obtained at Huhunya during the minor season (see Table 10).

Two experiments on variety-nitrogen interaction were established at Kumasi-Kwadaso and Aiyinasi to compare the grain yield response of improved and unimproved maize varieties to nitrogen. The Kumasi-Kwadaso experiment was continued from 1975. Two new experiments were established, one at Kumasi-Kwadaso and the other at Aiyinasi, to study the influence of lime on the yield response of food crops to phosphorus. Maize was grown during the major season and cowpeas would be grown in the minor season. The last two experiments were on the effects of two sources of potassium, KCl and K_2SO_4, on the growth and yield response of cassava to nitrogen. Both experiments were established in the 1976 major season at Aiyinasi and Huhunya.

Analytical date of a representative Basachia soil from the Aiyinasi experimental site are presented in Table 11. Analytical data for the Kumasi site were presented in last year's report.

The results obtained in the 1976 major season are presented in this report.

Lime x Phosphorus Experiment

Two lime x phosphorus experiments were established at Kwadaso and Aiyinasi in the major season of 1976 to study the influence of lime on the yield response of food crops to phosphorus applications on highly weathered soils. One experiment was established on Asuansi soil at the Soil Research Institute's farm, Kwadaso, and the other was established on Basachia soil, probably an Ultisol, at the Crops Research Institute's farm, Aiyinasi.

Grain yield of maize was significantly increased by lime ($P = 0.05$) and phosphorus ($P = 0.01$) at Aiyinasi but only phosphorus had a significant effect (P = 0.01) at Kwadaso. At both sites, the response to applied phosphorus was greatest at zero lime and lowest when 4.0 tons of lime were applied per hectare. This indicated that the main effect of liming was increased availability of native soil phosphorus. At zero lime, the best phosphorus treatments produced yield increases of 134 and 178 percent over yields obtained from control plots at Kwadaso and Aiyinasi, respectively. The increases were reduced to 28 and 11 percent, respectively, at the 4.0 tons/ha lime rate. However, the lime x phosphorus interaction was significant (P = 0.01) only at Aiyinasi.

Soil samples were taken at the end of the season for detailed analysis in order to identify the native forms of fixed phosphorus from which phosphorus was being made available by liming.

Grain yields were limited at Kwadaso by drought conditions which prevailed from two weeks after silking to the end of the season. During the month of July, only 15 mm of rain were recorded at the station. This undoubtedly affected the solubility of the banded phosphorus.

Table 10. Effects of lime and phosphorus applications on grain yield of maize, major season 1976 at Aiyinasi

Lime rate	Phosphorus rate	Replications				Mean
		I	II	III	IV	
tons/ha	kg/ha P_2O_5	kg/ha*				
	0	1330	810	1200	870	1050
	25	3170	1880	2490	2900	2630
0	50	3010	3240	2750	2690	2920
	75	3460	2750	2720	2650	2900
	100	2750	2070	3660	2820	2830
	0	1130	610	2720	1040	1380
	25	3400	2690	3010	2040	2790
1	50	2750	3240	3400	3010	3100
	75	2880	2820	3530	3270	3130
	100	3300	3140	4500	2820	3440
	0	2650	1460	2900	1910	2230
	25	3110	2650	3170	1880	2700
2	50	3070	2690	3750	2430	2990
	75	2820	2650	3400	3920	3200
	100	3490	3820	3720	3390	3610
	0	3170	2690	3300	3140	3080
	25	3300	2260	2980	3500	3010
4	50	4040	2430	3660	3560	3420
	75	2430	3560	3040	3200	3060
	100	3140	3400	3070	3720	3330

* The maize had a 25% moisture content

Table 12. Effects of lime and phosphorus applications on grain yield of maize, major season 1976, Kwadaso

Lime rate	Phosphorus rate	Replications				Mean
		I	II	III	IV	
tons/ha	kg/ha P_2O_5	kg/ha*				
	0	2140	710	710	710	1070
	25	1430	710	710	710	890
0	50	2140	710	1430	1430	1430
	75	2140	1430	1430	1430	1610
	100	2140	2850	2140	2850	2500
	0	1430	1430	2140	710	1430
	25	2140	1430	1430	710	1430
1	50	1430	1430	2140	1430	1610
	75	2140	3560	2140	710	2140
	100	1430	2140	2140	2140	1960
	0	1430	1780	710	1430	1340
	25	1430	1430	710	2140	1430
2	50	710	2140	1430	710	1250
	75	2140	1430	1430	1430	1610
	100	710	2140	1430	2140	1610
	0	710	2850	2140	2140	1960
	25	1430	2140	1430	1430	1610
4	50	2140	2140	2140	710	1780
	75	2140	2140	2850	2140	2320
	100	2140	3560	2140	2140	2500

* Weighed at 19% moisture

Table 11. Analysis of variance - Grain yield, L x P experiment major season 1976 at Aiyinasi

Source of variance	df	ss	ms	F
L x P (Total)	79	47.7692		
Main Plots	15	12.1349		
Blocks	3	4.0031	1.3344	
Lime	3	5.5062	1.8354	6.3*
Error (a)	9	2.6256	0.2917	
Phosphorus	4	18.5988	4.6497	22.2**
L x P	12	6.9626	0.5802	2.8*
Error (b)	48	10.0729	0.2098	

* Significant at the 5.0 percent level of significance
** Significant at the 1.0 percent level of significance
C.V. = 4.0%
LSD .05 lime rates = 386 kg
LSD .05 phosphorus rates = 326 kg
LSD .05 phosphorus at same lime rate = 650 kg

Table 13. Analysis of variance - Grain yield, L x P experiment major season 1976 at Kwadaso

Source of variance	df	ss	ms	F
L x P (Total)	79	36.5174		
Main Plots	15	12.2131		
Blocks	3	2.0109		
Lime	3	4.2716	1.4239	2.2
Error (a)	9	5.9306	0.6590	
Phosphorus	4	8.0285	2.0070	7.25**
L x P	12	3.0018	0.2500	NS
Error (b)	48	13.2740	0.2770	

** Significant at the 1.0 percent level of significance
C.V. = 7.9%
LSD .05 phosphorus rates = 374 kg

Nitrogen Experiment

The nitrogen experiment on maize established at Kwadaso in 1975 was continued. The 1975 minor season crop was a failure owing to severe bird damage to grain. During the 1976 major season, a similar experiment was established at Aiyinasi using the same improved varieties, Composite 4 and La Posta, but the local unimproved was changed to Nzima Red. The soil at Aiyinasi is of the Basachia Series (an Ultisol?) and analytical data for a representative Basachia soil are presented in Table 14 .

There was a significant increase in grain yield of maize at both sites as a result of nitrogen fertilization. Higher rates of nitrogen were not superior to the 60 kg/ha rate at Aiyinasi but at Kwadaso the 90 kg/ha rate produced a significantly higher grain yield than the 60 kg/ha rate.

The improved varieties did not significantly outyield the local unimproved varieties although they showed higher responses to nitrogen at both sites. The local varieties matured about three weeks later than the improved varieties and thus were able to reduce the yield gap by accumulating dry matter after the improved varieties had matured. However, the lateness of the local varieties could be disastrous in the minor season if the rains stop early.

The improved varieties matured during wet weather at Aiyinasi and about 25 percent of the yield was lost owing to spoilage. Considerable damage was also caused by the corn stalk borers. The low rate of phosphorus used (45 kg/ha P_2O_5) also was probably limiting to yield at Aiyinasi since a high response to phosphorus applied at a rate of 75 to 100 kg/ha P_2O_5 was obtained on an adjacent plot.

Table 14. Analytical date for a representative soil of the Basachia series (Aiyinasi)*

	pH	O.M	Ca	Mg	Mn	K	Sum of Bases
cm				m.e./100 gm			m.e./100 gm
0- 5	5.0	3.80	2.10	0.90	0.04	0.25	3.29
5- 15	4.8	1.58	0.64	0.40	0.01	0.15	1.20
15- 30	4.8	0.86	0.57	0.57	0.005	Nil	1.14
30- 60	4.6	0.55	0.31	0.31	0.005	Nil	0.62
60-107	4.6	-	0.43	0.43	0.005	0.01	0.87
107-140	4.8	-	0.40	0.40	0.005	0.09	0.89

* Adapted from Fig. 15, Technical Report No. 26, Soil Research Institute, Kumasi

Table 15. Maize grain yield as influenced by nitrogen rate on three varieties at Aiyinasi, major season, 1976.

Variety	Nitrogen Rate	Replications I	II	III	IV	Mean
	kg/ha	kg/ha*				
A	0	1110	1550	1230	1590	1370
	60	1660	2500	1570	1590	1830
	90	1930	1930	2160	1860	1970
	120	1410	1860	1710	2160	1790
B	0	800	1230	730	1090	960
	60	1730	2050	1890	2050	1930
	90	1910	1610	1800	2110	1860
	120	1770	2050	2270	2550	2160
C	0	960	1320	1300	1110	1170
	60	1730	2160	1730	2090	1930
	90	2000	1980	1910	1590	1870
	120	1750	1680	1890	1910	1810

* Weighed at 20% moisture
A = Composite 4
B = La Posta
C = Local (unimproved)

Table 16. Analysis of variance - Grain yield, N experiment major season, 1976 at Aiyinasi

Source of variance	df	ss	ms	F
U x N (total	47	7.2821		
Main Plots	11	0.8318		
Blocks	3	0.2904	0.0969	
Varieties	2	0.0071	0.0035	NS
Error (a)	6	0.5343	0.0891	
Nitrogen	3	3.8351	1.2784	20.3**
V x N	6	0.9104	0.1517	2.4
Error (b)	27	1.7048	0.0631	

** Significant at the 1.0 percent level of significance
C.V. = 4.2%
LSD .05 N Levels = 210 kg

Table 17. Maize grain yield as influenced by nitrogen rate on three varieties at Kwadaso, major season, 1976

Maize Variety	Nitrogen Rate	Replications I	II	III	Mean
	kg/ha		kg/ha*		
A	0	2610	1770	2430	2270
	60	3270	3730	2770	3260
	90	4390	4000	2820	3740
	120	3450	4270	3930	3880
B	0	2590	2360	2430	2460
	60	4390	3200	3320	3640
	90	4640	3750	3420	3940
	120	4050	2320	3950	3440
C	0	2140	2020	3500	2550
	60	2910	2680	3000	2860
	90	3090	3450	3700	3440
	120	2500	2770	3480	2920

* Weighed at 19% moisture content
A = Composite 4
B = La Posta
C = Local (unimproved)

Table 18. Analysis of variance - Grain yield, N experiment major season, 1976 at Kwadaso

Source of variance	df	ss	ms	F
V x N (total)	35	18.8657		
Main plots	8	5.3301		
Blocks	2	2.4041	1.2020	
Varieties	2	1.2225	0.6125	NS
Error (a)	4	1.7002	0.4250	
Nitrogen	3	8.0812	2.6937	12.52**
V x N	6	1.5813	0.2636	NS
Error (b)	18	3.8731	0.2153	

** Significant at the 1.0 percent level of significance
C.V. = 4.8%
LSD .05 N Levels = 450 kg

Phosphorus Experiments

The two experiments established in 1975 at Kwadaso and Huhunya were continued in 1976. The soils at both sites are Ultisols but the grain yield response of maize to phosphorus was different for each site. At Kwadaso there was an increase in grain yield from 4.7 tons/ha for control plots to a maximum of 5.8 tons/ha but phosphorus response was not significant. There was a significant ($P = 0.01$) response to phosphorus at Huhunya. The control treatment produced a yield of 1.2 tons/ha compared to a yield of 3.9 tons/ha obtained when phosphorus was broadcast at a rate of 400 kg/ha P_2O_5. Broadcast treatments appeared to be superior to banding. Banded treatments produced yields which were about 1.0 tons/ha lower than in the 1975 major season but yields obtained from broadcast treatments were essentially the same as those obtained in the previous major season. The poor moisture conditions which prevailed in the 1976 major season at Huhunya probably resulted in poor availability of the banded phosphorus. At the end of the next minor season when broadcast and banded treatments would have become equal, a valid comparison between band and broadcast application of phosphorus will then be possible.

Table 19. Maize grain yield as influenced by rate and placement of phosphorus, Huhunya, minor season, 1975

P_2O_5 Added		Replications					
Broadcast[1]	Banded[2]	I	II	III	IV	V	Mean
		kg/ha					
160	0	2800	2510	2660	3390	3540	2980
240	0	4570	2800	2660	2950	3840	3360
320	0	2800	2660	3250	3540	3390	3130
400	0	3250	3840	2660	2800	3840	3280
0	40	2800	2800	2800	3840	2950	3040
0	60	3840	2950	3100	2660	3100	3130
0	80	3100	3250	3100	3390	3100	3190
0	100	2950	3100	2510	2800	3100	2890
240	60	3540	2800	2660	3690	3100	3160
60	40	3390	2950	3390	3100	2340	3210
0	40	3100	2660	3250	3390	2950	3070
0	80	4130	2800	3100	2800	3690	3300
0	0	1770	1620	1920	2070	2360	1950

[1] Applied at start of experiment only

[2] Applied to each crop

Table 20. Analysis of variance - Grain yield at Hunhunya, minor season, 1975

Source of variance	df	ss	ms	F
Mean	1	598.6386		
Blocks	4	8.2833	2.0708	
Treatments	12	7.3312	0.6109	10.3**
Error	48	2.9245	0.0609	
Total	65	617.1776		

** Significant at the 1.0 percent level of significance
C.V. = 8.1%
LSD .05 = 314 kg

Table 21. Maize grain yield as influenced by rate and placement of Phosphorus, Kwadaso, major season, 1976

P_2O_5 Added		Replications					
Broadcast[1]	Banded[2]	I	II	III	IV	V	Mean
		kg/ha					
160	0	5660	5450	6490	5480	3860	4990
240	0	4680	5880	4790	6100	4620	5210
320	0	6040	6000	6120	5970	4890	5800
400	0	4510	5530	6870	5270	5100	5460
0	40	6460	5080	5020	6100	5350	5580
0	60	5100	4700	6500	6100	6310	5740
0	80	4620	5950	3770	6250	5110	5140
0	100	5200	6190	6220	5100	5920	5730
240	60	5010	5530	3250	4990	5010	4760
0	0	5630	4540	5750	5440	4170	4710
	40*	4800	2070	6100	6440	4670	4820
	80*	5080	6130	5860	5720	5260	5610

* Area not plowed
1. Initial application only
2. Applied to each crop

Table 22. Analysis of variance - grain yield at Kwadaso, major season, 1976.

Source of Variance	d.f	s.s	m.s	F
Mean	1	1726.0278		
Blocks	4	3.9778	0.9945	
Treatments	11	7.0022	0.6366	N.S
Error	44	32.8513	0.7466	
Total	60	1679.8591		

C.V = 16.0%

Table 23. Maize grain yield as influenced by rate and placement of phosphorus, Huhunya, major season, 1976

P_2O_5 Added		Replications					
Broadcast	Banded	I	II	III	IV	V	Mean
		Kg/ha					
160		3100	2950	2730	3250	2880	2980
240		3840	3620	3550	3320	3100	3490
320		3320	3100	3620	3400	3840	3460
400		4140	3770	3840	3550	4280	3920
0	40	1990	2360	1850	2070	2360	2130
0	60	2070	2220	2360	2510	2360	2300
0	80	2660	2730	2510	2440	2810	2630
0	100	2660	2810	2510	2660	2440	2620
240	60	2360	1920	2070	1920	2140	2080
60	40	2290	2140	2140	2140	2070	2160
0	40	2070	1770	2070	2290	2220	2080
0	80	2360	2290	2360	2220	2510	2350
0	0	1180	890	1110	960	1920	1210

Table 24. Analysis of variance - grain yield, P, experiment at Huhunya, major season, 1976.

Source of Variance	df	s.s	m.s	F
Mean	1	429.0102		
Blocks	4	0.3346		
Treatments	12	32.0194	2.6743	67.4**
Error	48	1.9073	0.0397	
Total	65	463.3435		

** Significant at the 1.0 percent level of significance

C.V = 7.8%
LSD .05 - 254 kg.

Potassium Sources x Nitrogen Experiment

Two new experiments were established, one at Aiyinasi and the other at Huhunya to investigate the growth and yield response of cassava to nitrogen and the modifying influence of two potassium sources on such a response. Potassium chloride and potassium sulfate were the potassium sources and nitrogen was applied at rates of 0, 25, 50 and 100 kg/ha.

The experiments are progressing well and vegetative growth is satisfactory. Plots receiving potassium sulfate are showing more vigorous growth than those fertilized with potassium chloride at both sites but the difference is more pronounced at Huhunya. Plants in plots fertilized with potassium chloride have dark green leaves while those in potassium chloride plots have leaves with a light green coloration at Aiyinasi and markedly yellowish which prevailed during the early stages of growth at Huhunya probably aggravated an existing sulfur deficiency.

Laboratory and greenhouse support to provide support for the field work in Puerto Rico, Brazil, and Ghana is provided by the Cornell staff in Ithaca. The laboratory work is done to provide a rational basis for the results obtained in the field and to provide a base for extrapolation of the results to other soils and conditions. Work was continued to screen maize varieties tolerant to mineral stress conditions found in highly weathered acid soils of the tropics. This work has been carried out by Dr. R. Dean Rhue. The work on the chemical and mineralogical studies of the highly weathered soils to help interpret the results of field experiments was continued through the year. This work was under the direction of Dr. R. M. Weaver (to 9/30/76).

Screening Maize Lines for Aluminum Tolerance

The previous annual report described a screening technique in which lateral roots of corn inbreds were given a brief exposure to Al and then transferred to an Al-free recovery solution. Marked differences were observed among inbred lines in the ability of their roots to re-initiate growth during the recovery period. It was hoped that by identifying those lines whose roots survived the Al injury, the Al tolerant lines could be quickly separated from the Al sensitive lines. Further evaluation of the new technique showed that the results were not compatable with those of screening techniques using more conventional apporaches, namely continuous exposure to complete nutrient solutions containing Al for extended periods of time. A possible explanation for the discrepancy is that results of the former technique are very sensitive to differences in root size and lateral roots of corn inbreds were observed to vary markedly from one inbred line to another. Therefore, the new technique was abandoned and replaced by a more conventional screening technique in which germinated seeds were suspended directly over complete nutrient solutions containing Al and allowed to remain for 12 days. Using this techinque marked differences in root growth were observed among inbred lines and hybrids. Plants which have been grown together in these solutions could be ranked visually on the basis of differential root growth. Roots of the more sensitive lines showed symptoms typical of Al toxicity, namely stunting, swelling, and discoloration. Roots of the more tolerant lines were long, well developed, and fibrous. We have screened a large number of inbred lines and hybrids using this differential ability to grow in the presence of toxic levels of Al as a criteria for selection. In addition to these materials, two composites, one temperate, the other tropical, have been screened. Within all of these materials a wide range in tolerance to Al has been observed. Results of these screenings have correlated well with results of greenhouse screening where these same genotypes were grown in acid silt loam soil.

Studies are presently under way to determine the genetic basis for this range in tolerance as well as the mechanism by which Al tolerance is inherited. Additional work is also going on to determine if changing the cytoplasm has any effect on tolerance to Al.

Reactivity to Phosphorus Among Highly Weathered Soils

The applicability of the adsorption isotherm approach to characterizing reactivity of highly weathered soils to phosphorus was assessed for incubation periods of up to 3 months. Samples from 23 highly weathered soils from Puerto Rico, Brazil, Ghana, Venezuela and Malawi were studied. Extractions of poorly ordered mineral fractions of the soils were carried out in order to establish possible relations with reactivity of the soils to phosphorus.

A given isotherm was prepared by reacting subsamples of a soil with KH_2PO_4 solutions covering a range of initial concentrations, with 0.01M $CaCl_2$ used as a carrier salt. Toluene was employed to inhibit microbial activity. After a given contact time final concentrations of P in solution were determined spectrophotometrically by the reduced molybdate method. Relations between final concentrations of P and P removed from solution by soil were found to conform to Langmuir and Freundlich isotherm treatment of the data for all incubation periods. Although for the 3 month incubations there was evidence in several isotherm systems of microbial activity. However, evidence was found that equilibrium conditions, assumed in the Langmuir adsorption model, were not attained in short incubation periods.

Estimation of poorly ordered mineral fractions in soils was attempted by extraction with 0.5M $CaCl_2$, dilute HC HCl; cold, 5% Na_2CO_3; or acid ammonium oxalate in darkness. Aluminum and iron in extracts were determined spectrophotometrically by the aluminon and orthophenanthroline methods respectively. Values of aluminum extracted by dilute HCl or 5% Na_2CO_3 were found to correlate strongly with phosphorus sorption indices derived from isotherm data for all incubation periods. Values for iron extracted by dilute HCl or acid oxalate were found to relate poorly to reactivity indices, though correlations improved slightly for indices derived from longer term isotherms. Amounts of phosphorus retained against 0.5M $NaHCO_3$ extraction following phosphorus isotherm incubations were found to exhibit relations to Al and Fe similar to those cited above. Significant correlations were found between phosphorus reactivity indices and clay or organic matter content. The latter two factors were found to correlate strongly with Al extracted by dilute HCl or 5% Na_2CO_3.

2. Operational Significance

Although fertilizer availability and its cost have varied greatly the past few years, it still is evident that a large portion of the world's population will continue to rely on fertilizers as an essential component of increased food production. Thus in experiments, on Oxisols and Ultisols in Puerto Rico, yields of corn grain with adequate nitrogen, phosphorus and lime have averaged 4.5 mt grain/ha; Planaltina, Brazil 6.2 mt grain/ha and in Ghana, 4.5 mt grain/ha. Unless lime or phosphorus is added to many of these soils yields are essentially zero.

The native capacity of many of these soils to supply nitrogen is greater than is generally appreciated and good crop production can be obtained with moderate applications of properly applied fertilizer nitrogen during the initial years of cropping. Fertilizer nitrogen must be supplied and managed in relation to the growth of the crop. Split applications are most effective for a crop like maize. Timing is critical and it is greatly affected by rainfall patterns as demonstrated by the work in Puerto Rico and Brazil.

Varietal differences are important and in preliminary results from Ghana improved varieties have higher yield potential with moderate applications of fertilizer nitrogen than do local unimproved varieties.

The problem of supplying sufficient phosphorus to meet crop needs at reasonable cost requires special consideration for most of the Oxisols and Ultisols. On the Oxisols of the Central Plateau of Brazil, phosphorus is extremely deficient in soils which have not been under cultivation and they require substantial applications of phosphate fertilizer in the first years of cultivation for good maize production. A combination of a large initial broadcast application of soluble phosphate as a capital investment followed by smaller annual applications of banded phosphate may be the best practice but data from subsequent crops will be required to answer this question. Preliminary results on Ultisols of Ghana indicate that only modest quantities of phosphate fertilizer may be required to meet the phosphorus requirements for good crop production. Interestingly, method of application may not be important on these particular soils.

The lack of response to phosphate on similar soils in Puerto Rico which have had a long history of phosphate fertilization is consistent with the experimental data collected in Brazil; heavy applications of phosphate have high residual effects. Use of certain rock phosphates or silicate materials to reduce costs should be carefully evaluated. Crops other than maize appear to require smaller amounts of applied phosphate for good production. A more reliable soil test for phosphorus still needs to be developed on these kinds of soils for particular crops.

Aluminum and/or manganese toxicity especially in the subsoil poses a problem on extensive areas of Ultisols and Oxisols. It restricts the root system of many food crops and thus affects the capacity of the plants to absorb nutrients and water. Incorporation of modest amounts of lime to depths of 30 to 60 cm helps but is not the answer for many situations where such placement is not feasible because of cost. Recent evidence from the liming experiments in Brazil indicates that calcium may move into the subsoil more readily than previously believed. In addition, development of aluminum and/or manganese tolerant varieties offers promise. Screening procedures to select maize varieties tolerant to aluminum have been developed at Cornell. Research during the past year in screening about 200 inbred and hybrid varieties of maize has demonstrated a wide range of tolerance to aluminum toxicity. The studies show that it is feasible to develop aluminum tolerant varieties which should produce well with little or no need for lime. This has important implications for farmers in regions where lime is not readily available or is too costly.

In the absence of toxic levels of aluminum and/or manganese, liming may be necessary in order to provide sufficient calcium and magnesium for adequate plant nutrition. This appears to be especially true of some of the soils of Ghana where toxic levels of aluminum and/or manganese are not present but the amount of exchangeable calcium and magnesium is extremely low. The amounts of lime needed for such purposes are usually small by conventional standards; the pH need not be raised much above 5 to achieve the necessary soil-plant relations for optimum productivity. A simple reliable test for lime requirement on the Oxisol and Ultisols of the tropics related to specific crop needs is needed.

Water is likely to be a limiting factor in extensive areas of the humid tropics even during the rainy season particularly where subsoil acidity restricts root growth. One or two weeks without rain can nullify the beneficial effects of all of the inputs described above. For extensive areas in Central Plateau of Brazil it is estimated that average yields of maize during the rainy season may be only be about half of what is possible if supplementary irrigation were provided or if lime is incorporated to 30 cm or more. Experience in Ghana likewise has shown that uncertainties in rainfall especially in the beginning of the rainy season may have serious consequences in crop establishment and early growth. Timing of planting and minimizing of runoff by good conservation practices where supplementary irrigation is not possible also should help to insure good crop production.

3. Side Effects of the Work

The research carried out under this project has identified a number of important considerations for farmers and those who work with farmers on a highly weathered, well-drained acid soils of the humid tropics. Some relatively new ideas; others are verification and extension of existing knowledge.

Although in retrospect it may have been obvious, the results of these experiments have demonstrated that the potential of the highly weathered soils of the tropics cannot be achieved by single practices. A combination or a complete package of practices is necessary if sustained production is to be obtained. This includes pest control, soil fertility, soil management, crop selection, and any number of other factors that may influence crop production.

The physical inputs for sustained production are likely to be appreciable (lime, phosphorus, potassium, micronutrients). The full value of the inputs however, will not be realized for several years because residual effects are appreciable, yet not permanent. Skilfull farm operators will be required to capitalize fully on the research results since more than the usual number of management parameters must be adjusted to provide some measure of proper balance.

The complexities of the soil management problems preclude any quick and easy answers. It is likely only a matter of time before population pressures force a more intensive utilization of all soil resources whether answers are available or not. In a negative sense, the research will hopefully go a long way toward preventing catastrophic failures of development schemes which would very likely result without some of the insights into the complexity of the soil management problems which have been developed.

In the Central Plateau of Brazil sufficient water is available at a reasonable cost to irrigate 1% to 3% of the land during the dry season and provide supplemental irrigation during the rainy season. Thus, intensive, year around crop production on small acreages appears feasible. Perhaps irrigation coupled with inputs of soil amendments and intensive management would provide very attractive investments.

This same situation may prevail locations other than Brazil also.

We have found few inconsistencies between our temperate region experience and our experience in the tropics. So far as we are concerned, most of the conceptual relationships derived from our temperate region experience have served us well and faithfully throughout our experience in the tropics. Experience with timing of fertilizer nitrogen is similar with corn in Nebraska, New York, Puerto Rico, Planaltina (Brazil) and with potatoes on Long Island. Phosphorus fertilizers partially compensate for adverse effects of soil acidity with potatoes on Long Island, sorghum on Carimagua (Colombia), and a variety of crops at Planaltina. Aluminum toxicity is related to pH in a similar fashion regardless of geographical location. To be sure the intensity of the various phenomena have varied, but the general principles are still valid.

4. Research Design

The basic approach to the soil fertility research has remained basically the same throughout the course of our experience. The interr ship between water supply and availability and utilization of plant nutrients continues to be of great interest. The application of plant nutrients in small amounts of irrigation water appears to have great potential.

The utilization of plant residues as nitrogen sources and the use of legumes to supply nitrogen remains a high priority research need. The potential of legumes to supply nitrogen to subsequent crops needs to be evaluated under a variety of conditions.

Wide differences in plant species in mineral accumulation and tolerances to deficiencies and toxicities have been known for a long time. Varietal differences, however, have only relatively recently become widely recognized although this was demonstrated many years ago. Although certain deficiencies in some crops have been found to be controlled by single genes, inheritance patterns worked out to date indicate that generally a more complex genetic system is involved.

Preliminary results indicate that by keeping the genotype (nuclear) constant a wide range of element uptake is possible through changing the cytoplasms. The possible influence of cytoplasms would open up a whole new field of plant-soil interactions. It would be possible through plant breeding procedures to transfer through the cytoplasm the desirable traits for the tolerance to low levels of soil nutrients and/or toxicities without altering such characteristics as yield, disease, insect, and drought resistance, grain quality, standability, and others. As a consequence a substantial effort to screen varieties of maize for tolerance to soil stress conditions has been undertaken.

DISSEMINATION AND UTILIZATION OF RESEARCH RESULTS

The following is a list of publications developed under the contract during the reporting period:

The effect of liming an Ultisol in Ghana on Maize (Zea mays L.) Yield and some properties. S.K. Mughogho. Ph.D. Thesis. 1977.

Soil plant water relationships as influenced by various soil and plant management practices on Campo Cerrado soils in the central plateau of Brazil. D. Bandy. Ph.D. Thesis. 1976.

Sulphate adsorption by some soils of the tropics. W. Couto. Ph.D. Thesis. 1976.

Mineralogical Aspects of Reactivity to Phosphorus Among Highly Weathered Soils, Peter Adams. M.S. Thesis. 1976.

Liming of highly weathered soils of the humid tropics. G. Amedee and M. Peech. Soil Sci. 1975.

Performance of high yielding corn hybrids X-306B Funk's 795-W at high levels of fertilization in the acid and relatively infertile soils (Oxisols and Ultisols) of Puerto Rico. H. Talleyrand, Lugo-Lopez. Journal of Univ. of P.R. Vol. LX., No. 1. 1976

Preliminary evaluation of two new high quality protein opaque-2 corn varieties on an acid and relatively infertile soil (Ultisol) of Puerto Rico. H. Talleyrand, Lugo-Lopez. Journal of Univ. of P.R., Vol. LX., No. 1. 1976.

Soil Water Studies on Oxisols and Ultisols of Puerto Rico: I. Water Movement. James M. Wolf and Matthew Drosdoff. Journal of Univ., P.R., Vol. LX No. 3. 1976

Soil Water Studies in Oxisols and Ultisols of Puerto Rico: II. Moisture Retention and Availability. James M. Wolf and Matthew Drosdoff. Journal of Univ. of P.R., Vol. LX No. 3. 1976.

Nitrogen Fertilization of a High Yielding White Kernal Corn in Oxisols Ultisols in Puerto Rico. H. Talleyrand, R. H. Fox and M. A. Lugo-Lopez. Journal of University of P.R., LX. No. 3. 1976.

Performance of Oilseed Sunflower Cultivars on an Oxisol in Northwestern Puerto Rico. M. A. Lugo-Lopez, J. Badillo-Feliciano and L. Calduch. Submitted to Ed. Brd. 1976.

Se Logran Altos Rendimientos en siembras de maiz Funk's G-795W con aplicaciones de 60 Kg/Ha de Nitrogeno en un Ultisol, H. Talleyrand, R. H. Fox, M. A. Lugo-Lopez. Ciencia y Tecnologia al Servicio de la Agricultura. No. 42, 1976.

Efecto de la disponibilidad del aqua del suelo en el ultisol y un oxisol sobre los rendimientos de maiz y sorgo. A. Wahab, H. Talleyrand and M.A. Lugo-Lopez. Ciencia y Tecnologia al Servicio de la Agricultura. No. 46. 1976.

Movimiento y Disponibilidad del aqua en Oxisols y Ultisols, J.M. Wolf, Matthew Drosdoff, and M.A. Lugo-Lopez. Ciencia y Tecnologia al Servicio de la Agricultura. No. 47. 1976.

Construccion de tensiometers a Bajo Costo. James Wolf. Ciencia y Tecnologia al Servicio de la Agricultura. No. 54. 1976.

The Effect of Soil pH and Related Acidity Factors on Yields of Sweet-potatoes and Soybeans Grown on Typical Oxisols and Ultisols of Puerto Rico. Sub. to Ed. Brd. 1976.

Effect of five levels and three sources of N. on Sweetpotatoe Yields on an Ultisol. H. Talleyrand, Lugo-Lopez. Journal of Univ. of P.R., Vol. LX, No. 1. 1976.

Response of Corn to Phosphorus Fertilization in Greenhouse, Sunken Drums and Field Experiments. R. H. Fox, J. Badillo, R. Del Valle and T. W. Scott. Journal of Univ. of P.R., Vol. LX, No. 1. January 1976.

Rooting Depth, Growth and Yield of Corn as Affected by Soil Water Availability in an Ultisol and an Oxisol. A. Wahab, H. Talleyrand, M. A. Lugo-Lopez. The Journal of Agr., of the Univ. of P.R., Vol. LX, No. 3. 1976.

Rooting Depth, Growth and Yield of Sorghum as Affected by Soil Water Availability in an Ultisol and an Oxisol. A. Wahab, H. Talleyrand and M. A. Lugo-Lopez. The Journal of Agr. of the Univ. of P.R., Vol. LX., No. 3. 1976.

Sweetpotato Production in Oxisols under a High Level of Technology, J. Badillo-Feliciano and M. A. Lugo-Lopez, Sub. to Ed. Board 1976.

Influence of Cultivars, N levels and Time of N application on plant characters, leaf composition and yields of corn grown on an Oxisol., J. Badillo-Feliciano, M. A. Lugo-Lopez and T. W. Scott, Sub. to Ed. Board July, 1976.

A partially annotated Bibliography on Sulfur in Soils of the tropics. Walter Couto. Agr. M.76-1. 1976.

The significance of KCl-extractable Al an index to lime requirement of soils of the humid tropics. G. Amedee and M. Peech. Soil Sci. 1975.

Quartz presence in relationship to Gibbsite stability in some highly weathered soils of Brazil. R. M. Weaver. Pergamon Press (Great Britain). 23:431-436. 1975.

Response of Soybeans Grown on an Ultisol to Residual Broadcast and Banded to Phosphorus Fertilizer, Reinaldo Del Valle, Jr., R. H. Fox, and M. A. Lugo-Lopez. Sub. to Ed. Board 1975.

Vuelven a lograrse Altos Rendimientos de Habichuelas Soyas en P.R., Reinaldo Del Valle, Jr., R. H. Fox, M. A. Lugo-Lopez, Ciencia y Tecnologia al Servicio de la Agricultura. No. 32, 1975.

Clay mineral occurrence in some highly weathered soils of the Central Plateau of Brazil. R. M. Weaver, Clay & Clay Minerals. 1975 (in press).

Soil fertility studies with Maize Variety, Funk G-795, in Puerto Rico. H. Talleyrand, R. H. Fox, and M. Lugo-Lopez. Journal Agric. of Univ. of P.R. 1975 (in press).

The results of the research have been disseminated in a number of ways as in previous years. Publications have a wide range of distribution depending on the nature of the material. Technical information is published in scientific journals where it is available to the scientific community. General bulletins are given wider distribution. Mimeographed reports also are prepared for distribution to get the results into the hands of the user quickly.

Interest remains high in the work in Puerto Rico and farmers and extension agents are using the results as soon as they become available. Results from Puerto Rico are being extended throughout Carribean America and utilized by the farmers.

The results obtained at the Cerrado Center in Brazil are becoming widely known and extension agents and farmers are using the information developed by the Center to improve production over a wide area of Brazil. The fertilizer and soil management recommendations are based, in large part, on the research carried out in cooperation with the university contracts. Included among the many visitors to the experiments at the Cerrado Center was President Geisel of Brazil as well as Ministers of Departments of the Government.

While the program has only nicely begun in Ghana, during the cropping season of 1976, experiments on maize and cassava were begun as part of the research project in Aiyinasi, Ghana. This is a rather remote, chronically food deficit area in rainforest area of southwestern Ghana. The first crop during the growing season was such a dramatic improvement over the traditional maize plantings of the area that many local farmers as well as extension agents of the area came to view the plots. The yields on the plots were low by our previous standards but they were still nearly double the traditional yields. The point is, however, that the peasant farmers in the immediate area recognized a good crop when they saw one. What can be done on a long term basis in this area to alleviate a chronic food deficit remains to be seen.

WORK PLAN - April 1, 1977 to June 30, 1977

No new work is planned at any of the locations during this period. The present experiments are being carried to their logical conclusions and the results will be summarized and reports prepared as the data becomes available. The time table given in the report for the period November 1, 1974 to October 31, 1975 is still appropriate if the project were to continue beyond the present termination date.

Proposed Budget - April 1, 1977 to June 30, 1977

AID/ta-c-1104

Salaries:	U.S.	$ 10,000
	Non U.S.	11,000
Overhead		12,000
Travel & transport		1,100
Supplies & materials		1,000
Allowances		6,000
Consultant		3,000
	Total	$ 44,100

PERSONNEL

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

Cornell Staff

Dr. Douglas J. Lathwell - Professor of Soil Science, Principal Investigator
Dr. K. Dale Ritchey - Research Associate, Project Leader in Brazil
Dr. Amos G. N. Ngongi - Research Associate, Project Leader in Ghana
Dr. Robert M. Weaver - Assistant Professor of Soil Science
Dr. David R. Bouldin - Professor of Soil Science
Dr. Robert B. Musgrave - Professor of Field Crops
Dr. Thomas W. Scott - Professor of Soil Science
Dr. R. Dean Rhue - Research Associate
Dr. Donald C. Kass - Research Associate
Mr. Dale E. Bandy - Research Assistant
Mr. Peter J. Adams - Research Assistant
Mr. Spider M. Mughogho - Research Assistant
Miss Kate B. Showers - Research Assistant
Mr. James R. Rundle - Research Assistant
Mr. Leslie A. Everett - Research Assistant
Mr. J. C. Keng - Research Assistant

Puerto Rico Staff

Dr. Mario E. Perez-Escolar - Acting Director, Puerto Rico Agricultural Experiment Station
Dr. Miguel A. Lugo-Lopez - Soil Scientist
Dr. Raul Perez-Escolar - Soil Scientist
Dr. Jose Badillo - Assistant Agronomist
Mr. Reinaldo del Valle - Assistant Agronomist

Brazil - EMBRAPA

Dr. Elmar Wagner Director, Cerrado Center
Dr. Wenceslau Goedert - Director of Research Cerrado Center
Mr. Edson Lobato - Soil Scientist
Mr. Elcios Martins - Research Technician

Ghana - Soil Research Institute

Dr. Henry Obeng - Director, Soil Research Institute
Dr. Peter K. Kwakye - Senior Research Officer
Mr. Ambrose L. Nyamekye - Research Officer

INVOLVEMENT OF MINORITY PERSONNEL AND WOMEN

The following women were employed under the research contract during the current reporting period:

M. A. Buyukcolak, Secretary
C. L. Quenette, Secretary
M. M. Dethier, Administrative Aide
T. J. Duffy, Laboratory Technician
L. Keng, Laboratory Technician

Partial support was provided to the following women graduate students:

Linda Lennox
Kate Showers
Milegua L. Bloom

The following Minority personnel received support from the project during the reporting year:

Blacks -

S. M. Mughogho - Graduate Research Assistant
O. Odeyemi - Graduate Research Assistant
A. G. Ngongi - Research Associate, Project Leader in Ghana.

Orientals-

J. C. Keng - Graduate Research Assistant