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

Annual Progress Report

for the period

July 1, 1970 to June 30, 1971

Submitted to the

U. S. Agency for International Development

Contract AID/csd 2490

Cornell University
Ithaca, New York

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APPENDIX I. Details of Procedures for Nitrogen Field Experiments

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SUMMARY

The nitrogen field experiments supplemented by greenhouse and laboratory studies have provided significant data on the utilization of applied nitrogen by corn and sorghum on representative acid soils. Post-plant nitrogen applications were more efficiently utilized and produced substantially higher yields than pre-plant applications. Considerable leaching losses generally occurred with the pre-plant nitrogen applications. Substantial losses through denitrification may occur in the field under temporary anaerobic conditions as indicated by laboratory experiments. A surprisingly high level of inorganic soil nitrogen was found even where no nitrogen was applied. The zero level nitrogen plots on a clayey Oxisol produced about 5900 kg/ha of corn (94 bushels/acre) and still contained about 180 kg/ha of nitrogen after harvest in the top 75 cm of soil. Continuous cropping with corn in pot tests with different soils without added nitrogen showed high amounts of mineralizable nitrogen released and the amounts released were not always associated with the organic matter content of the soils. It was found that laboratory chemical methods as well as incubation procedures can provide means for evaluating the capacity of tropical soils to supply nitrogen to cultivated crops.

The toxic effects of aluminum in the soil solution on root growth of corn and sorghum were confirmed in laboratory and greenhouse tests. It was found that calcium in the soil solution plays an important role in minimizing aluminum toxicity. In field experiments liming acid soils had little or no beneficial effect if the aluminum concentration was low and sufficient calcium was present regardless of the level of soil acidity.

A very high yield of almost 16,000 kg/ha of green beans was obtained on a clayey Ultisol limed to pH 7. However, the check plots with pH 4.5 in the surface soil and 4.8 in the subsoil produced almost 12,000 kg/ha.

The clay mineralogy studies on the Ultisol and Oxisol soils from the experimental sites, using X-ray diffraction, differential thermal, and chemical analysis techniques, showed that kaolinite, amorphous material, and chlorite make up the greater portion of the clay fractions with lesser amounts of mica, vermiculite, and gibbsite constituting the rest of the clay fraction. Research is now being directed toward relating the mineral composition of the clays to the properties of the soil as a whole and their relation to plant growth.

To interpret more adequately the results of the soil fertility experiments in relation to the climatic environment, tests have been initiated at the experimental sites to determine the rate of infiltration of water into the soil, rate of movement through the soil, and water retention by the soil at different tensions.

INTRODUCTION

This is the second annual summary progress report of the research project to determine the soil fertility and management requirements of the deep, well drained, infertile acid soils of the humid tropics to help realize their high productivity potential for food crops. As stated in the first report, it is estimated that there are some 600 million hectares of these soils in the tropics which are potentially arable, yet mostly uncultivated. Much of this land has favorable topography and the soils are generally deep and permeable with good drainage and favorable structure. One of the main limiting factors of these soils is their low fertility and the objective of the research is to determine the most effective and economic amounts and methods of application of nitrogen, phosphorus, potassium, liming materials, and micronutrients in relation to cropping systems and management practices.

Though Puerto Rico is used as a base for this research, the project is designed to have wide application over extensive areas in Latin America, Africa, and Asia. On site complementary studies are now being planned under this project for work in the Campo Cerrado soils of the central plateau in Brazil in collaboration with soil scientists of the Ministry of Agriculture. Though not directly financed by this project, soil fertility studies have been conducted during the past year in the Llanos of eastern Colombia on soils with characteristics similar to those in Puerto Rico.

PROGRESS TO DATE

NITROGEN STUDIES

Field Experiments

As stated in the first report, the objectives of the nitrogen experiments are primarily to: (1) devise procedures for applying nitrogen to non-

leguminous row crops to insure a reasonable recovery of fertilizer nitrogen, and (2) to obtain enough subsidiary data which will give some insight into the relative importance of leaching and denitrification in nitrogen loss, and conditions under which the two mechanisms are of most significance.

The initial field experiments involving studies on the effects of time and rate of nitrogen applications were conducted at four locations on different soils. The soil at each site had characteristics similar to properties of counterpart soils extensive in other regions of the humid tropics (Oxisols and Ultisols). The four soils used in these experiments and the tentative classification under the new USDA Soil Taxonomy are:

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

Procedures. A Jamaican hybrid corn, Pioneer X-306 was planted in April and May, 1970 at the four sites followed by RS-671 grain sorghum planted in October and November, 1970 at three sites (the Coto soil site was abandoned after the first corn crop as the soil properties of the soil at this site was judged not to be representative of any extensive soil area in the humid tropics of the Western Hemisphere). The X-306 corn was again planted at the three sites in April and May, 1971 following the harvest of the sorghum plots.

The differential nitrogen treatments were 0, 34, 67, and 134 kg/ha of N as urea and 67 kg/ha of N as sulfur coated urea applied as a preplant plow down treatment and 34, 67, and 134 kg/ha of N as urea applied as a postplant sidedress. The sidedress was applied when the plants were approximately 30-45 cm high. This

Table 1. Corn Yield and Nitrogen Uptake - Clayey Oxisol (Catalina)

Treatment No.	Treatment kg/ha of N[1/]	Yield of Grain (15% H_2O) kg/ha[2/]	Yield of Stover kg/ha[1/]	Total Plant N[3/] kg/ha[1/]
1	Check	5884	5937	139
2	34 preplant	6332	7128	152
3	67 preplant	6275	6916	144
4	134 preplant	5865	6931	145
5	34 postplant	6105	6168	142
6	67 postplant	5783	5512	135
7	134 postplant	6035	6118	145
8	67 S.C.U. preplant	5845	5981	129
	Average	6016	6224	141
	Coefficient of variation of grain = 10.0% Coefficient of variation of stover = 11.0%	- No significant difference between yields		

1/ To convert to pounds per acre multiply by 0.89

2/ To convert to bushels per acre multiply by 0.016

3/ Stover N + Grain N + Cob N

All of the excess N was in the NO_3^- form. Most of this fertilizer was present in the 0-25 and 50-75 cm soil depths. A possible cause of this distribution may have been that part of the NH_4^+ derived from the urea was nitrified and leached to the 50-75 cm depth. The NH_4^+ present at that time did not move and at the time of sampling the NH_4^+ had become nitrified and had not yet leached to greater depths.

After the corn harvest, approximately 50 percent of the preplant fertilizer N was recovered and 100 percent of the postplant N was present in the soil. Again, the largest amounts of excess inorganic N was in the 0-25 and 50-75 cm layers although a considerable fraction, at least 33 percent of the 134 kg/ha preplant treatment, had leached to depths below 75 cm. Apparently none of the 134 kg of postplant applied N was leached below 75 cm.

b. Sorghum - Winter 1970.

Due to the lack of response to nitrogen by the preceding corn crop, no additional nitrogen fertilizer, except for 11 kg/ha of starter nitrogen, was applied to the soil for the sorghum crop. There was no significant difference in sorghum yields among the nitrogen treatments applied to the previous corn crop. The average grain yield was 2583 kg/ha with a range of 2270 to 2900 kg/ha. The average stover yield was about 3200 kg/ha. The nitrogen taken up by the above ground portion of the plant averaged about 52 kg/ha.

This yield of sorghum was relatively low and whether it was due to the time of planting, lack of applied fertilizer nitrogen, insufficient radiation or some soil factor, or a combination of factors is not known.

There was sufficient moisture in the soil profile throughout the growth of the crop, very few weeds, no apparent insect or disease problems, and only very slight bird damage. Observations of the roots 89 days after planting indicated that the root proliferation to a depth of 75 cm was quite good.

2. Humatas soil site - clayey Ultisol

a. Corn - Summer 1970.

The corn growth was very good at this site; the height of the corn was generally about 30 cm less than at the clayey Oxisol site but maximum yields were slightly higher and there were significant differences between treatments.

The grain yield (Table 2, Figure 1) ranged from 4315 to 6571 kg/ha (70 to 104 bushels per acre). Treatments of 157 kg/ha of preplant N and 67 or 120 kg/ha of postplant N consistently gave increased yields above that of the check. The postplant application of nitrogen consistently resulted in higher yields than the preplant application of the same quantity of fertilizer. With 67 kg/ha of nitrogen applied the yield was 6081 kg/ha for the preplant treatment and it was 6275 kg/ha for the postplant application. It appears that 67 kg/ha of N applied as a postplant treatment was sufficient nitrogen to attain maximum yield. The 67 kg/ha of N as sulfur coated urea gave results similar to the 67 kg/ha of preplant urea.

The uptake of nitrogen reflects the yield data in that the postplant treatments resulted in recovery of a much higher percentage of the applied fertilizer. With the preplant urea treatments the average recovery of fertilizer N was only about 17 percent in comparison with 65 percent recovery for the postplant treatments.

Table 2. Corn yield and nitrogen uptake - clayey Ultisol (Humatas)

Treat. No.	Treatment kg/ha N 1/	Yield of grain (15% H_2O) kg/ha 1/	Yield of stover kg/ha	Total plant N 3/ kg/ha 1/	Total N minus check N kg/ha 1/	Recovery of fertilizer N 4/ percent
1	Check	4479 a 5/	4714 a 5/	104	-	-
2	34 preplant	4215 a	4985 ad	107	3	8
3	67 preplant	4681 a	5392 acd	111	8	12
4	134 preplant	5897 bc	6322 b	145	41	31
5	34 postplant	5078 ac	6141 bcd	130	26	76
6	67 postplant	6275 b	6426 bcd	145	41	61
7	134 postplant	6571 b	6741 bc	180	76	57
8	67 S.C.U. preplant	4996 ac	5722 bcd	119	15	22

Coefficient of variation of corn yield = 15.9%
Coefficient of variation of stover yield = 118.7%

1/ To covert to pounds per acre multiply by 0.89

2/ To convert to bushels per acre multiply by 0.016

3/ Stover N + Grain N + Cob N

4/ $\frac{\text{Total N Minus Check N}}{\text{Fertilizer N Applied}} \times 100$

5/ Numbers followed by the same letter are not significantly different at the 5% probability level.

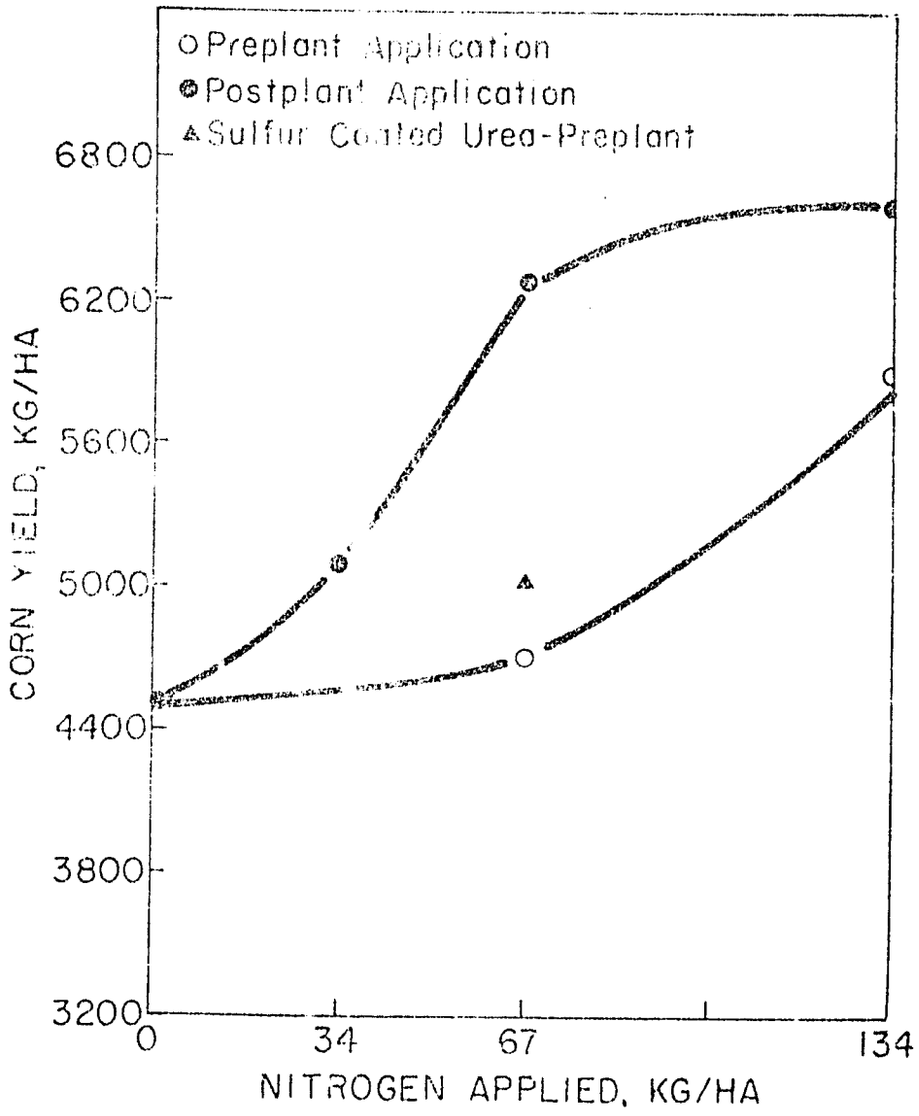


Figure 1. Effect of rate and time of application of fertilizer N on corn grain yield - clacey Ultisol (Humatas)

The low recovery of preplant nitrogen can be partially explained by the fact that approximately 15 cm of rain fell between the time of application of preplant fertilizer and planting, resulting in the possibility that a considerable portion of the fertilizer was leached below the root zone. Some fertilizer nitrogen may have been lost in surface run off although it was plowed under before the rains occurred. It was also observed during postplant soil sampling that the soil below 50 cm was waterlogged in many cases. This could have led to denitrification of the added nitrogen. This is assuming that the added urea had nitrified to NO_3^- in this slow nitrifying soil in the 41 days after its application. However, laboratory data indicate that denitrification below 50 cm is unlikely.

An interesting difference between this soil and the clayey Oxisol is that there was a substantial response to nitrogen fertilizer on the clayey Ultisol in spite of the fact that the soil contained 300 kg/ha of inorganic N in the top 75 cm of soil before planting, almost as much as the 380 kg/ha in the clayey Oxisol where there was no response to added N. A possible explanation is that losses of nitrogen by denitrification or leaching may have occurred on the clayey Ultisol or the nitrogen may have been held in a form not readily available to the plants.

Root examination approximately 80 days after planting showed good root proliferation in the top 60 cm of soil with a few fine roots growing to 75 cm.

After the corn harvest the soil inorganic N content in the top 75 cm was still 195 kg/ha. As there was a significant response in yield and N uptake to only 67 kg/ha of postplant applied N indicates that much of this

195 kg/ha of inorganic N was not available to the corn plants. One possible explanation is that in the method of inorganic N determination being used some organic N is being hydrolyzed and measured as inorganic N. Another possibility is that in these soils there is a certain base amount of inorganic N always present but not available to plant roots. For example, perhaps all the NH_4^+ or NO_3^- in concentrations of less than 3 ppm in the soil, as determined by our methods, is not available for plant absorption. Support for this is the observation that at one of the other experimental sites which was a subsoil containing less than 1% organic matter, there was 153 kg/ha of inorganic nitrogen in the top 75 cm of soil before planting. Yet the corn yield was only 1700 kg/ha and the above ground portion of the plants contained 42 kg/ha of nitrogen. Certainly not all of the inorganic soil N was available for plant use. Conditions were such at this site that the possibility of loss by leaching or denitrification were also very slight.

Another interesting observation is that apparently the postplant applications of fertilizer to corn on the clayey Ultisol produced a flush of mineralization activity in the soil. The fertilizer N recovery, plant plus top 75 cm of soil, ranged from 113 to 263 percent for the postplant treatments. The sulfur coated urea treatment also resulted in greater N recovery than the applied N. The N recovery in the preplant urea treatments ranged from 7 to 58 percent.

b. Sorghum - Winter 1970.

Heavy rains began immediately after the preplant and blanket fertilizers were plowed under at the site and it was 17 days and 41 cm of rain

later before the sorghum could be planted. At the time of the postplant application of fertilizer the whole field appeared nitrogen deficient except for an area in the upper section of the field where the plants were darker green and taller. Inorganic N analysis of the soil showed a relatively small amount of N left from the preplant treatments.

There was a very marked response to the postplant N applications that could be observed beginning 2 weeks after the application. The postplant plots turned dark green and began to grow more rapidly. The difference between the postplant N plots and the rest of the field was so striking that the color differences could be observed from a distance of at least a mile. The sorghum plants containing more nitrogen matured up to 3 weeks sooner than did the N deficient plants.

The grain yield from the plots receiving a postplant application of N were significantly larger than that of the preplant applications (Table 3, Fig. 2). Plotting the grain yield as a function of N rate resulted in the commonly observed hyperbolic relationship for the postplant N application (Fig. 2). There was no significant yield response to the additions of preplant N. This lack of N response to the preplant N application was substantiated by the very low recovery (average of 7 percent), of fertilizer N from the preplant N applications.

The maximum grain yield was 4284 kg/ha (68 bushels per acre) which was considerably higher than the high 2900 kg/ha obtained on the Oxisol. The fairly low recovery, average 40 percent, of fertilizer N from the postplant treatments is a reflection of the small quantities of N that were absorbed by the plants. The maximum plant N content found in sorghum at this site

Table 3 - Sorghum yield and nitrogen uptake - clayey Ultisol (Humatas)

Treat. No.	Treatment kg/ha of N 1/	Grain Yield kg/ha 2/	Stover yield kg/ha 1/	Total Plant N 3/ kg/ha 1/	Total N minus check N kg/ha 1/	Recovery of Fertilizer N 4/ percent
1	Check	1701 c 5/	1764 c 5/	36	-	-
2	34 preplant	1890 c	1736 c	46	4	12
3	67 preplant	1701 c	1518 c	37	1	2
4	134 preplant	2016 c	2126 b	44	8	6
5	34 postplant	3213 b	2367 ab	56	20	59
6	67 postplant	3054 b	2293 ab	60	24	36
7	134 postplant	4284 a	2252 a	71	35	26
8	67 S.C.U. preplant	2079 c	2138 b	49	13	19

1/ To convert to pounds per acre multiply by 0.89

2/ To convert to bushels per acre multiply by 0.016

3/ Stover N + Grain N + Head Straw N

4/ $\frac{\text{Total N minus Check N}}{\text{Fertilizer N}} \times 100$

5/ Numbers followed by the same letter are not significantly different at the 5% probability level.

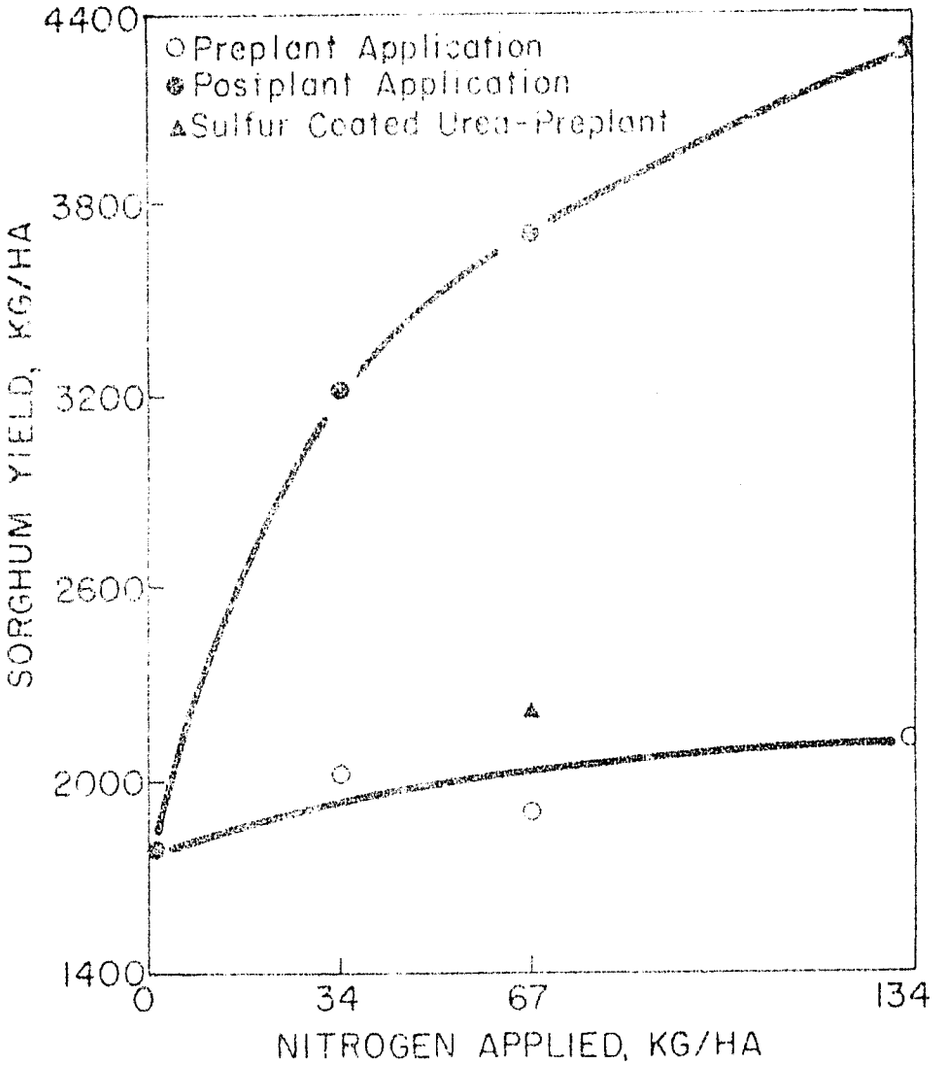


Figure 2. Effect of rate and time of application of fertilizer N on sorghum grain yield - clayey Ultisol (Humatas)

was 71 kg/ha whereas with corn the maximum was 180 kg/ha.

Root observations revealed that root growth was primarily restricted to the topsoil. At the site of the observation pit, the topsoil was approximately 20 cm thick. There was some root growth in the cracks in the B horizon to a depth of approximately 50 cm. These fracture surfaces were coated with a darker material that was presumably clay and organic matter leached from the topsoil. There were no roots growing in the solid, red portion of the B horizon. This limited root growth was not unexpected as the low pH and high aluminum content of the subsoil coupled with the sensitivity of sorghum to aluminum would cause severely limited root growth in the subsoil. The soil pH at the time of the postplant application of nitrogen was an average 5.07 for 0-25 cm, 4.03 for 25-50 cm, and 3.95 between 50 and 75 cm. The restricted root growth partly explains the lack of nitrogen response to the preplant applications, as only the amount of nitrogen that remained in the top 20 to 25 cm would be available for absorption.

3. Pinas soil site - sandy Oxisol

a. Corn - Summer 1970

During the first few weeks after planting a number of seedlings were killed by the lesser corn stalk borer, and zinc deficiency symptoms were observed. The corn borer problem ceased with the arrival of heavy rainfall and zinc deficiency symptoms were corrected with a foliar application of 0.5 percent $ZnSO_4 \cdot 7 H_2O$. The plants grew fairly well, although not as well as at the other sites, reaching a maximum height of a little over

2 meters. The plants were severely affected by moisture stress during tasseling and silking.

There were some N deficiency symptoms before tasseling but apparently the plant water stress during the critical silking period reduced all yields to more or less the same level, as there were no significant differences between treatments. The average yield was about 3000 kg/ha of grain (48.6 bushels per acre) and 4700 kg/ha of stover. These low values were undoubtedly due in part to the water stress during silking.

The mineral N in the top 75 cm of soil before planting was about 290 kg/ha, surprisingly high for such a sandy soil. After the corn crop the content of the check treatment had dropped to about 180 kg/ha. Plants receiving fertilizer nitrogen contained more nitrogen than the check plants with an average of approximately 15 percent of the applied fertilizer being recovered in the aerial portion of the plants. The fertilizer recovery from the top 75 cm of soil plus plant N ranged from 27 to 70 percent with an average of 54 percent for the preplant urea treatments and 40 percent for the postplant treatments. There was almost no excess soil N below 75 cm in the two 134 kg/ha treatments indicating that there was little leaching of N below this depth.

Root examination at this site revealed that water stress was partly caused by restriction of the majority of the roots to the top 15 cm of soil by a hardpan. A few roots grew to 20 cm and the very few that were able to penetrate the hardpan grew to a depth of approximately 60 cm. The top 12 to 15 cm of the soil were a mass of roots and many of the root tips at a depth

of 12 to 20 cm were swollen due to their inability to penetrate the soil. Almost daily rains would be necessary to avoid water stress in full grown corn plants at this site with its high evapotranspiration, sandy soil, and extremely restricted root zone.

There appears to be little one can do to prevent the formation of this hardpan, as it is a function of the soil texture. Limiting surface traffic slows down the formation but it has re-formed at this site after one crop and 8 months after having been deep [illegible] level. Plowing to 30 cm before every crop would probably alleviate the pan problem a great deal. It was observed that the pan was hardest between 15 and 30 cm. It was also observed, however, that the disc plow normally used at this site rode on top of the pan where it was well formed. Perhaps a moldboard plow should be used.

b. Sorghum - Winter 1970

The early growth and vigor of sorghum at this site were adversely affected by heavy rains at the time of planting and for the first month of growth. In spite of the soil having a sandy texture the drainage is quite slow due to the hardpan at this site. After the heavy rains during the first part of the crop, water would remain standing in some spots for one or two days and plants in a few plots were lost to erosion. There was also a heavy infestation of weeds that could not be completely controlled by two hand cultivations.

At the time of the postplant fertilizer applications the plants in all treatments except the 134 kg/ha preplant treatments were approximately 30 cm high and somewhat N deficient. In the 134 kg/ha preplant treatment, the

plants were approximately 50 cm high and darker green. This treatment matured 3 weeks before any other treatment and consequently was more severely attacked by birds. The plants responded well to the postplant nitrogen application and overcame their deficiency symptoms within two weeks.

The grain yields were quite low at this site ranging from 819 to 2457 kg/ha (13 to 39 bushels per acre). The top yields of 2331 and 2457 kg/ha were obtained with the 134 kg/ha treatment. The grain yield for the 134 kg/ha preplant treatment was somewhat reduced by bird damage. The stover yield for this treatment was significantly larger than for all other treatments. As on the clayey Ultisol the fertilizer nitrogen recovery was higher from the postplant treatments, 23 percent, than from the preplant treatments, 8 percent.

It is recommended that for sorghum the postplant N application be applied when the plants are 15-22 cm high or perhaps 30 days after planting. Waiting till the plants were 30 cm high resulted in N deficiency symptoms and probably some reduction in yields and N utilization.

As on the clayey Ultisol, the grain yield from the 67 kg/ha of nitrogen applied as sulfur coated urea was slightly higher and the N uptake considerably higher than the same amount applied as urea. Some of this increased N uptake may be nitrogen from very slowly decomposing sulfur coated urea applied to the previous crop.

After 80 days growth the root system was primarily confined to the 30 cm inches of surface soil except in the channels caused by the subsoiler. These channels contained surface soil and root growth extended down their length.

As on the clayey Oxisol there were almost no sorghum roots in the acid subsoil.

The average pH of soil samples taken after the sorghum harvest were 5.17, 4.48 and 4.37 for 0-25 cm, 25-50 cm, and 50 to 75 cm. The pH in the top 25 cm was quite variable with values as low as 4.2 in some plots. Lime will be applied before the next crop.

4. Coto soil site - clayey oxisol

Corn - Summer 1970

The experiment was conducted on a site from which several feet of soil had been removed from the surface several years previously and had not been cultivated since that time. As the exposed subsoil was only slightly acid due to the influence of the underlying limestone parent material, it was decided to run a nitrogen trial on this site for comparison with the soils having highly acid subsoils. It was anticipated that the high base status of this soil would be favorable to root growth and responsive to applied nitrogen fertilizer. The site was virtually weed free before planting and, it was later learned, had been so for many years. The corn germinated well but had several strange symptoms including a grayish green color, wilted leaves, purplish lower leaves and some yellowing at the base of the youngest leaves typical of Zn deficiency. A tremendous response to 3 foliar applications of 0.5 percent $ZnSO_4$ was obtained. Plants in guard rows which were not sprayed generally failed to mature and in many cases died. One unusual Zn deficiency symptom observed in the older non-treated plants was the inward curling of the leaves as if under water stress even when the plants were standing in irrigation water

The exposed subsoil at this site contained considerably less organic matter and inorganic nitrogen than at the other sites. Consequently, the grain yield increased almost linearly with increased applications of nitrogen (Table 4, Fig. 3). The yield increased from 1700 kg/ha (27 bushels per acre) with no nitrogen to about 5000 kg/ha (80 bushels per acre) with 134 kg/ha of nitrogen. As it does not appear that the yield curve flattens out much at 134 kg/ha of nitrogen, increased quantities of fertilizer would most probably have produced even higher yields.

An average of about 47 percent of the fertilizer N was recovered by the plants with a slightly higher percentage being recovered from the preplant treatments. While the postplant treatments yielded slightly higher at the 67 and 134 kg/ha rate than the corresponding preplant treatments, the differences were not significant. The lack of a significant difference in N recovery from the preplant versus postplant applications of N is in part due to a combination of low rainfall during the growth of the crop and a low level of soil inorganic N resulting in very little, if any, leaching loss of the preplant N.

Root growth at this site was mainly confined to the top 20 cm of soil. There was some root growth down to 75 cm but this occurred almost exclusively in vertical channels of softer silt-like soil. The main soil mass between these channels was extremely hard and brittle. It broke easily into small granules when disturbed, but had an extremely high resistance of vertical penetration *in situ*. For example, it was impossible to penetrate the soil with hand soil sampling tubes, even when the soil was moist.

Table 4 - Corn yield and nitrogen uptake - clayey Oxisol (Coto)

Treat. No.	Treatment kg/ha of N 1/	Yield of Grain (15%H_2O) kg/ha 2/	Yield of stover 3/ kg/ha 1/	Total plant N 1/ kg/ha 1/	Total N minus Check N kg/ha 1/	Recovery of fertilizer N 4/ percent
1	Check	1662 a	3036 a	43	-	-
2	34 preplant	2739 bc	3809 ab	60	17	50
3	67 preplant	3478 cd	4858 bc	75	32	48
4	134 preplant	4845 e	5492 c	111	68	51
5	34 postplant	2589 b	3578 ab	55	12	35
6	67 postplant	4062 d	2960 ab	77	34	51
7	134 postplant	5065 e	4764 bc	107	64	48
8	67 S.C.U. preplant	3081 d	4648 bc	72	29	43

Coefficient of variation of corn yield = 15.3%
Coefficient of variation of stover yield = 25.2%

1/ To convert to pounds per acre multiply by 0.89

2/ To convert to bushels per acre multiply by 0.016

3/ Stover N + Grain N + Cob N

4/ $\frac{\text{Total N minus Check N}}{\text{Fertilizer N applied}} \times 100$

5/ Numbers followed by the same letter are not significantly different at the 5% probability level

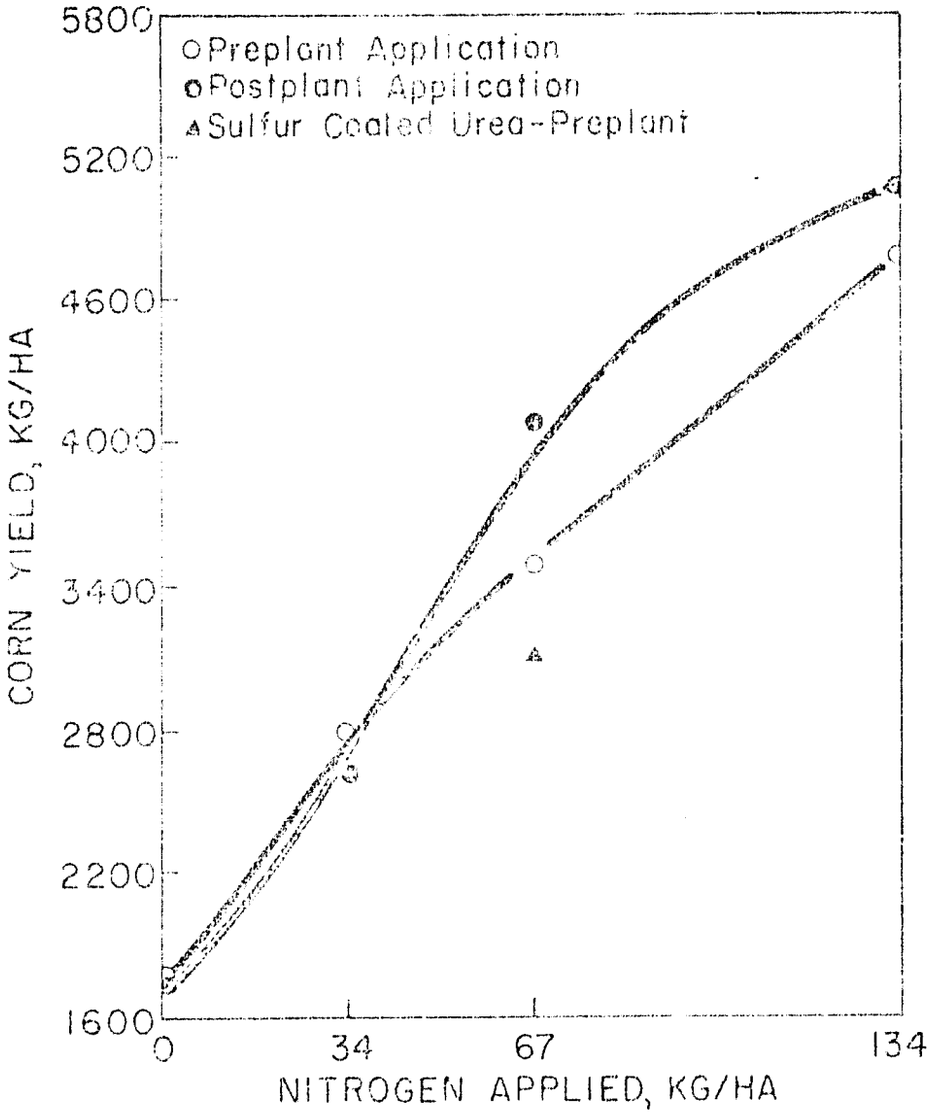


Figure 3. Effect of rate and time of fertilizer N on corn grain yield - Clayey Oxisol (Goto)

As mentioned earlier, it was decided to abandon this site after the first crop, as the soil properties were not judged to be representative of any extensive areas in the humid tropics in the Western Hemisphere

Greenhouse and Laboratory Studies on Nitrogen Supplying Power

Considerable effort has been expended in recent years to evaluate the N supplying power of temperate region soils. Incubation procedures as well as a number of chemical extraction procedures have been devised to measure the mineralizable soil N in these soils. Useful soil N availability indices have resulted from these studies. Little is known, however, about the N supplying power of tropical soils or the applicability of chemical extraction procedures to obtain a measure of the mineralizable N in these soils.

The studies reported here were made to evaluate the N supplying power of representative Oxisols and Ultisols of Puerto Rico as measured by continuous cropping in the greenhouse. Four crops were grown in sequence; corn, sorghum, corn, corn, except for Cialitos (3) and Cialitos (4) on which four crops of corn were grown. Various chemical extraction procedures were employed and the relation between the amounts of N extracted by these reagents, mineralizable N by incubation, and N removed by continuous cropping was measured. In addition, the effect of drying these soils upon subsequent N availability was tested in the greenhouse.

Procedures. Of the 10 soils used (Table 5) in this study collected during September and November, 1970, 9 were surface samples (0-20 cm) and 1 was a subsoil (10-30 cm). The soils were passed through a 10 mm screen, thoroughly mixed, and air-dried immediately. One subsample was used for a greenhouse study and

another was passed through a 2 mm screen and stored in polyethylene bags at room temperature for analysis by chemical and incubation methods. Details of the greenhouse procedures and laboratory methods are given in Appendix II.

Results and Discussion. All of the soil samples used in these experiments were collected from areas that were under cultivation although the samples of the Cialitos, Humazas, and Los Guineos were in pasture when they were collected. The area where the Nipe sample was collected apparently had not been cultivated to any extent in recent years. All of the samples were clay except for the Piñas which was a loamy sand.

As shown in Table 5 a wide range in soil pH existed which undoubtedly was a reflection of past treatment since all of these soils are moderately to strongly acid in the native state except possibly the Nipe. The soils differed widely in organic matter content and total N content although the subsoil sample of Cialitos (2S) was the only clay soil low in organic matter and total N. This sample was taken to provide a wider range in organic matter and total N in the clay soils.

The Nipe sample likely came from an area where some of the surface soil had been removed previously since samples from other locations have a higher organic matter and total N content than the sample used in these studies. The C/N ratio was not unusual in these soils and is fairly typical of soils found in other areas. The mean values for C and N content are very similar to the Iowa soils studied by Bremner.

These soils contained substantial quantities of inorganic N (Table 5) as extracted by 1.0 N KCl. The Catalina and Los Guineos samples contained

Table 5. Some Chemical Properties of Soils Used in Study of Nitrogen Supplying Power.

Soil		pH H_2O	pH 0.1 N KCl	Organic Matter %	Organic C %	Total N %	Inorganic N[2/] PPM
Pinas	- sandy Oxisol	4.1	4.1	1.4	0.71	0.072	25.5
Nipe	- clayey Oxisol	5.7	5.5	2.4	1.45	0.100	20.2
Catalina	- clayey Oxisol	5.4	5.2	4.7	2.92	0.280	90.5
Los Guineos	- clayey Ultisol	4.9	4.1	5.7	3.66	0.328	74.1
Humatas	- clayey Ultisol	4.9	4.0	4.7	2.50	0.220	52.2
Cialitos (1)	- clayey Ultisol	5.8	5.1	5.3	3.26	0.320	35.0
Cialitos (2)	- clayey Ultisol	6.4	5.8	5.9	3.26	0.335	30.9
Cialitos (2S)[1/]	- clayey Ultisol	6.2	5.7	1.8	1.01	0.127	23.0
Cialitos (3)	- clayey Ultisol	5.9	5.4	4.0	2.24	0.238	35.1
Cialitos (4)	- clayey Ultisol	5.0	4.2	3.1	1.67	0.196	27.3
Average				3.9	2.27	0.222	

1/ Subsoil of Cialitos (2)

2/ 1.0 N KCl extract. About equal amounts of NH_4^+ and NO_3^- were generally found.

particularly large quantities of inorganic N. These soils in general contained somewhat more inorganic N than those used by Bremner with the average being substantially higher. In addition about half of the inorganic N found in these soils was present as exchangeable NH_4^+ with little variation among soils being found. The content of inorganic N remaining in the soils after four consecutive crops was fairly high and again about half was present as exchangeable NH_4^+ and the other half as NO_3^-. In only three soils; Catalina, Humatas, and Los Guineous, was there a marked reduction in the inorganic N content of the soil as a result of cropping. Little effect of cropping on the inorganic N content of the other soils was apparent.

Whether the method of handling the samples influenced these results is not known. The samples were removed from the pots immediately after the fourth crop was harvested and air-dried and stored as before until the analyses were made. Most of the analyses were made within a few days of collecting and drying the samples. Analyses made at various times after collecting both the original samples and the after cropping samples gave essentially the same results so that storage apparently had little effect on the results. This agrees with the results of Bremner so that likely the inorganic N content of these soils after cropping represented the actual conditions of the soil.

The amount of N extracted by four crops from these soils (Table 6) varied widely among the soils. Differences in supply from the soil decreased with cropping until at the last crop relatively small differences among soils were found. Soils with the highest organic matter content supplied somewhat more N to the fourth crop than those with a lower organic matter content. Humatas was

an exception in that its ability to supply N fell rapidly to a rather constant and relatively low value.

The amounts of total N found in the soil extracts before cropping as measured by the four methods used are given in Table 7. The total extractable N varied widely from soil to soil and the differences persisted through the cropping period. Although the quantity of N removed by the four extractants varied, the values were strongly related to each other.

The relationship between total yield of and N uptake by the four crops and various methods of evaluating N availability are given in Table 8. All of the correlation coefficients shown in Table 8 are highly significant. Total N in the various soil extracts and N mineralized by incubation were particularly closely related to yield and N uptake by the four crops.

The dry matter produced and N uptake by a corn crop following a drying cycle after the fourth crop was higher than that found for crops grown just previous to the drying cycle. These results show that drying of these soils induces a release of soil N upon subsequent rewetting and cropping. Furthermore, the release of soil N can be measured under greenhouse conditions.

Conclusions

The results of these experiments reveal that these tropical soils can supply substantial quantities of N upon cropping. While the absolute quantities that may become available under field conditions cannot be deduced from these results significant portions of the total N requirements of all but the most demanding crops may be met by release from the soil supply. Furthermore, the data presented demonstrate that laboratory chemical methods as well as incubation procedures can provide means for evaluating the ability of these tropical soils to supply nitrogen.

Table 6. Yields of Four Crops, Total N Uptake by Four Crops, and the Quantity of N mineralized by Incubation.

Soil	Yield Dry Matter Total 4 Crops g/pot	N Uptake 4 Crops mg/kg Soil	N Mineralized 4 wks.	8 wks.	16 wks.
			ppm		
Piñas	7.7	55	15.0	16.1	36.0
Nipe	7.1	42	15.6	20.5	45.6
Catalina	13.4	142	84.2	95.3	135.6
Los Guineos	17.0	229	188.1	193.4	259.8
Humatas	10.9	81	58.2	68.5	117.7
Cialitos (C)	14.7	143	99.0	117.5	172.2
Cialitos (U)	11.4	117	121.3	148.6	178.7
Cialitos (US)	5.2	41	6.5	10.8	28.9
Cialitos (uP1)	6.9	53	22.2	32.0	48.2
Cialitos (uP2)	7.6	59	42.4	52.6	79.3

Table 7. Total NH_4^+ -N contained in soil extracts before cropping *

Soil	NH_4^+ -N, ppm			
	1 N KCl	1 N K_2SO_4	0.01M $CaCl_2$	0.05N Na-P
Piñas	28.3	47.6	60.6	66.2
Nipe	20.5	37.9	59.1	43.6
Catalina	81.0	131.6	137.1	122.0
Los Guineos	94.8	146.6	176.7	116.6
Humatas	42.5	70.5	106.7	70.3
Cialitos (C)	52.5	84.0	113.2	93.3
Cialitos (V)	63.4	95.5	149.5	106.5
Cialitos (VS)	34.7	55.1	53.4	43.8
Cialitos (MP1)	40.2	62.8	80.2	69.5
Cialitos (MP2)	51.5	79.0	74.6	62.8

* Includes exchangeable NH_4^+ and organic N removed by extractants.

Table 8. Correlations found Between Yield and N Uptake and Various Procedures for Measuring N Availability.

Variable Correlated	Correlation Coefficients (r) Total Yield Without N	Total N Uptake, mg/kg Soil
Soil organic matter	0.82	0.77
Total Soil N	0.80	0.79
Soil inorganic N	0.70	0.73
Total N found in Soil Extract:		
(a) KCl	0.82	0.90
(b) K_2SO_4	0.84	0.91
(c) $CaCl_2$	0.90	0.92
(d) Na-P	0.87	0.87
Mineralizable N:		
(a) 4 weeks	0.92	0.96
(b) 8 weeks	0.91	0.94
(c) 16 weeks	0.95	0.95

SOIL ACIDITY INVESTIGATIONS

Laboratory and Greenhouse Studies

The objective of these studies is to define the interrelationships in representative Oxisols and Ultisols between soluble and exchangeable aluminum, soluble and exchangeable calcium and other bases, and pH as related to plant root growth. A better understanding of these relationships should provide a more adequate basis for the optimum use of liming materials.

Research on Ultisols in the Southeastern United States has indicated that the percentage saturation of aluminum in the cation exchange sites in soils is related to the pH of the soil and to plant growth. Different crops vary in their tolerance to the percentage saturation of aluminum in soils; for example, cotton is rather sensitive and root growth may be restricted if the saturation of aluminum is more than 10 percent, while corn will tolerate up to 40 percent or more of aluminum saturation. Though the percentage saturation of aluminum has been a useful measure for estimating the lime requirement of acid soils, it is frequently not reliable under different soil conditions. More recent work has indicated that the amount of aluminum in the soil solution is a more reliable measure for predicting plant root growth. To test this approach, experiments have been carried out to determine the relationships between displaced soil solution composition and plant root growth on representative Oxisols and Ultisols.

1. Relationships between the composition of soil solutions displaced from a clayey Oxisol (Coto) and a clayey Ultisol (Humatas) and root behavior of corn and sorghum.

Lime requirement curves were determined for both soils and three pH levels were established for each soil. Displaced soil solutions were obtained and their composition determined.

Three hundred and fifty grams of each of the treated, moist soils were put into a number two tin can (previously lined with a plastic bag) taking care to avoid compaction of the moist soil. A saran mesh disc having the same diameter as the can was laid on top of the soil. Thirty grams of a potting mixture composed of a filter press cake and a sandy loam was put on top of the saran mesh to serve as germinating medium.

Corn (Pioneer 304) and sorghum (RS671) were used as test crops. The rate of seeding per plot was five seeds for corn and nine for sorghum. Each treatment was replicated four times.

After 34 days, the plants were allowed to wilt in order that the soil be depleted of moisture so as to make the retrieval of roots easier. The soil root mass was taken out of the can by pulling the plastic bag. All the roots growing outside the soil mass, i.e. between the plastic bag and the soil surfaces, were trimmed off and discarded while those growing into the soil mass were picked, dried, cleaned of loose soil particles, and weighed.

The data on root weights at the different pH and soil solution aluminum levels are given in Table 9. The most striking feature of these data is the large decrease in aluminum in the soil solution as the pH is raised from about 4.0 to 4.5 with the concomitant increase in root growth especially in the case of corn. Also, as has been reported by others, sorghum roots are less tolerant of soluble aluminum in soils than corn.

2. Effect of salt concentration on pH and soil solution aluminum.

To explore further the relationship between the concentration of aluminum in the soil solution and pH as affected by the amount of salt present, a clayey Ultisol (Humatas) was given various treatments. These are shown in

Table 9. Oven Dry Weight of Roots of Corn and Sorghum at Different pH and Soil Solution Aluminum Levels.

Soil	pH	Al in Soil Solution ppm	Corn mg/pot	Sorghum mg/pot
Clayey Ultisol (Humatas)	3.95	9.3	209	19
	4.45	0.7	874	296
	4.75	0.4	931	400
Clayey Oxisol (Coto)	4.05	2.8	389	128
	4.45	0.8	630	126
	4.75	0.1	687	344

Table 10 with the results obtained.

The outstanding feature of these data is the large increase in the concentration of aluminum in the soil solution and only a small decrease in pH with the addition of a relatively small amount of KCl. There was also an increase in Ca and Mg in the soil solution. If root growth is related to the concentration of aluminum in the soil solution, one would expect that the large increase in aluminum as a result of the salt additions would be very harmful. However, recent chemical and root growth studies at Cornell on an Oxisol from the Llanos of Colombia indicate that the toxic effects of aluminum on root growth are not governed solely by the concentration of aluminum in the soil solution but that the calcium present in solution may play an important role in counteracting the toxic effects of the aluminum. Preliminary tests with Oxisols and Ultisols from Puerto Rico indicate that these soils may act similarly.

As a result of these studies, it is postulated that reduced root growth is the result of lack of calcium at the growing root tip. The inability of the meristematic cells to avail themselves of enough calcium may be caused by a barrier zone in which ion activities are regulated by exchange phenomena. Consequently, if the calcium level is very low in the soil solution in comparison with aluminum plus other ions, root growth will be severely restricted. But, if there is an adequate supply of calcium in solution, root growth will be normal even though substantial amounts of aluminum and other ions are present in the soil solution. However, much more additional experimental work in the laboratory, greenhouse, and field will be required on a wider range of acid Ultisols and Oxisols to verify this hypothesis.

Table 10.- Soil pH, exchangeable cations and displaced soil solution composition of a clayey Oxisol (Humatas) treated with various amounts of $Ca(OH)_2$ and KCl.

Treat. No.	Description	Soil pH	Exchangeable Cations			Displaced soil solution		
			Al meq/100g	Ca + Mg meq/100g	Mn meq/100g	Al ppm	Ca + Mg meq/liter	Mn ppm
1	Control	4.18	8.9	1.08	nil	3.8	2.02	nil
2	0.50 meq $Ca(OH)_2$/100g	4.20	10.2	1.46	nil	5.0	2.68	nil
3	1.00 meq $Ca(OH)_2$/100g	4.28	8.0	1.89	nil	3.2	3.46	nil
4	1.25 meq $Ca(OH)_2$/100g	4.30	9.3	2.29	nil	2.0	3.55	nil
5	Treatment 2 + 0.5 meq KCl/100g	4.01	9.3	1.36	nil	16.9	5.86	nil
6	Treatment 3 + 0.5 meq KCl/100g	4.07	10.2	1.89	nil	12.8	7.42	nil
7	Treatment 4 + 0.5 meq KCl/100g	4.11	7.4	2.22	nil	15.0	7.95	nil
8	1.75 meq $Ca(OH)_2$ + 1.0 meq KCl/100g	4.08	8.2	2.70	nil	21.7	12.45	nil

As there are extensive areas of Oxisols and Ultisols in the tropics with very low calcium contents, these studies have important implications for the management of these soils especially with regard to liming and fertilizer practices. As calcium is usually the predominant base in most of these soils, a better understanding of the interrelationship between aluminum and calcium in the soil solution and on the exchange sites as related to plant root growth is essential. Preliminary tests have shown that the ratio $\frac{\sqrt{Ca^{++}}}{\sqrt[3]{Al^{+++}}}$ in the soil solution is equal to a constant times $\frac{\sqrt{Ca^{++}}}{\sqrt[3]{Al^{+++}}}$ in the exchangeable form and that plant root growth is a function of $\frac{\sqrt{Ca^{++}}}{\sqrt[3]{Al^{+++}}}$ in the soil solution. Confirmation of this relationship in field experiments should lead to the development of simple laboratory procedures for predicting more accurately the most economic amounts of lime to use to obtain desired crop responses on a wide range of acid soils in the tropics.

3. Aluminum and Manganese Interaction.

The purpose of this experiment was to determine if there exists an interaction between aluminum and manganese which could influence the effects of the former upon root growth. A bulk sample of a clayey Ultisol (Los Guineos) was collected from the site of one of the field experiments on liming. Some chemical properties of this soil are given in Table 11.

Preliminary treatment of the soil was done to determine the amount of $MnCl_2$ to be added to achieve a definite concentration of Mn^{++} ion in the displaced soil solution. Five soil treatments were established (Table 12). The treated soil was put into number 10 tin cans previously lined with plastic bags; each can contained 2,250 grams of soil at field capacity. Each treatment was replicated four times. The pots were planted to tomatoes and kept in a

Table 11. Some chemical characteristics of Los Guineos clay (clayey Ultisol)

Soil pH 1:2 soil to water	4.25
Moisture at 1/3 bar	44.6 percent
Organic Matter	9.2 percent
Exchangeable	
Ca	2.24 meq/100g
Mg	1.19 meq/100g
Al	6.8 meq/100 g
Displaced soil solution	
Ca	128 ppm
Mg	26 ppm
Al	2.8 ppm
Mn	0 ppm
K	72 ppm

Table 12.- Displaced soil solution composition, exchangeable cations, and soil pH of a clayey Ultisol (Los Guineos) treated with varying amounts of $MnCl_2$, and yield of corn roots.

Treatment Number	Displaced soil solution composition				Exchangeable Cations				Soil pH	Corn roots g/pot
	Mn ppm	Al ppm	Ca ppm	Mg ppm	K meq/100g	Al meq/100g	Ca meq/100g	Mg meq/100g		
1	0	2.8	128	26	72	6.8	2.24	1.19	4.25	1.76
2	10	2.2	128	26	72	6.8	2.31	1.42	4.25	2.01
3	20	4.0	140	26	80	6.5	2.23	1.08	4.25	1.87
4	41	4.3	161	51	80	7.2	2.31	1.72	4.18	1.80
5	60	3.5	167	56	88	6.8	2.31	1.94	4.10	1.94

greenhouse; however, the plants did not fare well and appeared to suffer from lack of light. After three weeks growth, they were discarded and the pots were planted to corn, which was allowed to grow for a month. All the roots growing in the soil mass were recovered, dried, cleaned, and weighed. From the appearance of the corn plants and from the yield of roots there seems to be no interaction between manganese and aluminum on corn roots in this soil at the levels tested.

Field Experiments on Liming

Field trials were established at several of the Oxisol and Ultisol sites to test the response of corn and green beans to different levels of lime. Five levels of $Ca(OH)^2$ were used: check, 336 kg/ha, and enough $Ca(OH)^2$ calculated to bring the surface soil pH to 5.5, 6.0, and 7.0. A basic fertilizer treatment was applied to all plots.

1. Sandy Oxisol (Pinos). Pioneer 3-306 corn was planted August, 1970 and harvested in December, 1970. The yield of corn was relatively low in this experiment because of several uncontrollable factors but there was a significant response to liming as indicated in Table 13.

It is apparent that on this soil the lowest level of lime was as effective as the higher levels. As this soil is very low in calcium and in soluble aluminum and manganese it appears that the primary benefit of liming was to supply calcium to the plant.

2. Clayey Oxisol (Catalina). A liming experiment with corn at this site with the same treatments as the previous experiment showed no differences in yield between treatments. All of the plots were affected by the southern leaf blight before the cobs were fully developed and consequently the grain

was soft and fluffy and the yields were low, averaging about 1600 kg/ha. Before the blight struck, the corn was growing vigorously on all plots and there were no observable differences between treatments. Though the pH is about 5 on this soil, it is very low in aluminum and manganese and has a relatively high level of exchangeable calcium, about 4 meq/100 g. It is not surprising, therefore, that there was no indication of a liming response on this soil even though it is quite acid.

Table 13. Corn yield and soil pH in response to lime levels on a sandy Oxisol (Pinas).

Treatment	Yield kg/ha	pH 0-15 cm	pH 15-30 cm
Check	728	5.15	5.14
$Ca(OH)_2$ - 336 kg/ha	1848	5.48	5.02
$Ca(OH)_2$ to pH 5.5	1803	5.41	5.10
$Ca(OH)_2$ to pH 6.0	1949	5.52	5.22
$Ca(OH)_2$ to pH 7.0	1915	6.02	5.48

3. Clayey Ultisol (Los Guineos). (a) Corn - A liming experiment with corn similar to the above showed striking responses to the different levels of lime. Unfortunately, the crop was destroyed by cattle about two weeks before harvest and no yield records were obtained. This soil is very acid, pH 4.5, and has a relatively high content of exchangeable aluminum. Striking responses to lime would be expected on this soil and it is planned to repeat the liming trial with corn at this site.

(b) Green beans - The same liming treatments were used on green beans (Bountiful variety) with some rather striking results as shown in Table 14.

The surprising feature of these data is the high yield of the check plots in spite of the low pH of the soil, about 4.5 in the surface 15 cm. There was a significant response to the higher liming levels with a very high yield of almost 16 tons of green beans per hectare at the highest lime level.

Similar trials at two other sites of clayey Ultisols gave comparable results. Though the yields were not as high, they were quite respectable, about 10 tons per hectare for the high lime treatments.

PHOSPHORUS EXPERIMENTS

The objectives of the phosphorus experiments are:

(1) Define the response curves for applied P fertilizers on representative Oxisols and Ultisols.

(2) Measure the relative efficiency of banded P fertilizer versus broadcast.

(3) Estimate the residual effects of the broadcast and banded P fertilizers.

Field experiments to meet these objectives were originally planned for two sites; one on an Oxisol and one on an Ultisol. However, circumstances were such

Table 14. Yield of green beans (Bountiful) with different levels of lime on a clayey Ultisol (Los Guineos).

Treatment	Yield of Beans kg/ha
Check	11,700
$Ca(OH)_2$ - 300 kg/ha	10,500
$Ca(OH)_2$ - to pH 5.5	14,200
$Ca(OH)_2$ - to pH 6.0	14,300
$Ca(OH)_2$ - to pH 7.0	15,800

that it was not feasible to initiate the field work at the Oxisol site this year. The clayey Ultisol site was chosen after considerable field checking, and greenhous and laboratory assays. The soil had a relatively low level of available P and a greenhouse test with beans as an indicator crop showed a definite response to applied P.

Sorghum was used as the test crop in the field trials. The 10 treatments used were as follows:

Treatment No.	Broadcast P (first year)	Banded P (each year)
	kg/ha	
1	0	0
2	90	0
3	180	0
4	360	0
5	1120	0
6	360	22
7	34	22
8	--	45
9	--	90
10	--	180

The plot size was 4.5 by 9 meters. A blanket application of lime and fertilizer other than phosphorus was applied to all plots. The sorghum was planted in November, 1970 and harvested in April, 1971.

Only moderate yields were obtained; the average for all plots was about 2728 kg/ha of grain and there were no significant differences between treatments.

Apparently, there was enough residual P in the soil in the check plots to satisfy the requirements for the yield of sorghum obtained; yet a response was obtained with beans to applied P in the greenhouse test.

There was some question about whether to continue the phosphorus trials on this site. It was decided to follow the sorghum with corn to determine if there would be a response of the latter to the different levels of P. Meanwhile, another clayey Ultisol site has been selected which appears to be more favorable for the phosphorus experiments and field work has been initiated at this site.

In order to get information on a wider range of soils to P response and its residual availability, it is planned to start a series of tests in bottomless steel drums sunk in the ground at a convenient location. Surface and subsoils from representative sites will be hauled in and placed in the drums. Corn will be used as the test crop for rates and method of application of P and interaction with different lime levels.

CLAY MINERALOGY STUDIES

The objective of these studies is to characterize the clay minerals in the soils of the field experimental sites in order to aid in the interpretation of the responses to applied nutrients. This will provide a sounder basis for extrapolating the experimental results to similar soils in other areas. To date, the mineralogical characterization has been completed on five soils: one sandy Oxisol (Pinas), two clayey Oxisols (Catalina and Coto), and two clayey Ultisols (Humatas and Los Guineos).

The qualitative mineralogy of the sand (2000-50μ) fractions on an iron free basis were determined by X-ray diffraction. Weatherable minerals that would furnish a reserve of bases were not detected. The sand fractions were dominated by quartz except in the lower depths of the clayey Ultisol (Los Guineos) where gibbsite was present in addition to quartz. The silt fractions were composed predominantly of quartz, kaolinite, and gibbsite. A decrease of kaolinite and gibbsite and a concomitant relative increase of quartz in the silt fraction the closer to the surface would indicate a weathering breakdown of silt-sized kaolinite and gibbsite particles.

The clay fraction of each of the five soils were generally homogeneous in mineralogical composition with depth. X-ray diffraction, differential thermal, and chemical analysis showed that kaolinite, amorphous material, and chlorite (2:1 - 2:2 intergrade) made up the greater portion of the clay fractions with lesser amounts of mica, vermiculite, and gibbsite constituting the rest of the clay fractions (Figures 4 to 8).

X-ray diffraction and differential thermal analysis indicate that the kaolinite in these soil clay fractions is moderately to poorly crystalline. The amorphous material determined by a boiling alkali extraction has SiO_2 to Al_2O_3 molar ratios of approximately two and is probably a weathering residue of kaolinite. The amorphous material in these soil clay fractions contributes little to the cation exchange capacity of the clay fractions as removal of the amorphous material made little change in the values of the cation exchange capacity.

Chemical treatments designed to extract the interlayer hydroxy polymers of the chlorite component of 2:1 - 2:2 intergrade indicate that a significant amount of hydroxy polymers of iron were present in the interlayer spaces in addition to

those of aluminum. Mica, vermiculite, and chlorite are given in Figures 4 to 8 as separate entities, but the listed values should be interpreted as equivalents of the respective clay minerals, as X-ray diffraction results indicate that the three clay minerals occur as a randomly interstratified species.

The absence of greater amounts of gibbsite in the clay fractions of these soils is probably a result of the presence of quartz in the coarser fractions which can support a solution activity of $Si(OH)_4$ that prevents de-silication of kaolinite to form gibbsite and/or the preferential precipitation of aluminum in hydroxy polymeric form in the K-depleted interlayer spaces of weathered mica (vermiculite) to form a chlorite-like mineral (2:1 - 2:2 intergrade).

The research to date has given a fairly comprehensive view of the nature of the clay-sized minerals in these Puerto Rican Oxisols and Ultisols. Future research will be directed toward relating the mineral composition of the clays to the properties of the soil as a whole in their natural state. In particular, the electrochemical properties of the soils will be investigated to determine the distribution of positive and negative charges as a function of pH and salt concentration. Also, these studies will be extended to similar soils in other tropical areas. Efforts will be made to correlate the results of this research with data obtained by other investigators who have been doing similar work on soils of the tropics.

Figure 4. Composition of Catalina soil profile clay fractions (clayey Oxisol)

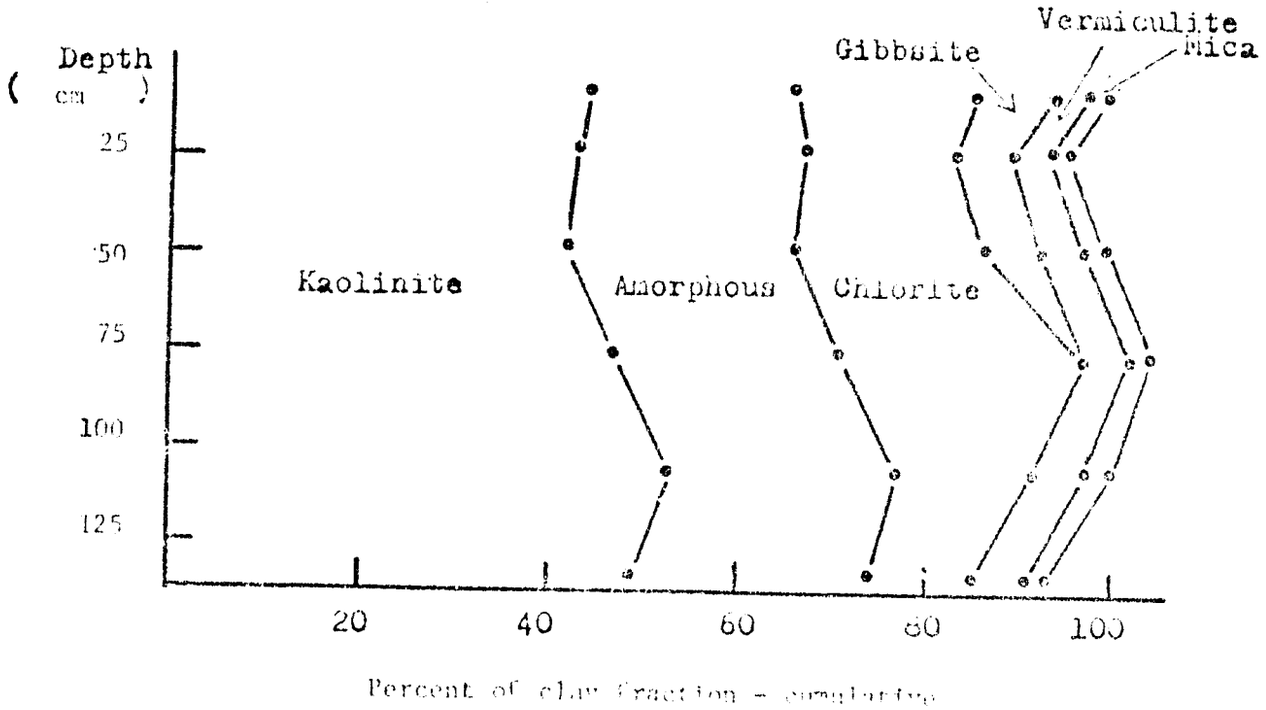


Figure 5. Composition of Buratas soil profile clay fractions (clayey Ultisol)

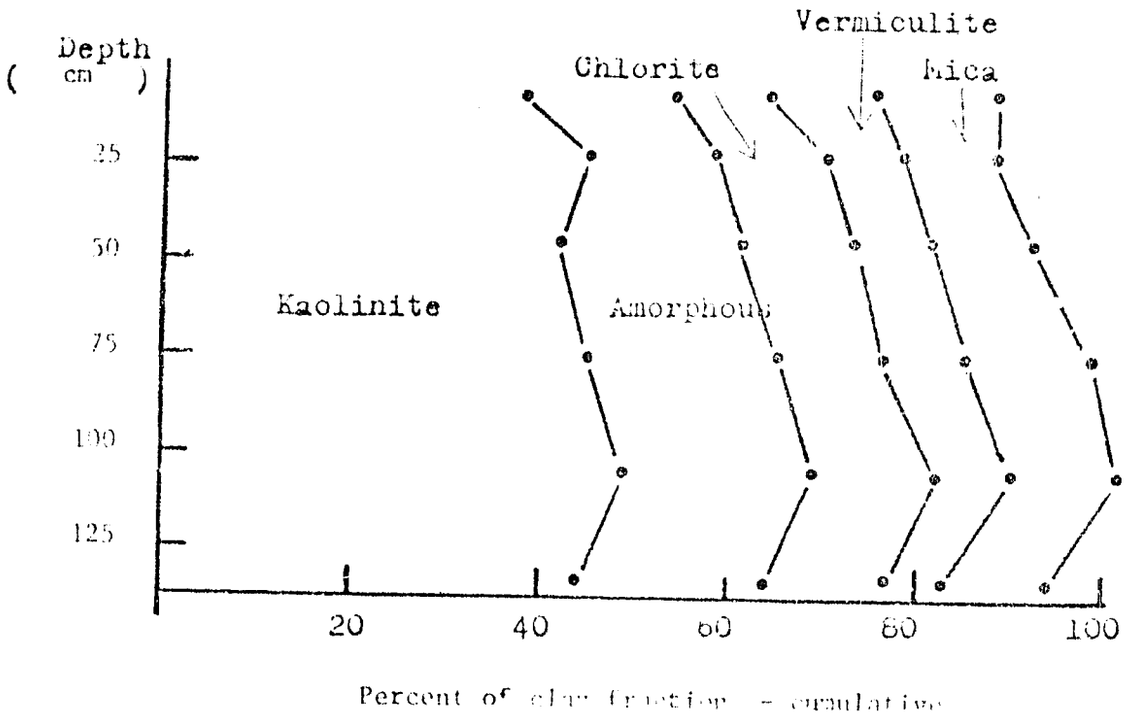


Figure 6. Composition of Coto soil profile clay fractions (clayey Oxisol)

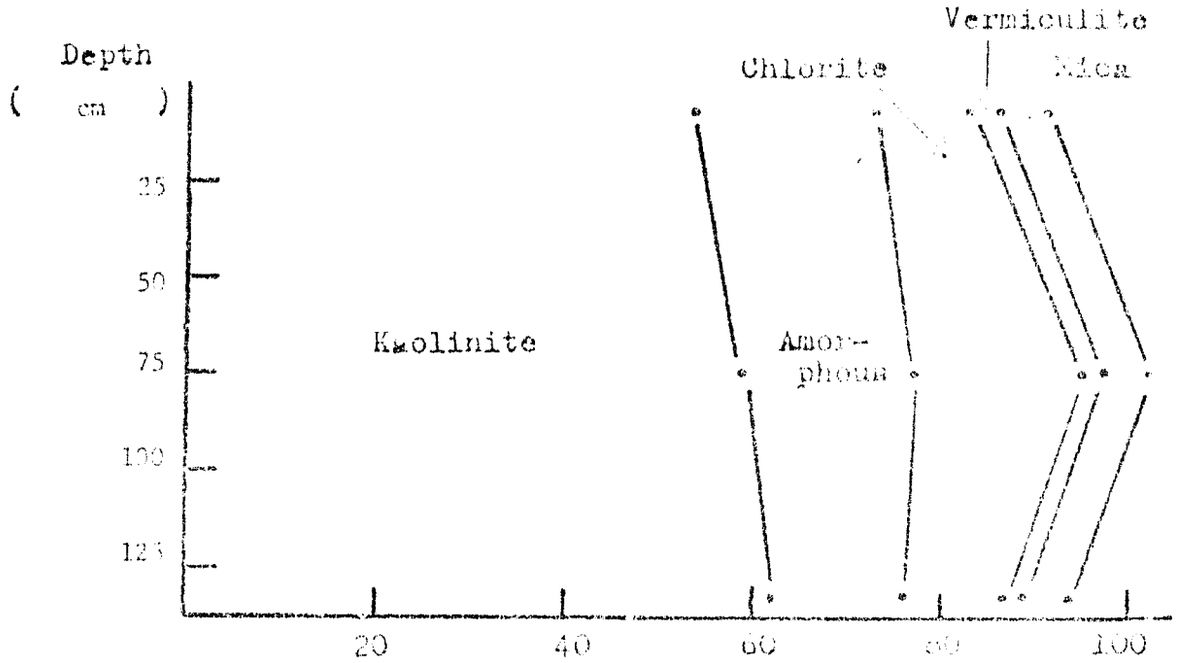


Figure 7. Composition of Ticoca soil profile clay fractions (Gibbsite Oxisol)

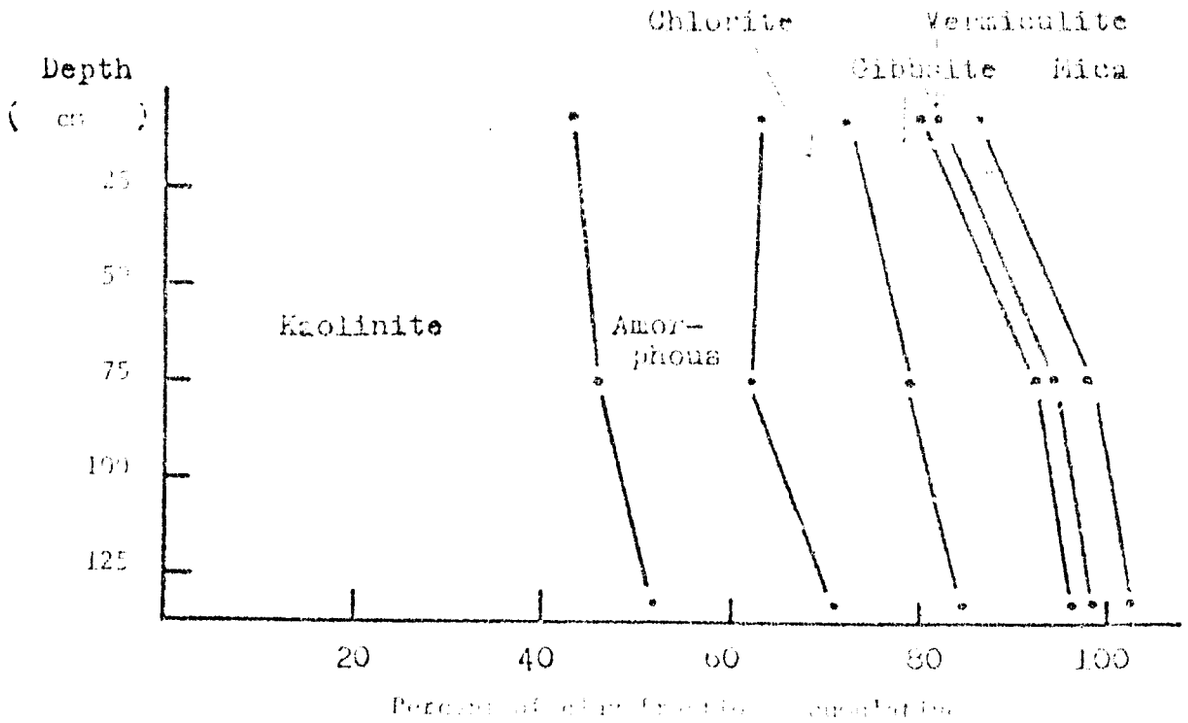
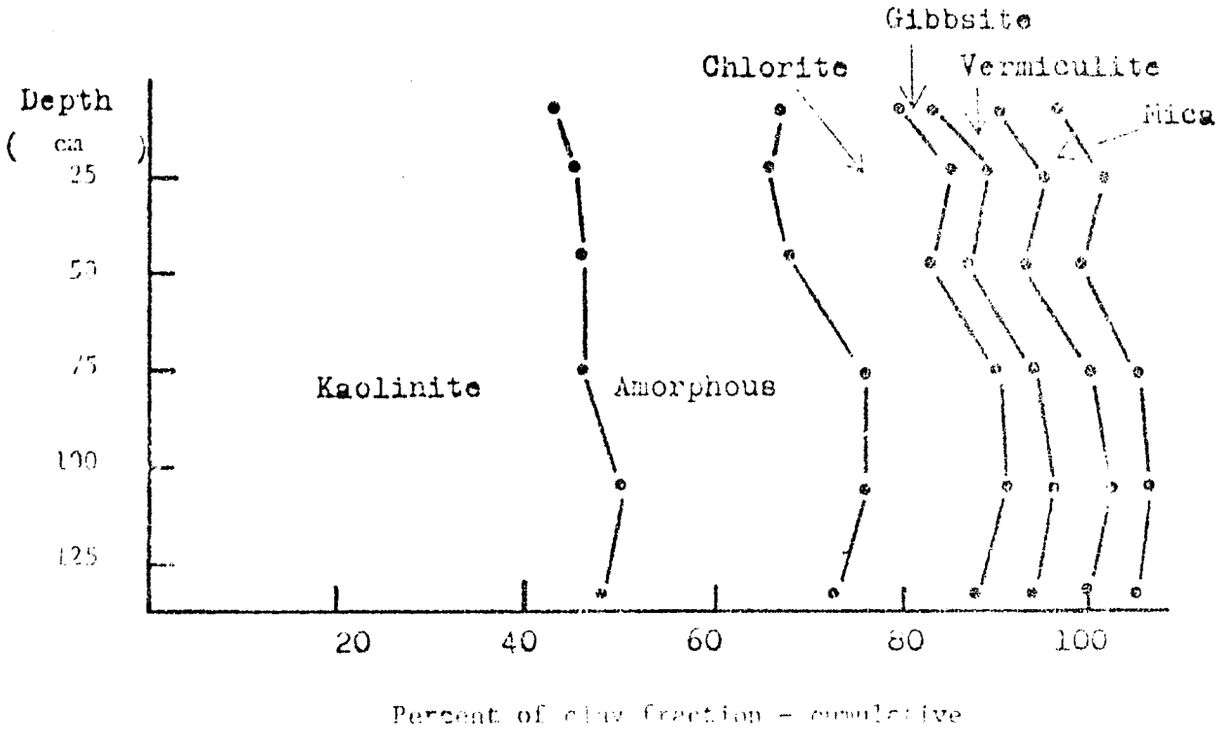


Figure 8. Composition of Los Guineos soil profile clay fractions (clayey Ultisol)



SOIL-WATER EXPERIMENTS

In order to interpret more adequately the results of the soil fertility experiments in relation to the climatic environment, it was decided to obtain measurements at the soil fertility experimental sites on the rate of infiltration of water into the soil, rate of movement through the soil, and water retention at different tensions. Tests were initiated in June, 1971 at four sites, two clayey Ultisols (Humatas and Torres), a sandy Oxisol (Olmos), and a clayey Oxisol (Catalina). At each site, plots of 3 x 3 meters were selected adjacent to the soil fertility experimental plots.

The plots were instrumented with tensiometers at depths of 7.5, 30, 60, 90, and 120 cm. The plots were flooded with water and covered with plastic to prevent evaporation. Water movement was monitored with the tensiometers for up to 35 days. Two 1.5 meter deep pits were dug adjacent to the plots and soil samples collected at 15 cm intervals. Two undisturbed soil cores were taken at 30 cm depths down to 120 cm.

Preliminary findings are as follows:

1. Infiltration. The initial infiltration rate was very rapid at all four sites regardless of soil texture. Considerable lateral movement in the subsoil was observed in the clayey soils as indicated by the water flow into the pits adjacent to the plots.

2. Water retention. After two or three days of free drainage, the moisture tension was in the range of 1/50 to 1/12 bar. This finding is significant in that it indicates that much more water is held in the soil at "field capacity" than is calculated conventionally. Usually, the water held in the soil between tensions of 1/3 and 15 bars is used as a measure of "available" water although

in some cases 1/10 bar is used for the lower tension limit. If indeed, subsequent analyses should confirm that for the soil studied, the lower tension limit for field capacity should be in the range of 1/50 to 1/12 bar, this would increase substantially and in some cases, double the calculated values for "available" water.

COMPLEMENTARY STUDIES IN OTHER LATIN AMERICAN COUNTRIES

1. In cooperation with the International Center of Tropical Agriculture (CIAT) and the Colombian Agricultural Institute (ICA), a field study is being conducted on liming in relation to aluminum toxicity and plant root growth on the acid soils in the Llanos of Colombia. Corn and sorghum are the test crops. This work is a follow up of preliminary laboratory and greenhouse studies conducted at Ithaca the previous year. Preliminary results indicate that the calcium present in the soil solution may play an important role in counteracting the toxic effects of soluble aluminum. This study has important implications for the management of the highly acid soils especially with regard to efficient liming and fertilizer practices.

2. Field trials are being conducted in the Llanos of Colombia to test methods for the control of a physiological disease of rice called "yellowing" or "bronzing." It is generally agreed that the trouble is related to some unfavorable condition in the soil and has caused a serious reduction in rice yields in many fields in the Llanos. This work is also being done in cooperation with CIAT and ICA. Previous laboratory and greenhouse work on the problem in Ithaca has provided some leads which are

being tested in the field. Preliminary findings indicate that the problem is related to inactivation of the roots by iron oxide coatings which reduces greatly the needed oxygen supply to the surficial roots.

3. A cooperative soil fertility research project proposal has been developed for work on the highly acid soils of the Campos Cerrados in the central plateau of Brazil. This project involves the collaboration of Cornell and North Carolina State Universities with the Brazilian Ministry of Agriculture and will be centered at an experiment station about 40 km northeast of Brasilia. The research will follow up the previous experimental work done at the station and involve studies on the efficient utilization of nitrogen, phosphorus, potassium, lime, and micronutrients by food crops.

RESEARCH UTILIZATION

1. A paper on the soil acidity studies was presented at the Annual Meetings of the Southern Agricultural Wrokers Association in Jacksonville, Florida on February 3-7, 1971. It is being submitted for publication in the Soil Science Society of America Proceedings.

2. A Ph.D. thesis has been accepted at Cornell which deals with aluminum toxicity in the highly weathered soils of the tropics and involves studies on the acid soils of Puerto Rico and Colombia. A manuscript based on these studies is being prepared for publication in one of the Soil Science journals.

3. Some of the more significant results of the nitrogen studies during the past year are now being compiled and written up for submission

to appropriate journals for publication. A paper on one aspect of the soil nitrogen research supported by other funds but directly related to the objectives of the project has been published in the Soil Science Society of America Proceedings. It deals with non symbiotic nitrogen fixation in tropical soils. About 150 reprints have been distributed to soil scientists around the world. As part of this research, a literature survey and evaluation of sources of nitrogen in soils of the tropics has been made and a mimeographed publication prepared for distribution to interested scientists. About 50 copies have been distributed to scientists from some 12 countries.

4. A conference was held in Raleigh, North Carolina in November, 1970 with representatives of U. S. institutions involved in soil fertility/soil management research in the humid tropics. The following institutions were represented in addition to Cornell: North Carolina State University; University of Puerto Rico; Tennessee Valley Authority; University of Hawaii; Prairie View A and M College; Agency for International Development; and the U. S. Department of Agriculture. At this meeting, plans were developed for coordination of the tropical soils research programs of the different institutions and the related teaching and training activities.

WORK PLAN FOR 1971-1972

NITROGEN EXPERIMENTS

The field experiments will be continued at the four sites in Puerto Rico for another year with corn as the test crop. Periodic soil sampling will be continued to gain additional information on the efficient utilization of applied nitrogen as affected by rate and method of application. Further work will be done on the amount of nitrogen mineralized from soil organic matter and crop residues. The work done during the past year indicated the feasibility of developing a simple chemical method for estimating the soil nitrogen supplying capacity during the cropping season and this will be tested further.

SOIL ACIDITY EXPERIMENTS

The relationship between extractable aluminum and exchangeable calcium and other cations in relation to plant growth and crop production will require additional study. Field experiments with corn, sorghum and legumes will be continued in Puerto Rico supplemented by laboratory and greenhouse studies. Some of the completed studies will be written up for publication. The data obtained in the field trials in the Llanos of Colombia and supplementary laboratory work will be analyzed and prepared for publication. A study will be initiated on the influence of organic matter on aluminum toxicity.

PHOSPHORUS STUDIES

The field experiment at the clayey Ultisol site will be continued with corn as the test crop and another one established at another location which appears to be more favorable for the phosphorus experiments. In order to get information on a wider range of soils on response to applied phosphorus

fertilizer a series of tests will be initiated in bottomless steel drums sunk in the ground at a convenient location. Surface and subsoils from representative soils will be hauled in and placed in the drums. Corn will be used as the test crop for rates and method of applied phosphorus and its interaction with different lime levels.

CLAY MINERALOGY STUDIES

The next stage of this research will be directed toward relating the mineral composition of clays to the properties of the soil as a whole in their natural state. The electrochemical properties of the soils will be investigated to determine the distribution of positive and negative charges as a function of pH and salt concentration. Comparative mineralogical studies will be made on highly leached acid soils from the eastern plains of Colombia and the "Campos Cerrado" of the central plateau in Brazil.

POTASSIUM STUDIES

There is increasing evidence that potassium may be a more limiting factor on many of the acid soils in the humid tropics than has previously been thought. Consequently a field experiment on a representative soil low in potassium will be initiated to determine the response to applied potassium with different rates and methods of application. Corn followed by soybeans will be the test crops.

CAMPO CERRADO SOIL STUDIES IN BRAZIL

It is planned to initiate field, greenhouse, and laboratory soil fertility research at the experiment station near Brasilia. This will be in collaboration with the Ministry of Agriculture and North Carolina State University. A project

proposal has been agreed to by all parties concerned and implementation of the research is planned for the coming year. The priority areas for the suggested research may include (1) methods of economically supplying the nitrogen requirements of important food crops, (2) methods of economically correcting soil acidity as a factor limiting crop production, (3) methods of economically supplying phosphorus for sustained crop production, (4) correlation of yields with soil properties and climates so as to provide a sound basis for application of the experimental results to other areas in the humid tropics, and (5) determination of micronutrient deficiencies through observation, soil analysis, plant analysis, and plant yield response experiments. It is planned to provide a full time soil fertility specialist to be stationed in Brasilia to collaborate with the Brazilian soil scientists in the implementation of the project. Short term consultants and technical backstopping will be provided by Cornell and North Carolina senior soil scientists.

PERSONNEL

Professional personnel with full or part time involvement in the project during the year are:

Cornell Staff

Dr. Matthew Drosdoff - Professor of Soil Science, Project Director

Dr. Richard H. Fox - Assistant Professor of Soil Science, Director of Operations in Puerto Rico.

Dr. Robert M. Weaver - Assistant Professor of Soil Science

Dr. David R. Bouldin - Professor of Soil Science

Dr. Douglas J. Lathwell - Professor of Soil Science

Puerto Rico Staff

Mr. Jose Vicente-Chandler- Director, Puerto Rico Agricultural Experiment Station.

Dr. Raul Perez - Associate Soil Scientist

Dr. Fredrick Beinroth - Assistant Soil Scientist

Dr. Eduardo Brenes - Associate Soil Scientist

Dr. Hari Dubey - Associate Soil Scientist

Dr. Socorro Gaztambide - Assistant Chemist

Mr. Jaime Jordan - Assistant Agronomist

Mr. Juan Juarez - Soil Scientist

U.S. Department of Agriculture Staff

Dr. Robert W. Pearson - Soil Scientist

Mr. Fernando Abruna - Soil Scientist

APPENDIX I

DETAILS OF PROCEDURES FOR THE NITROGEN FIELD EXPERIMENTS

The spring planting of corn in 1970 was planted by hand in 75 cm rows at a density of 87,000 seeds per hectare and thinned to 43,500 plants per hectare. The sorghum was planted in 50 cm rows by machine at a density of approximately 11 kg/ha of seed. The 1971 spring corn was planted in 75 cm rows by machine at a density of 48,800 seeds/ha. Missing plants in the center four rows were replanted by hand.

A blanket application of 112 kg/ha of K_2O, as K_2SO_4, 224 kg/ha P_2O_5 and 56 kg/ha of Mg were plowed in before planting. All sites were limed to pH 5.5 to 6.0 with $Ca(OH)_2$. The quantities of lime applied were equivalent to 7.5 tons/ha of $CaCO_3$ for the clayey Ultisol (Humatas) and 5 tons/ha for the clayey Oxisol (Catalina) and sandy Oxisol (Piña) soils. Additional $Ca(OH)_2$, equivalent to 3,800 kg/ha of $CaCO_3$, was applied to the clayey Ultisol before the fall sorghum planting. The blanket fertilizer application remained the same for the other two plantings except that 17 kg/ha of $ZnSO_4 \cdot 7H_2O$ was added to the Piña soil after Zn deficiency was observed in the first crop, and the rate of K_2O was increased to 170 kg/ha for the spring 1971 crop at all sites. A starter fertilizer was applied to all crops at the rate of 11 kg/ha each of N, K_2O, and P_2O_5. This was banded 5 cm below and to the side of the seed.

To control soil insects the soil was treated with Aldrin for the first crop, Di-syston for the second, and Parathion for the third. The soils were tested for the presence of nematodes and D-D was applied at the sandy Oxisol site to control the high population encountered there. The plants were sprayed weekly with DDT for the first crop and Sevin for the subsequent crops in order

to control fall army worms. Sevin was applied every other day for 22 days at silking in an unsuccessful attempt to control ear worms. All ears were infested with ear worms; however, damage was not excessive as only a few kernals were eaten in each ear. The sorghum was sprayed weekly with Arasan after the grain began to form as a bird repellent. This seemed a fairly effective method of controlling bird damage. Warfarin bait was placed around the edges of the field in an attempt to control rats and mice.

Pest problems encountered were: the fall army worm, which was controllable; the ear worm, which was not controllable with the methods employed; the lesser corn stalk borer, which killed many young plants under dry conditions; rats and mice, which dug up young plants to eat the corn kernals. Northern leaf blight attacked the corn plants at the clayey Oxisol (Catalina) site as the grain was maturing but probably caused no lessening of yield. However, leaf blight attacked and killed an adjacent corn experiment planted at a later date before the grain was mature lowering the yield drastically. A mild leaf-spot blight affected N deficient sorghum plants; and a black mold attacked sorghum heads which had been partially eaten by birds.

Soil management problems were encountered on the clayey Ultisol and sandy Oxisol soils. The clayey Ultisol (Humatas) is very hard and cloddy when dry, and slippery and sticky when wet. Therefore, the soil can be prepared for planting only when it is at the proper moisture level. The sandy Oxisol forms a hardpan below the plow layer which extends to a depth of approximately 50 cm. This pan was broken by chiseling to 90 cm after the first crop but it had formed again by the end of the second crop. This seems to be a function of the soil texture and there appears to be no remedy for it except to plow as deeply

as possible and keep the traffic over the field to a minimum.

Weeds were controlled by hand for the first two crops and by a preplant application of Simazine for the third.

In order to study the nitrification, movement, and recovery of the applied fertilizer N, soil samples were taken before planting, immediately before the postplant fertilizer application, and after harvest. For the original samplings 2 cores per plot were taken and composited to give one sample per block. Later, when individual plots were being studied, 6 cores per plot were composited. The sample depths were 0-25 cm, 25-50 cm, and 50-75 cm except after the first harvest when 75-100 cm and 100-125 cm samples were also taken.

Inorganic nitrogen analyses were made of the samples after they had been quickly dried in a greenhouse and stored in a freezer. Inorganic N analysis was accomplished by shaking 50 gram samples for one hour on a horizontal shaker with 100 ml of 1.0 N KCl and then leaching it through a Buchner funnel and filter paper. The leaching was completed with 150 ml of 1.0 N KCl.

Ammonium nitrogen was determined by distilling a 25 ml aliquot of the extract with MgO into 2% boric acid and titrating with standarized HCl. Devarda's alloy was added to the aliquot and the sample redistilled to determine the NO_3^- content. It was determined that NO_2^- was never present except occasionally in minute quantities.

Roots of the first two crops were examined at all sites by digging a pit between plots approximately 80 days after planting.

Corn grain yield was determined by picking the ears from 7.5 meters of each of the two center rows of the plot. The stover was harvested from 3 meters of each of the 2 center rows.

Sorghum yields were determined by harvesting the heads from 6 meters and stover from 3 meters of each of the 3 center rows of the plots. A subsample of grain and stover was analyzed for shelling percentage, moisture and N content. The entire above ground portion of the plants was later harvested and removed from the field.

Rainfall data is being collected at all sites. Solar radiation is being determined at the clayey Oxisol and clayey Ultisol sites. Temperature is being recorded at the clayey Oxisol site. Maximum and minimum temperatures are being taken at stations nearby the clayey Ultisol and sandy Oxisol sites and evaporation is also being determined at the clayey Ultisol location. A rainfall intensity recorder has been installed recently at the clayey Oxisol site. Soil humidity was determined at 3 depths at the three sites with soil moisture blocks during the growth of the sorghum crop.

APPENDIX II

DETAILS OF PROCEDURES FOR THE GREENHOUSE AND LABORATORY STUDIES ON NITROGEN SUPPLYING POWER

Greenhouse Study

To determine the ability of these soils to supply N, 4 consecutive crops were grown on each soil in the greenhouse. On all soils except the Cialitos (3) and Cialitos (4) the cropping sequence was corn, sorghum, corn, corn. On soils Cialitos (3) and Cialitos (4) consecutive crops of corn were grown. 1600 grams of soil (except for Nipe and Piña soils where 2,000 g of soil was used per pot) was placed in polyethylene bags in 15 cm plastic pots. Two treatments of 5 replications each were used; one was a complete treatment including Mg and micronutrients, while the other was identical except that N was omitted. All soils were limed where necessary to bring the pH to 5.5 to 6.0. In addition a small application of lime was made to the Nipe soil to supply calcium. Seeds of corn or sorghum were planted directly into the pots and were thinned to 4 plants per pot for corn and 6 plants per pot for sorghum. The pots were watered whenever necessary (at least daily) bringing the water content to approximately the field capacity by weighing.

In all soils except Cialitos (3) and Cialitos (4) the first crop was planted on October 13, 1970 and was grown for 4 weeks. Subsequent crops were also grown for 4 weeks with the fourth crop being harvested March 16, 1971. Soils Cialitos (3) and Cialitos (4) were included in the experiment on December 3, 1970 and the fourth crop on these soils were harvested April 13, 1971. Between each crop the soil was removed from the pot and mixed and refertilized except before the fourth crop where no additional treatment was

added.

Following the harvesting of the fourth crop, the soils from the treatment receiving no N were removed from the pots, thoroughly mixed, and air-dried in the greenhouse. The soils were then stored in the air-dry condition in the greenhouse from March 17 until April 27, 197., except for soils Cialitos (3) and Cialitos (4) which were stored from April 13 until April 27, when they were repotted (with 4 replications) and planted to corn to measure N availability in these soils after prolonged drying. Corn was harvested on May 20.

Plants from each harvest were dried at 60°C, weighed, and ground in a laboratory Wiley Mill. Total N in the ground sample was determined in the Technicon Auto-Analyzer using phenol and chlorox reagents after digestion. Each replicate of each harvest was analyzed separately.

Chemical Methods

General

Organic carbon was determined by dry combustion, total N by the Kjeldahl method, total organic matter by the modified Walkley-Black method, and pH in water and in 0.1 N KCl by the glass electrode at a soil water ratio of 1:2. Inorganic N in the original soils was extracted by shaking 20 g of soil with 40 ml of 1.0 N KCl for 1 hour followed by leaching through a Buchner funnel. Leaching was completed by an additional 60 ml of 1.0 N KCl for a total of 100 ml of extract. Ammonium N was determined by distilling a 20 ml aliquot of the extract with MgO into 2% boric acid using a semimicro-Kjedahl apparatus and titrating with standard HCl. A second distillation with Devarda's alloy of the aliquot used earlier for NH_4^+ determination gave the value of NO_3^- -N.

Extraction Methods

Method 1- (Estimation of N extracted by 1.0 N KCl)

In addition to the direct distillation of NH_4^+ -N and NO_3^- -N from the 1.0 N KCl extract as described previously, a 20 ml aliquot was heated with 2 ml of concentrated sulfuric acid in a 100 ml Kjeldahl flask on a micro-Kjeldahl digestion rack until the digest cleared. Digestion was continued for 1 hour after clearing. The NH_4^+ -N in the digest was determined as described previously.

Method 2- (Estimation of N extracted by 1.0 N K_2SO_4)

In this method both the extraction procedure and the determination of N in the extract was identical to Method 1 except that 1.0 N K_2SO_4 was substituted for 1.0 N KCl.

Method 3- (Estimation of N extracted by boiling 0.01 M $CaCl_2$ and potassium sulfate solution)

This is essentially the procedure of Keeney and Bremner except that 0.01 M $CaCl_2$ was used instead of water and 0.5 N K_2SO_4 solution was used instead of a 10% K_2SO_4 solution. Five grams of soil were placed in a 125 ml Erlenmeyer flask and treated with 30 ml of 0.01 M $CaCl_2$ solution. The mixture was boiled under reflux for 1 hour. After the mixture had cooled, 20 ml of 0.5 N K_2SO_4 solution were added, the flask was swirled vigorously to mix the contents and the mixture filtered on a Buchner funnel. On one 20 ml aliquot of the filtrate NH_4^+ -N was determined directly by distillation as described previously. In some instances NO_5^- -N was also determined by the use of Devarda's alloy in a subsequent distillation of the aliquot used for the NH_4^+ -N determination. A second 20 ml aliquot was treated with 2 ml of concentrated sulfuric acid and digested as before. Ammonium N was determined by distillation as described previously.

Method 4- (Estimation of N extracted by 0.05 sodium pyrophosphate and 0.5 potassium sulfate solution)

In this procedure modified from those described by Stanford 10 g of soil was placed in a 125 ml Erlenmeyer flask and 25 ml of 0.05 N sodium pyrophosphate was added. The mixture was shaken for 30 minutes on a wrist action shaker. After shaking 50 ml of 0.5 N K_2SO_4 solution were added. The flask was swirled vigorously to mix the contents and filtered on a Buchner funnel. Distillable NH_4^+ -N and total N in the extract were determined by the same procedures used in the other methods

Incubation Methods

To 50 g (oven-dry basis) samples of air dry soil sufficient $CaCO_3$ was added to bring the pH near neutral. After treatment the soils were transferred to 250 ml Erlenmeyer flasks. Sufficient water was added to bring the soils to field capacity and the flasks were capped with "Parafilm." The treatments were replicated 3 times and were incubated in the laboratory at 24°C for up to 16 weeks. At 2, 4, 8, and 16 weeks a set of treatments were taken for determination of pH and NH_4^+ -N and NO_3^- -N. The 50 g cultures were shaken with 100 ml of 1.0 N KCl for 1 hour on a horizontal shaker, followed by leaching through a Buchner funnel. The leaching was completed by an additional 150 ml of 1.0 N KCl making a total of 250 ml of the extract. Ammonium -N and NO_3^- -N in the extracts were determined by the distillation procedures described previously.