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# AGRONOMIC-ECONOMIC RESEARCH ON SOILS OF THE TROPICS

## Annual Report for 1976-1977

**Soil Science Department**
**North Carolina State University**
**Raleigh, N.C.**

**under**
**Contract AID ta-C-1236**
**with the**
**U.S. Agency for International Development**

# RESEARCH PROGRAM ON SOILS OF THE TROPICS

## ANNUAL REPORT FOR 1976–1977

Soil Science Department
North Carolina State University
Raleigh, North Carolina 27650

supported by

Contract AID/ta-C-1236
with the
U. S. Agency for International Development

November, 1978

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# TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

# INTRODUCTION

From the time the small farmer prepares his soil for planting, he is as interested in and affected by the economic return on his investment as he is the agronomic yield he will realize.

This is the sixth annual report of the Soil Science Department's Research Program on Soils of the Tropics and covers the period from 1976 through early 1977. Hence, this report departs from precedent in that it will be called Annual Report for 1976-1977. The bulk of the 1977 data will be included in the forthcoming report, Annual Report for 1977-1978.

This research program has been supported by the U. S. Agency for International Development under Contract AID/ta-C-1236 which runs for a three-year period from July 1, 1975 through June 30, 1978.

The overall objectives of the program have been focused into developing economically-sound soil-crop management systems for 1) acid tropical savannas and 2) acid tropical rainforests. The field research activities, to achieve these objectives, continue to be based in Brasilia, Brazil for the savannas and in Yurimaguas, Peru for the jungle areas.

The final objective of the contract is to gather additional information needed for establishing a sound basis for extrapolating the research results to other tropical areas of the world with similar soil management situations. The three supporting activities to achieve this objective are as follows: 1) Soil characterization studies are used with basic laboratory and greenhouse studies to determine the soil properties of little-known tropical areas in order to better comprehend certain basic concepts not fully understood at present; 2) the soil fertility capability classification system (FCC) is utilized as a practical means for grouping soils with similar fertility limitations and thus bridges the gap between the subdisciplines of soil survey and soil fertility; 3) the data are economically interpreted to evaluate the profitability of the proposed soil-crop management systems and also to provide physical coefficients for economic planning means such as linear programming and sector analysis. The format for this report follows that established by the 1975 Annual Report in that the staff responsible for each research project are identified to give more direct credit to the individuals involved.

## HIGHLIGHTS

### Amazon Jungle

A new fertilization strategy in the continuous cropping experiment successfully reversed the severe crop yield decline which had occurred in 1975. The main causes of the decline were fertility-related. When the lime, N, P and K rates were increased along with inclusion of Mg, B, Cu and Mo fertilizers, yields of rice, corn, soybeans and peanuts increased markedly. Inference drawn from these findings is that abandoned or soon-to-be-abandoned chacras can be recovered and farmed continuously and economically.

For example, using a rice/corn/soybean rotation and no fertilizer or lime, a farmer in the Yurimaguas area would realize a new profit of $128/ha/yr on a plot of land that he would normally abandon after two croppings. Utilizing the 1974-1975 fertilizer strategy of 1000-240-79-240 kg/ha/hr of lime-N-P-K, the farmer could realize a net profit of \$579/ha/yr on the same parcel of land. Employing the same rotation on the same land area with the improved 1976-1977 fertilization strategy of 1000-350-211-333 kg/ha/yr of lime N-P-K, the farmer could obtain a new profit of \$1539/ha/yr. This \$1539/ha/yr net profit represents a 1202% increase over no fertilizer or lime and a 266% increase over the lower fertilizer rates of 1974 and 1975.

Viewed another way, the \$ profit/\$ invested in fertilizer and lime was \$2.66 for the 1976-1977 strategy and \$1.72 for the 1974-1975 strategy.

Utilizing the 1976-1977 fertilization strategy, soybean and peanut yields increased to 2.5 and 4.5 tons/ha, respectively, while rice and corn yields approached 3.5 and 4.0 tons/ha, respectively.

As was noted in the 1975 Annual Report, although the response to lime is great, the residual effect of $Ca(OH)_2$ is rather short-lived. For instance, 1 ton $Ca(OH)_2$/ha had a residual effect of only 10 months. Corn yield response to $Ca(OH)_2$ applied 10 months earlier was linear with yields increasing from 0 to 5.2 tons/ha as lime increased from 0-4 tons/ha. The suggested application rates of 3-4 tons/ha/3-4 years appear agronomically feasible. By reducing Al saturation in the soil from 48 to 24%, rice yields were increased to 3.5 tons/ha.

Preliminary research found that Mg and several micronutrients became limiting after a newly-cleared field had been twice cropped. A micronutrient shotgun spray of Cu, Fe, Mn and Zn sulfates and B, Mo, lime increased corn yields from 1.2 to 5.2 tons/ha. Soybean yields were increased less dramatically by this spray.

Each of the micronutrients were then evaluated in several crops. In a newly cleared and burned chacra, soybean yields were increased from 1.5 to 2.1 tons/ha with the 2 kg Cu/ha and from 2.1 to 2.6 tons/ha with 0.5 kg B/ha. Soybean yields decreased to 2.1 tons/ha when B rates exceeded 0.5 kg/ha. Soybeans did not respond to Mo, Mn or Zn. Also on newly cleared and burned land, peanut yields were increased from 3.0 to 4.5 tons/ha with application of 0.5 kg B/ha and from 3.8 to 4.5 tons/ha with 1.5 g Mo/kg seed.

When chacras are continuously cropped, one would expect response to B, Mo and Cu applications. No soybean or peanut response to Zn or Mn was obtained. However, the question remains as to how this response or lack of response to micronutrients will change as plants utilize the native micronutrients in the soil. Present data indicate the need to apply 0.5 and 1.0 kg/ha of B and Cu, respectively per crop of soybeans and peanuts and 1.5 g Mo/kg peanut seed.

An additional research emphasis was begun to look at integrated cropping systems using lower inputs and relay cropping. Preliminary results have indicated no substantial negative effect of the lower fertilizer and lime rates on yields of relay-cropped rice, cowpeas, soybeans, peanuts, cassava and sugarcane.

A six-year kudzu fallow study was initiated to determine whether it is possible to shorten the traditional 20-year fallow period of the slash-and-burn system for recycling of nutrients to regenerate an exhausted soil. Should it be possible to reduce the fallow period to 4 years, a small farmer could permanently farm 5 hectares by rotating a 1-ha cropping area/yr with 4 hectares in different stages of fallow.

The evaluation of adaptation of corn varieties to the Yurimaguas environment found that the relatively short, lodging resistant and early maturing Amarillo Planta Baja outyielded all other varieties tested under both adequate and low lime and fertilizer levels. Corn grain yields of this variety at the two fertility conditions were 3.86 and 2.09 tons/ha, respectively. Yields of all 10 varieties planted in September exceeded those planted in April by 43%, due primarily to improved rainfall distribution during the latter growing season.

The establishment of a meteorological station at the Yurimaguas Experiment Station has allowed for the first detailed views of the climatic pattern of the area. These detailed data will allow for improved interpretation of the agronomic research results.

<u>Savannas</u>

The long-term experiments on the residual effects of liming and fertilizer applications on Oxisols of the Cerrado of Brazil continued for the fourth year. The original application of 8 tons lime/ha incorporated deep (0-30 cm) continued to provide the maximum corn yield although shallow incorporation was only slightly inferior. Chemical soil analysis and depth of rooting measurements indicated that downward movement of Ca and Mg in the deep and shallow lime incorporation treatments has diminished the differences in subsoil acidity between incorporation methods and the increased rooting depth has improved water reserves for plants during dry spells. A corn experiment with roots extending to a 120 cm depth yielded 6 tons of grain/ha despite a 40-day dry spell of which 19 days occurred after 50% tasseling.

After six consecutive corn crops, two strategies for obtaining desirable soil P levels were evidenced. An initial broadcast application of 141 kg P/ha with maintenance applications of 35 kg P/ha before each crop provided yields which were 80% of the treatment receiving an initial broadcast application of 560 kg P/ha. A cumulative yield of 72% of the maximum was obtained with an application of 35 kg P/ha broadcast and 35 kg P/ha banded before each crop. Yearly differences in input/output cost may dictate a given strategy. Based on October, 1976 prices it was economically feasible to apply as much as 440 kg P/ha.

The satellite experiment on the loamy Red Yellow Latosol continued to stress the importance of fully understanding the factors limiting the utilization of Cerrado Oxisols. The high available water content, lower P fixation and decreasing Al saturation with depth in this soil resulted in sustained high yields with lower inputs of lime and P fertilizer.

A new experiment was installed to evaluate response to K and Mg. Of special interest is the application of 62 kg K/ha which almost doubled corn grain yields providing a return equivalent to 9.3 times the cost of the K fertilizer.

For the fourth consecutive year corn grain production was near 4 tons/ha in the absence of applied N. Maximum yields were obtained with the application of 200 kg N/ha, but 82% of the maximum was produced with 80 kg N/ha.

Studies on varietal tolerance to Al toxicity and low available P were continued in both greenhouse and field experiments. Among the species and varieties studied the most tolerant cultivars to P and Al stress were Taylor Evans Y-101, Pratão Precoce, Agroceres-259 and Carioca-1030 for sorghum, corn and beans, respectively. These studies indicate that the most satisfactory method of crop management on savanna Oxisols involves this use of varieties tolerant to high Al saturation and low available P combined with low levels of surface applied lime.

Additional information on the properties of Cerrado soils were obtained by on-campus studies. Investigations on P sorption indicated that previous P applications were more effective than liming materials in reducing additional P sorption, but the liming effects were sufficient to cause overestimations in soil P requirements for field conditions when P sorption measurements were performed on unlimed soils. The increases in net negative soil charge through the combined effects of P and lime applications should have significant effects on the ion retention properties of these Oxisols.

Large texture variations were observed among 44 representative surface samples of Cerrado soils. The chemical composition, ion exchange and P sorption characteristics of these samples varied according to surface texture. Water release characteristics resembled those of sand irrespective of soil texture.

Intercropping

Field experiments in North Carolina have compared the N response and productivity of several intercropping combinations relative to monocultures of the same crops. Land equivalency ratios indicated that productivity was increased when corn competed interspecifically with soybeans or snapbeans. The proper selection of intercropping combinations was exemplified by the apparent nutritional incompatibility between intercropped corn and sweet potatoes.

Considerations on some of the methods currently used in intercropping studies have revealed that time is an important factor in comparisons of crops in mixture and monoculture. The area-time equivalency ratio (ATER) is proposed as a feasible method of accounting for time in such comparisons.

Extrapolation

The mineralogy of iron compounds in chemically similar pairs of red and yellow colored soils indicated hematite and goethite were the major iron components in the clay sized fractions. Redness of the soils was associated with increasing amounts of hematite relative to goethite.

The "i" modifier in the FCC system, which characterizes soils fixing considerable P by iron compounds was evaluated over a broad range of Oxisols, Ultisols and Alfisols. Results suggested that a useful criterion is both a ratio of iron oxides to percent clay greater than 0.15 and more than 35% clay in the plow layer.

Assessment of the FCC system was performed using soybean experiments from 184 sites in southeastern United States. High yields were obtained on a variety of soil conditions using the appropriate management. Although the required management depended largely on soil properties the influence of these properties on yield varied between years.

Characterization studies were continued in the savanna and rainforest regions of Venezuela. Soils from southern Venezuela were more intensively weathered and had lower effective CECs than soils of the northern region. The Ultisols and Alfisols were considered intergrades to Oxisols when this criterion was applicable.

Initial economic analysis of data produced by the Yurimaguas program has focused on defining factors necessary to produce near maximum yields. Various alternatives for producing the different crops have been quantified. Results from this phase of the analysis have delineated specific areas where additional agronomic research is necessary.

## COLLABORATING INSTITUTIONS AND INDIVIDUALS

The research reported is conducted in cooperation with several national and international institutions and involves a high degree of collaboration.

In the Amazon Jungle of Peru, field research is conducted at the Yurimaguas Experiment Station which is part of the Centro Regional de Investigaciones Agropecuarias III ( CRIA III) of the Ministerio de Alimentación. Supporting laboratory work is conducted at the La Molina Experiment Station. The Dirección General de Investigaciones of the Ministerio de Alimentación has assigned Dr. Carlos Valverde as project leader, representing Peru. Dr. Valverde has been very effective in expediting administrative matters with the Peruvian Government. The International Potato Center (CIP) plays a major role in providing administrative and logistical support. In turn, the program grows its potato trials at Yurimaguas as the lowland tropical station for adapting potatoes to the region. The Peruvian meterological network, SENAMHI, established a meteological station at Yurimaguas in 1976, which has allowed for the first detailed looks at the climatic pattern of this area.

In the Cerrado of Brazil, this project is conducted jointly with Cornell University and the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) at the Centro de Pesquisa Agropecuaria dos Cerrados, located about 40 km north of Brasilia. The USAID Mission in Brasilia and the Interamerican Institute of Agricultural Sciences provided valuable logistical support. EMBRAPA has assigned Mr. Edson Lobato as project leader, representing Brazil. Cornell and N. C. State staff stationed at the Cerrado Center form an integral part of the Center's research staff.

Several extrapolation studies are also collaborative in nature. Soil characterization studies have been conducted with partial financial support in the form of scholarships for graduate students from the USAID Mission to Colombia, the Ministerio de Obras Publicas of Venezuela, The Fundo de Amparo a Pesquisa do Estado de São Paulo, Brazil. Data for evaluating the Fertility-Capability Soil Classification System has been provided by EMBRAPA, the Instituto Colombiano Agropecuario, Instituto Geográfico Agustín Codazzi in Colombia. The extrapolation work at Pucallpa, Peru is in cooperation with the Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA). Dr. José Toledo, as the individual in charge of the Tropical Pasture Production and Evaluation Research Line, is directing all extrapolation-related activities at Pucallpa.

The following individuals from the different cooperating institutions provided substantial administrative support or are coauthors of some of the research projects. We wish to acknowledge and recognize their assistance at this time.

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# AMAZON JUNGLE OF PERU

Aerial view of Yurimaguas Agricultural Experiment Station.

Research at the Yurimaguas Experiment Station in the Amazon Jungle of Peru in 1976-1977 continued to gather information for developing agronomically and economically sound soil management practices for continuous cultivation in jungle areas where population pressures dictate an alternative to shifting cultivation. The experimental strategy followed continued to be that of 1) determining the factors responsible for the marked decline in crop yields following clearing, typical of shifting cultivation in acid soils, and 2) the development of corrective measures to enable continuous cultivation in small farming units with emphasis on low energy technology options.

The research has dictated higher fertilization levels in the central experiment of continuous cropping, which now also includes micronutrients. The phosphorus and potassium studies, as designed in earlier experiments, have continued. New experiments in 1976 and 1977 at the Yurimaguas Experiment Station included 1) corn varietal response to various agronomic practices, 2) lime, K, Mg and micronutrient studies with rice, corn, peanuts and soybeans, 3) substituting kudzu fallow for forest regeneration, and 4) integrating cropping systems. With the new meteorological station established at the Yurimaguas Experiment Station, the detailed climatic pattern for this area was observed for the first time.

As in the previous years, all experiments were conducted on the Yurimaguas soil series Ultisol, classified as Typic Paleudult, fine loamy, siliceous, isohyperthermic, which is considered to be representative of the region. Soil analyses reported in the previous annual reports show the soil to be deep, well drained, quite acid, low in organic matter, and deficient in N, P, K, Ca, Mg and, in some cases, S, B, and Mo. As earlier reported also, the sandy topsoil texture contributes to the susceptibility of this Ultisol to soil compaction and at the same time, prevents any serious phosphorus fixation problems.

## 2.1 CROP WEATHER

D. E. Bandy

In 1976 a meteorological station was established at the Yurimaguas Experiment Station in cooperation with SENAMHI, the Peruvian meteorological network, which has its area headquarters in Tarapoto. Most of the results presented in this report were taken at the Experiment Station. Other results were provided by the Yurimaguas Airport, which is 6 km from the station.

For the first time, the detailed climatic pattern for the Experiment Station can be observed (Table 2.1:1). The greatest surprise is perhaps that it is not as hot as one might expect, although this does not mean that one does not feel uncomfortable living there due to the high relative humidity and low amounts of wind.

In terms of plant growth, the temperatures are not too high during the day (absolute max. 35.8°C or 96°F) or night (avg. 22.5°C or 71°F) to adversely affect plant growth or yield. On the contrary, the temperatures are quite favorable for such crops as maize, sugar cane, rice, cassava, peanuts, and soybeans. A max-min temperature reading system does not show the duration of any temperature reading; thus, it is possible that night temperatures are too high for most of the night, falling very rapidly just prior to daybreak.

Table 2.1:1. Climatic data for the experimental station at Yurimaguas, Peru, 1976.

| MONTH | TEMPERATURE, °C | | | PRECIPITATION | WIND | RELATIVE HUMIDITY | SOLAR RADIATION |
|---|---|---|---|---|---|---|---|
| | Maximum | Minimum | Average | | | | |
| | | | | (mm) | (m/sec) | (%) | (Cal/cm$^2$/day) |
| January | 30.8 | 22.0 | 26.4 | 396 | 0.86 | 84.8 | 337 |
| February | 31.5 | 22.2 | 26.9 | 67 | 1.14 | 80.5 | 357 |
| March | 31.0 | 22.3 | 26.7 | 222 | 0.92 | 82.5 | 355 |
| April | 30.5 | 21.9 | 26.2 | 245 | 0.53 | 89.7 | 332 |
| May | 30.6 | 22.5 | 26.6 | 167 | 0.53 | 87.4 | 340 |
| June | 30.6 | 21.9 | 26.3 | 93 | 0.42 | 86.5 | 320 |
| July | 30.1 | 17.9 | 24.0 | 62 | 0.67 | 76.8 | 371 |
| August | 31.2 | 19.9 | 25.6 | 126 | 0.55 | 77.1 | 407 |
| September | 32.6 | 19.6 | 26.1 | 129 | 0.55 | 77.5 | 416 |
| October | 32.1 | 21.1 | 26.6 | 402 | 0.61 | 81.2 | 397 |
| November | 31.7 | 21.1 | 26.4 | 230 | 1.17 | 81.1 | 408 |
| December | 31.1 | 21.2 | 26.2 | 219 | 0.88 | 82.6 | 387 |
| Year | 31.2 | 21.1 | 26.2 | 2359 | 0.74 | 82.3 | 369 |
| Absolute Daily | 35.8 | 11.2 | ---- | 115 | ---- | ---- | 609 |
| Reading (Date) | Sept. 17 | July 23 | | Oct. 20 | | | Oct. 23 |

If this is the case, high rates of dark respiration could be occurring. This, rather than photorespiration as was previously thought, may account for some of the low yields of previous crops, since daytime temperatures are not that high.

In addition, Table 2.1:1 shows that solar radiation is not high enough to cause significant photorespiration losses. On the contrary, low solar radiation could be an important factor in limiting yield potential during the rainy season.

Wind speeds do not seem to be too high, but a seasonal effect is noted. The rainy season shows more windiness than the cooler, drier months. However, the monthly data results may be misleading, since strong gusts of wind appear in the drier season for short periods of time, usually before a storm. These strong wind gusts can cause serious yield reductions of some crops due to plant lodging.

Yurimaguas is similar to many other places in the tropics in that rainfall distribution may be a serious problem even though the yearly or monthly results show sufficient rainfall to grow most crops the year around (Table 2.1:1).

If one studies the rainfall data shown in the Annual Reports of 1974 and 1975, it can be seen by the large 20% variability curves that monthly rainfall distribution, especially during the rainy season, varies greatly. The large variation in rainfall is not serious in terms of causing plant water stress during the rainy season, but excessive rainfall can be a problem. For example, the daily rainfall distribution for January 1976 is shown in Fig. 2.1:1, where about 400 mm of precipitation was recorded. It rained 19 days out of 31 days in January. Even though these are deep, well drained soils, such high amounts and frequencies of rainfall make it extremely difficult for a farmer to plant and harvest his crops and to control weeds, diseases, and insects. Crop growth and yields are also negatively affected by low solar radiation and prolonged periods of water saturated soils.

Conversely, plant water deficit may also reduce yields even in the humid environment of Yurimaguas due to poor rainfall distribution. The 21-year rainfall records for the Yurimaguas area show an average of 100 mm during the driest months of June, July, and August (Annual Reports 1974, 1975), but this can be extremely misleading. For example, Fig. 2.1:1 shows that most of the rain falls during one thunderstorm. Of the 93 mm of rain that fell in June 1976, 57.3 mm fell in one 24-hour period, and 78% of the monthly total fell during the same 3-day rainy period.

July was even worse than June. Severe water stress was observed on all crops. Benites and Naderman have shown (Sec. 2.4) that water stress was probably one of the main factors contributing to lower corn yields in the April planting compared to the September planting.

In conclusion, it can be stated that the climate at Yurimaguas and in other humid tropical areas of the Amazon jungle basin, is, in general, quite favorable to crop production. However, the climate can also cause serious yield reductions if proper agronomic practices are not followed. The climate strongly mandates the pest control program required at Yurimaguas. For example, fungus diseases start becoming a serious problem about three months into the rainy

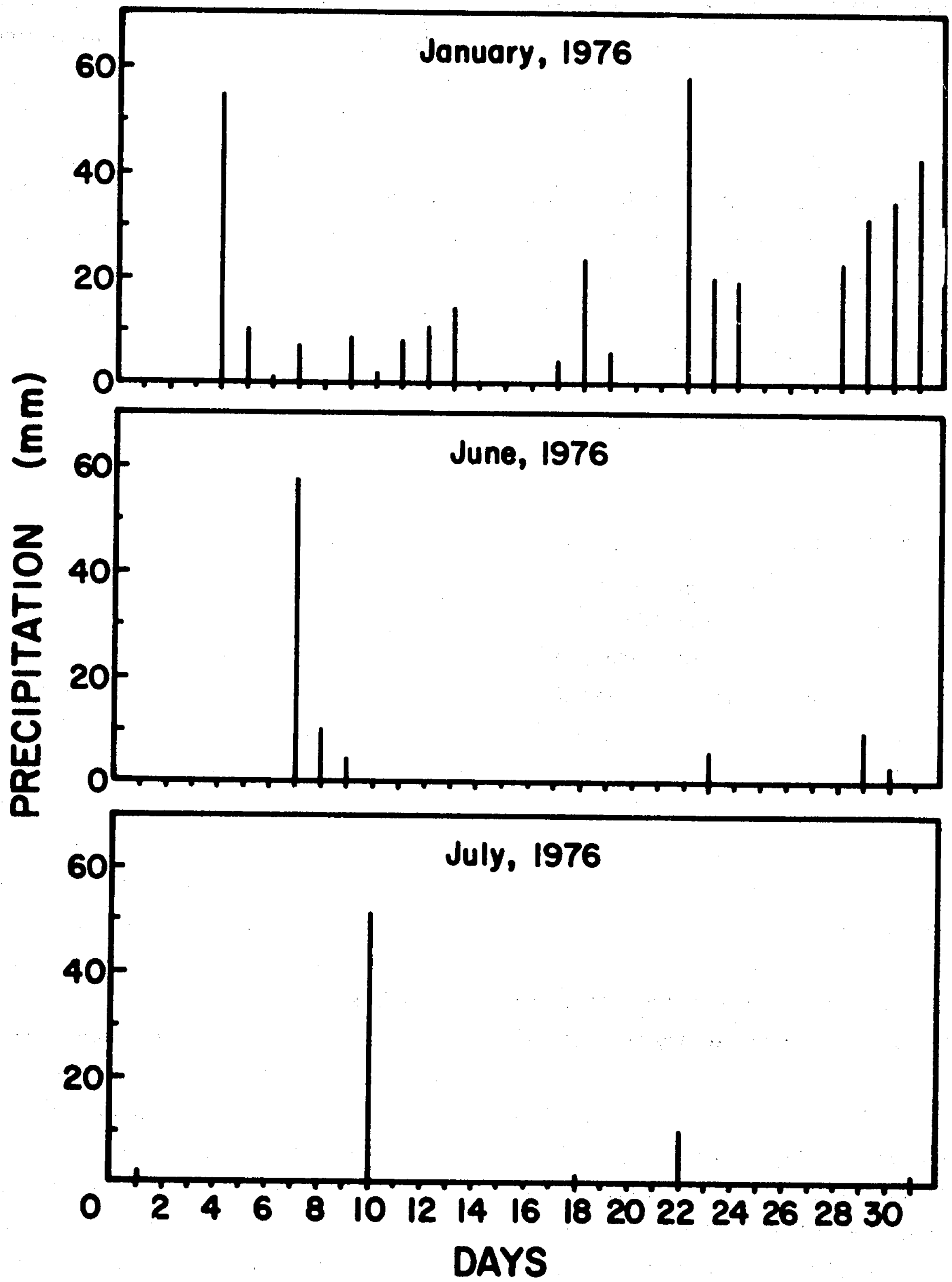



Figure 2.1:1. Rainfall distribution for January, June and July 1976, at Yurimaguas, Peru.

season and prohibit the planting of cowpea and some soybean varieties. Toward the end of the rainy season and the start of the drier season (April through July) insects and birds become the major pest problem. Weed control is also closely related to the climatic pattern. At least four cultivations are needed for adequate weed control in crops grown during the rainy season, whereas one, or at most two, weedings are needed during the drier part of the year.

## 2.2 CONTINUOUS CROPPING EXPERIMENTS

J. H. Villachica and P. A. Sanchez

According to the plan of work outlined for 1976, rice was planted in early February 1976 in crop sequence 1 (continuous upland rice) and crop sequence 3 (rice—corn—soybean) in all three chacras. The only exception was continuous rice in Chacra 3, which was planted by December 1975. The treatments and the level of nutrients applied were the same as those described in the 1975 Annual Report. By the middle of March 1976, some results on soil and plant analyses were obtained. Results on the satellite experiments with lime, K, Mg, and micronutrients were also available. All this data aided a better understanding of what occurred in the plots of continuous crops during the last 6-8 months of 1975.

It was evident that new fertility levels had to be developed for continuous cropping in all the chacras. The results of three years of research in continuous cropping in Yurimaguas were showing that the model that we had been using was good only for no more than two years and that our fertilization strategies, which were adequate and economically sound in 1974, were found to be inadequate in 1975 (Annual Report 1975). Minor changes made in these fertilizer strategies during 1975, i.e., raising the amount of N applied to the soil from 80 to 100 kg/ha, did not significantly improve yields. These minor changes were reported in the 1975 Annual Report.

With these results, it was obvious that a change in the research strategy for continuous cropping was needed. We were studying moderate to low fertilizer rates, even dropping some of them, to lower the costs. However, yields obtained during 1975 were also moderate to low. By March 1976, the decision was made to change our fertilization strategy to levels that would ensure better yields. Satellite experiments with S, Mg, K, lime and micro-elements were very helpful for establishing these new levels. The missing nutrient strategy was changed to one of having a complete as a treatment and then adding other elements to form the additional treatments (Table 2.2:1). Since continuous upland rice had already achieved the goals for which it was designed, it was changed for a crop sequence with better agronomic and economic possibilities. Thus, rice—soybean—peanut was begun in the plots formerly used for continuous rice. In March 1976, rice was growing very poorly in all chacras and crop sequences, so it was harvested and straw dry matter production measured. At that time, it was too late in the season to plant rice again, so the next crop in each sequence (soybeans in new sequence 1, corn in sequence 3) was sown. The results obtained with each crop will be discussed later.

Table 2.2:1. Description of the new treatments for the Rice-Soybean-Peanut and the Rice-Corn-Soybean systems used after April 1976.

| Treatment | | | Amounts Applied (kg/ha)[1/] | |
|---|---|---|---|---|
| No. | Former Identification | New Identification | For Corn | For Soybean |
| 1 | Check | Check | None | None |
| 2 | Tilled check | Complete plus mulch | Same as treatment 5, plus standard mulch | Same as for corn, except with only 30 N |
| 3 | Complete, P residual | Complete plus kudzu and mulch | Same as treatment 5, plus standard kudzu and mulch | Same as for corn, except with only 30 N |
| 4 | Maintenance | Lime, kudzu, and mulch | Lime, standard amounts of kudzu and guinea grass | Same as for corn |
| 5 | Complete | Complete | Lime, 160 N, 70 P, 125 K, 30 Mg, 124 S, 3 Zn, 3 Cu, 1 B, 0.1 Mo | Same as for corn, except with only 30 N |
| 6 | Complete, K residual | Complete plus kudzu, mulch and SCU as N source | Same as treatment 3, except that SCU was used as N source, instead of common urea | Same as for corn, except that no N was applied |
| 7 | Half complete | High complete | 1.5 times the amount of NPK applied in 5, and twice the standard amounts of kudzu and mulch | Same as for corn, except with only 30 N |

[1/] The amounts of lime applied were equivalent to 1.5 times the exchangeable acidity in each replication tested individually; this varied from 1/4 to 2 tons/ha. Standard amounts of kudzu incorporated refer to 1 kg fresh kudzu/$m^2$ (30% dry matter) and mulch refers to 1 kg of fresh guinea grass (26% dry matter)/$m^2$.

Changes in treatments and the amounts of fertilizer and amendments applied are presented in Table 2.2:1. The non-tilled check was maintained, and the tilled check was fertilized and mulched (treatment 2). The complete fertilizer level was higher than the previous complete and also included Mg, Zn, Cu, B, and Mo, at optimum rates as determined by the 1975 results. Since soil analysis results cannot be obtained as rapidly as desirable, there is a time lag for correcting soil fertility changes. For this reason, a high complete treatment was designed to be used (treatment 7). Should there be a deficiency of any element being applied, this treatment should so indicate, giving higher yields than the complete.

Lime and kudzu were incorporated to 10-12 cm depth when applied. Lime, as $Ca(OH)_2$, was applied 10-15 days before planting. Kudzu was incorporated the day before planting. Mulch was applied the day following planting. All the fertilizer P, K, Mg, Zn, Cu, and B were broadcast at planting time and mixed with the soil and the kudzu. Nitrogen applications were equally split at 18 days and 45 days after planting. When SCU was used, it was applied at planting time. Molybdenum was applied as a coating to the seeds. The fertilizer sources used were urea (or SCU in treatment 6), simple superphosphate, potassium chloride, magnesium sulfate, zinc sulfate, copper sulfate, borax, and ammonium molybdate. A foliar application of a commercial formulation of micronutrients was made at 15 and 50 days after planting for soybeans and 15 and 40 days after planting corn.

The rice-guinea grass system was continued as described in the 1975 Annual Report. Thus, a six-week interval cut was given to each plot, and 320-50-320 kg/ha/year of NPK were applied to the complete plot. The N and K were split in equal amounts after each cut, while P was applied once a year. Maintenance treatment continued receiving 120-20-90 kg/ha of NPK. Fertilization strategies for all other treatments continued as before.

Rice—Soybean—Peanuts Sequence

As previously mentioned, rice growth during early 1976 followed the same pattern described for 1975 (1975 Annual Report). Thus, it was not doing very well. For this reason, and for time considerations, it was harvested at 60 days of planting. After rice was cut, in April 1976, soybeans (cv. National) were planted in the same plots, but using the new treatments.

The results of soybean grain yield in Chacras 1, 2, and 3, obtained during 1976, are presented in Table 2.2:2. Yields of soybeans ranged from 0.3 to 2.5 tons/ha. Highest yield was 2,725 kg/ha (41 bu/acre), excellent even by North Carolina standards. When the former maintenance plots received lime, incorporated kudzu, and guinea grass mulch, soybean yields increased to about 1,500 kg/ha (treatment 4). When lime and all the nutrients were added, with and without kudzu incorporated or guinea grass mulch, soybean yields were between 2,000 to 2,500 kg/ha (tmts. 3, 5 and 6). The yield of the high complete treatment (number 7) was about equal to that of the complete (treatment 5). This indicated that the levels of fertilizers used with the complete were sufficient.

Table 2.2:2. Soybean grain yields in Chacras 1, 2, and 3 for cropping sequence 1, as affected by soil treatments. Yurimaguas 1976. Average of 4 replications.

| Treatment[1/] | | Soybean grain yield (kg/ha) | | | |
|---|---|---|---|---|---|
| No. | Identification | Chacra 1 | Chacra 2 | Chacra 3 | Average |
| 1 | Check | 1 | 564 | 466 | 334 |
| 2 | Complete plus mulch | 1,985 | 2,081 | 2,572 | 2,213 |
| 3 | Complete plus kudzu and mulch | 2,386 | 2,089 | 2,179 | 2,218 |
| 4 | Lime, kudzu, and mulch | 1,287 | 1,554 | 1,554 | 1,455 |
| 5 | Complete | 2,703 | 2,208 | 2,725 | 2,546 |
| 6 | Complete as 3 but N as SCU | 1,761 | 2,319 | 2,695 | 2,258 |
| 7 | High Complete | 2,368 | 1,939 | 2,542 | 2,283 |
| | Average per chacra | 1,784 | 1,822 | 2,100 | |
| | $LSD_{.05}$ for chacras | | 320 | | |
| | $LSD_{.05}$ for treatments | | 241 | | |
| | $LSD_{.05}$ for treatment x chacra | | 417 | | |

[1/]Treatments as defined in Table 2.2:1

It is worth mentioning that the yield differences usually observed during 1974 and 1975 among Chacras 1, 2, and 3 were no longer present with soybeans in cropping sequence 1 and with corn in cropping sequence 3 (to be shown later). This means that the differences in soil fertility between the complete treatment in all three chacras, so clearly present during the past years, were overcome by the application of moderately high rates of lime and fertilizers, with very good yield responses. The main implications of this result are twofold. Firstly, yields will be higher regardless of the age or use of the chacra. Secondly, it suggests that all abandoned or to-be-abandoned chacras with similar soils can be recovered using this new fertilizer strategy, with a high probability of obtaining very good yields. Soybean yields in Chacras 1 and 2 as compared with rice yields in the same plots are shown in Fig. 2.2:1. Yield patterns on Chacra 3 are not shown, but they are similar to those of Chacras 1 and 2. It can be observed that the decreasing slope of the response curves has been reversed. Soybean yields with the new complete treatment in Chacra 1 were higher than any of the last four crops of rice with the former complete, even though soybeans do not have as high grain yield potential as rice. Yields were also higher than those obtained with soybean cropping sequence 3, rice–corn–soybeans, in the same chacras during 1975 (1975 Annual Report). All these data indicate the successful reclamations of these plots.

Peanuts, the next crop in the sequence, were harvested at the moment of writing this report. Preliminary evaluation of the data indicate that the complete plots have yields between 4,000 to 6,000 kg/ha. These results also indicate that good yields are still being obtained with the new complete treatments.

A preliminary economic evaluation of the cost of the new fertilizers and their profitability is presented at the end of this Section 2.2.

Rice–Corn–Soybean Sequence

Results on corn yield planted in April 1976 are presented in Table 2.2:3. Results of rice dry matter harvested before corn was planted are not presented here. Table 2.2:3 shows that yield of the check treatment was 0.4 tons/ha; when the former maintenance plots were limed and kudzu and guinea grass mulch were applied, yields improved somewhat but were still low (treatment 4). When the new complete treatment (number 5) was used, yields increased sharply up to 3.6 tons/ha. These yields are considered very good for the zone and for the growing period–110 days from planting to harvesting time. Statistical analysis shows that the response to the treatments was different between chacras, except in treatment 7. The lower yield in treatment 3 in Chacra 3 was due to a high percentage of lodged plants. In general, yields were expected to be higher, but heavy winds at the grain filling period produced a high number of lodging plants which, it is believed, reduced the yields. When these yields are compared to those obtained in previous years, some interesting data are obtained. The decreasing trends in yields in all three chacras were reversed in 1976 (Fig. 2.2:2). From Table 2.2:3 one also notes that

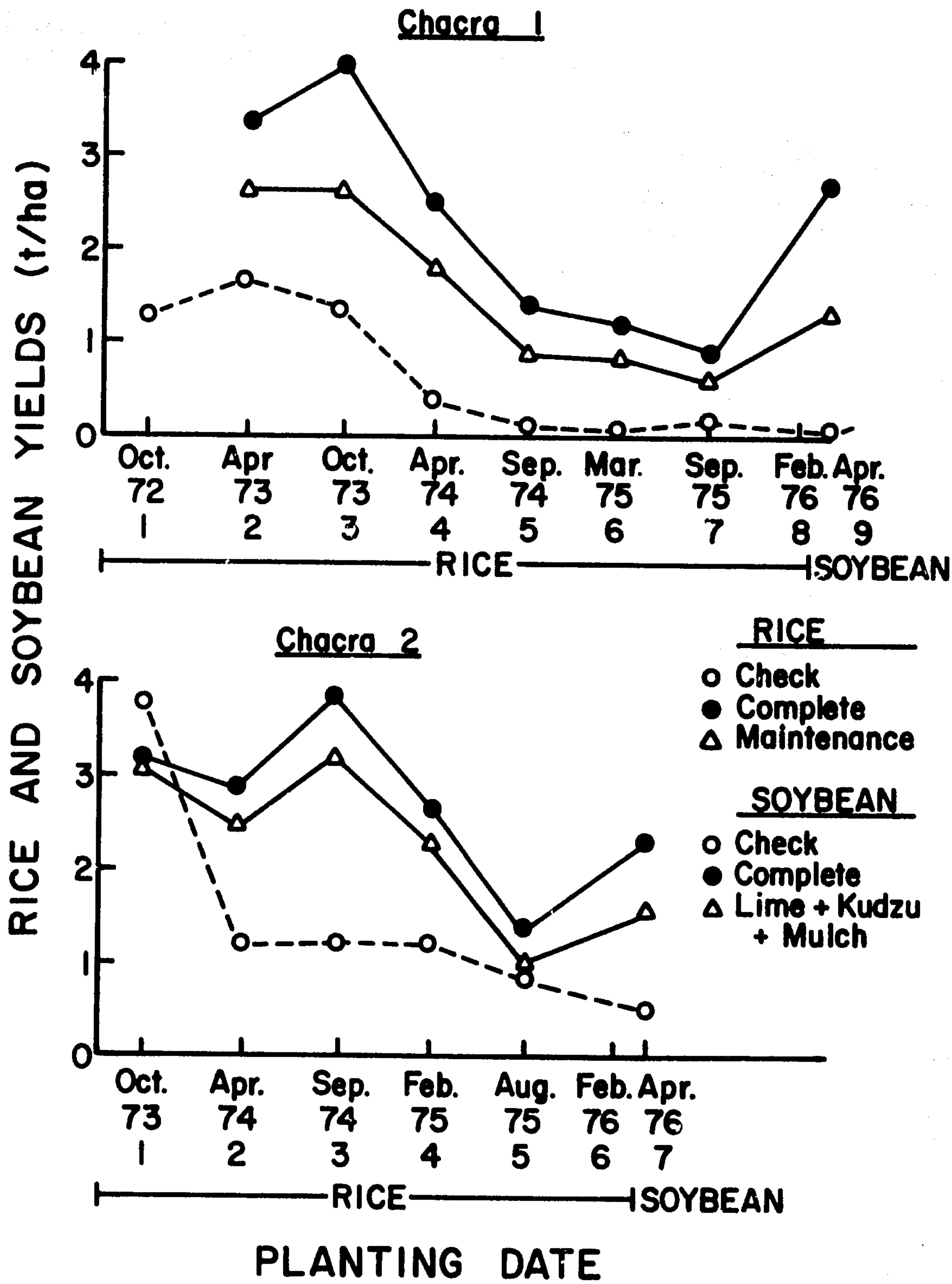



Figure 2.2:1. Rice and soybean yields in the new rice-soybean-peanut sequence as a function of time. Mean of four replications. Yurimaguas, 1972-1976.

Table 2.2:3. Corn grain yields in Chacras 1, 2, and 3, cropping sequence 3, as affected by soil treatments. Yurimaguas 1976. Average of 4 replications.

| Treatment[1/] | | Corn grain yields (kg/ha) | | | |
|---|---|---|---|---|---|
| No. | Identification | Chacra 1 | Chacra 2 | Chacra 3 | Average |
| 1 | Check | 1 | 243 | 846 | 363 |
| 2 | Complete plus mulch | 3,204 | 2,894 | 2,798 | 2,965 |
| 3 | Complete plus kudzu plus mulch | 3,944 | 3,802 | 2,618 | 3,454 |
| 4 | Lime, kudzu and mulch | 493 | 679 | 1,392 | 855 |
| 5 | Complete | 4,054 | 2,971 | 3,805 | 3,610 |
| 6 | Complete as 3, but N as SCU | 4,321 | 3,524 | 4,019 | 3,955 |
| 7 | High complete | 3,193 | 3,287 | 2,809 | 3,097 |
| | Average per chacra | 2,744 | 2,486 | 2,612 | |
| | $LSD_{.05}$ for chacras | | 566 | | |
| | $LSD_{.05}$ for treatment | | 376 | | |
| | $LSD_{.05}$ for treatment by chacra | | 651 | | |

[1/] Treatments as defined in Table 2.2:1

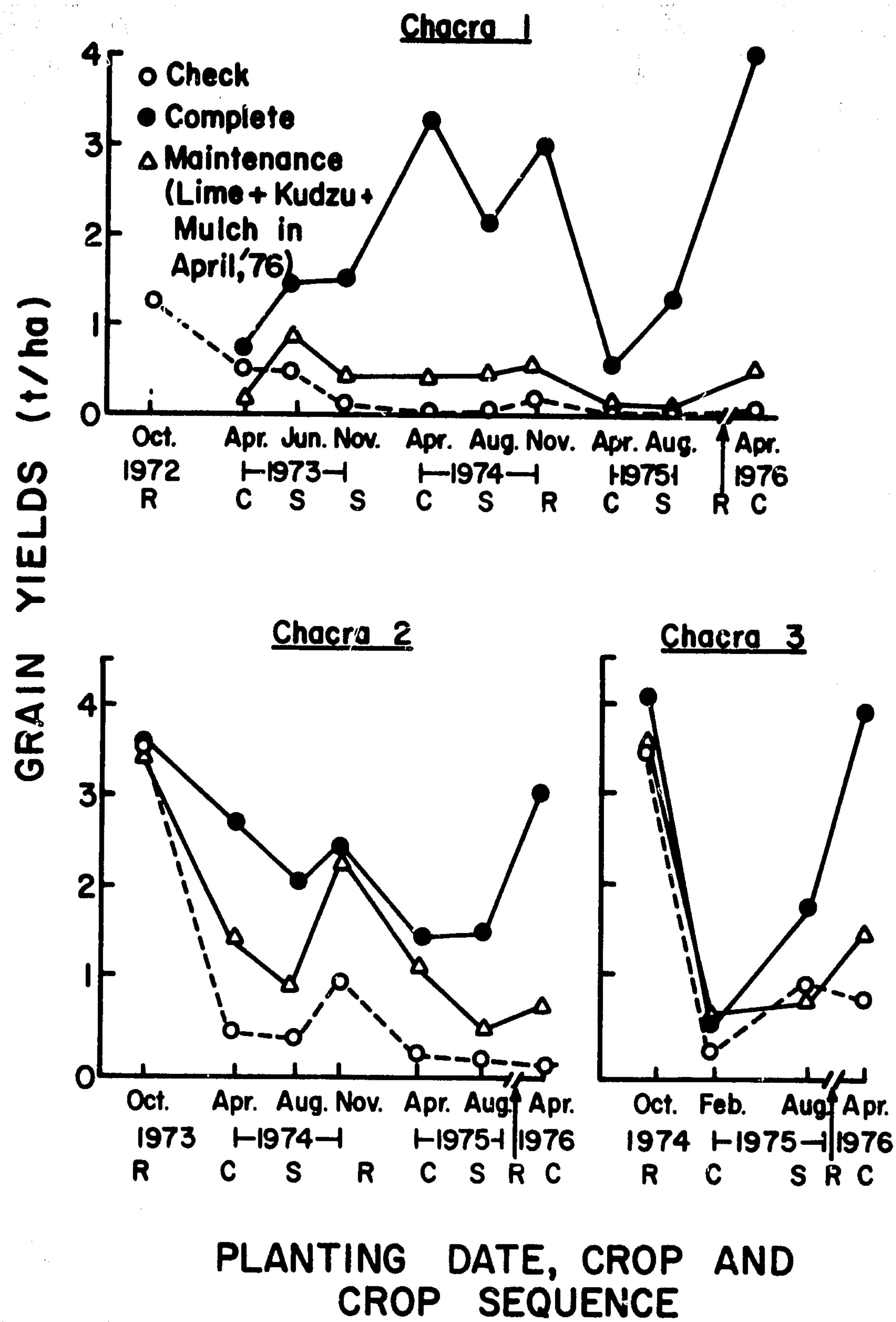



Figure 2.2:2. Grain yields of the rice(R)-corn(C)-soybean(s) cropping system as a function of time after clearing. Mean of four replications. Yurimaguas, 1972-1976.

1976 corn yields for the complete fertilization plots were higher than those obtained with corn from 1972 to 1975.

Table 2.2:3 shows that best yields were obtained with treatment 6, which had the same levels of fertilization and soil amendments as treatment 3, except that sulfur-coated urea (SCU) was used as the N source instead of common urea. Average difference in yield was 501 kg/ha (14.5% more than treatment 3), indicating the possibility that better N management could still improve yields. As previously mentioned, common urea was split into two applications for corn, while N as SCU was applied only once. Some N leaching loss can still be expected on this sandy soil under the high rainfall conditions of Yurimaguas.

The complete plus mulch treatment and the high complete (treatments 2 and 7) did not yield as well as the other treatments, even though they were around the 3.0 t/ha yield level. The failure of the high complete treatment to give higher yields than the complete most likely indicates that the complete treatment contained sufficient nutrients.

Table 2.2:4 shows some of the chemical properties on these plots sampled in December 1975. Main differences in chemical properties among plots were due to pH and extractable Ca and Al. These differences were corrected by individually liming each plot, according to its exchangeable Al. There were also differences in the levels of available P and K, but all plots were low in these nutrients, regardless of length of cropping of the chacra.

Soybeans following corn were harvested at the moment of writing this report. Preliminary evaluation of the data indicate that soybean yields were very low in the check plots, as was expected. Soybean yields over 2,600 kg/ha were observed with the complete treatments. These results will be discussed in the next annual report.

Rice–Guinea Grass Sequences

Results of the total amount of guinea grass dry matter produced during seven consecutive cuts in all three chacras are given in Table 2.2:5. In general, yields were low, producing around 12 tons dry matter/7 cuts/ha in the complete treatments in all three chacras. Differences within the treatments were observed. The complete and the complete with residual P yielded an average of over 12 tons dry matter/ha/year, which was twice the amount produced by the checks and the complete, residual K. However, this "high yield" was not comparable to those obtained during 1973 for Chacra 1 (18 tons/ha) and Chacra 2 (20 tons/ha). As was pointed out in the 1975 Annual Report, these low yields were, in part, due to changing the cutting frequency from 8 to 6 weeks, which was recommended by pasture specialists. Table 2.2:6 shows that soil exchangeable Ca and available P in the complete treatment in Chacras 1 and 3 were about adequate and Al toxicity was not a problem in October 1975. However, according to the critical levels established at La Molina, the amount of available K was low in Chacra 3 and medium in Chacra 1. It is also probable that by October 1976 (a year after the sample was taken), the amount of organic matter present in Chacra 3 was lower and N availability was reduced. Soil samples are being analyzed to test the hypothesis that N, Mg and K were also limiting guinea grass yields during 1976.

Table 2.2:4. Topsoil (0-10 cm) chemical properties in the rice-corn-soybean plots in Chacras 1, 2, and 3, sampled in December 1975. Analyzed at La Molina Experiment Station. (Mean of four replications)

| Treatment[1/] | | pH | | | Modif. Olsen P | | | 6N $H_2SO_4$ K | | | Exchangeable K | | | Exchangeable Ca | | | Exchangeable Mg | | | Exchangeable Al | | | Al Sat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Identification | C1 | C2 | C3 | C1 | C2 | C3 | C1 | C2 | C3 | C1 | C2 | C3 | C1 | C2 | C3 | C1 | C2 | C3 | C1 | C2 | C3 | C1 | C2 | C3 |
| | | | | | ---ppm-- | | | ---ppm--- | | | ---------- me/100g ---------- | | | | | | | | | | | | --- % ---- | | |
| 1 | Check | 4.2 | 4.1 | 4.5 | -- | 1 | 3 | 25 | 39 | 50 | .13 | .15 | .15 | .65 | 1.90 | 2.50 | .4 | .6 | .7 | 2.70 | 2.20 | 1.75 | 70 | 45 | 34 |
| 2 | Complete plus mulch | 4.3 | 4.2 | 4.4 | -- | 1 | 3 | 28 | 39 | 44 | .13 | .13 | .14 | .70 | 1.40 | 1.80 | .4 | .5 | .8 | 2.70 | 2.30 | 1.70 | 69 | 53 | 38 |
| 3 | Complete plus kudzu and mulch | 5.3 | 4.9 | 4.9 | -- | 2 | 7 | 57 | 104 | 75 | .19 | .28 | .18 | 4.95 | 5.00 | 3.95 | .6 | .5 | .8 | .40 | .40 | .90 | 7 | 6 | 15 |
| 4 | Lime, kudzu and mulch | 4.4 | 4.1 | 4.1 | -- | 5 | 6 | 44 | 76 | 55 | .16 | .24 | .15 | 1.40 | 2.40 | 2.80 | .4 | .5 | .8 | 2.60 | 2.10 | 1.50 | 57 | 40 | 29 |
| 5 | Complete | 5.0 | 4.4 | 4.7 | -- | 6 | 9 | 52 | 81 | 69 | .17 | .28 | .15 | 4.05 | 4.30 | 3.60 | .5 | .5 | .8 | .60 | .90 | 1.00 | 11 | 15 | 18 |
| 6 | Complete plus kudzu, mulch and SCU as N source | 5.2 | 4.6 | 5.0 | -- | 4 | 11 | 35 | 33 | 42 | .14 | .14 | .13 | 4.80 | 5.00 | 4.35 | .5 | .5 | .8 | .65 | .60 | 1.00 | 11 | 10 | 16 |
| 7 | High Complete | 4.7 | 4.4 | 4.7 | -- | 4 | 6 | 38 | 60 | 51 | .14 | .20 | .15 | 3.10 | 3.10 | 3.05 | .4 | .6 | .8 | 1.40 | .90 | 2.05 | 27 | 18 | 34 |

[1/]Treatments as defined in Table 2.2:1

Table 2.2:5. Annual dry matter production of *Panicum maximum* in the rice-guinea grass cropping system (sum of 7 cuts during 1976).

| Treatment[1/] No. | Identification | Chacra 1 17th to 23rd cuts | Chacra 2 13th to 19th cuts | Chacra 3 8th to 14th cuts | Average |
|---|---|---|---|---|---|
| | | kg dry matter/ha | | | |
| 1 | Untilled, unfertilized | 3,300 | 4,358 | 7,975 | 5,211 |
| 2 | Tilled, unfertilized | 3,305 | 4,611 | 7,111 | 5,009 |
| 3 | Maintenance | 8,512 | 8,622 | 10,317 | 9,150 |
| 4 | Complete | 11,986 | 11,590 | 12,550 | 12,042 |
| 5 | Complete, residual P | 11,994 | 12,138 | 12,999 | 12,377 |
| 6 | Complete, residual K | 4,626 | 5,819 | 9,684 | 6,709 |
| 7 | Half complete | 9,357 | 10,443 | 10,455 | 10,085 |
| | Average per chacra | 7,583 | 8,226 | 10,156 | |
| | $LSD_{.05}$ for chacras | | 1,170 | | |
| | $LSD_{.05}$ for treatments | | 1,355 | | |
| | $LSD_{.05}$ for treatments by chacras | | 2,346 | | |

[1/] Treatments are the same as those employed in 1975 (1975 Annual Report)

Table 2.2:6. Some soil chemical properties in the rice-guinea grass plots sampled in October 1975. Analyzed at La Molina Experiment Station. Average of 4 replications.

| Soil Property | Chacra 1 Tmt. 1 Check | Chacra 1 Tmt. 5 Complete | Chacra 3 Tmt. 1 Check | Chacra 3 Tmt. 5 Complete |
|---|---|---|---|---|
| pH (1:2.5 in water) | 4.0 | 4.9 | 3.8 | 5.1 |
| P (0.5M $NaHCO_3$ at pH 8.5), ppm | 6 | 33 | 3 | 11 |
| K (6N $H_2SO_4$), ppm | 65 | 143 | 39 | 91 |
| O.M. (Walkley and Black), % | 2.3 | 2.3 | 3.2 | 4.6 |
| Extr. Al (N KCl), me/100g | 2.3 | 0.4 | 1.5 | 0.3 |
| Exchangeable bases | | | | |
| Ca (N KCl), me/100g | 1.4 | 4.0 | 2.4 | 5.8 |
| Mg (N KCl), me/100g | 0.6 | 0.4 | 0.4 | 0.4 |
| K (N $NH_4OAC$), me/100g | 0.09 | 0.12 | 0.08 | 0.22 |
| Na (N KCl), me/100g | 0.08 | 0.08 | 0.02 | 0.24 |
| Al saturation, % | 51 | 4 | 34 | 4 |

Calculations on nutrient uptake by guinea grass during 1973 or 1974 showed that an increase in the amount of nutrients added to the soil was needed. Results of the last cuttings during 1976 also indicated the need for this action, i.e., Fig. 2.2:3 shows that the difference between the complete and the maintenance treatments is, either minimal or non-existent. New fertility levels and lime applications were started in January 1977.

Some Economical Yield Data

Some draft calculations for fertilizer profitability with the 1976 complete as compared with 1975 complete are given in Table 2.2:7. Yields of 1975 complete were taken from the 1975 Annual Report, using the best averages in all three chacras. Thus, the cropping sequence was calculated to yield 1,500, 1,200, and 1,600 kg of rice—corn—soybeans, respectively. Yields of the non-fertilized checks were taken in average from the three chacras. Rice yields for the 1976 complete were taken from the lime—K—Mg microelement satellite experiment carried out in a soil with initial similar chemical properties as the check plots in Chacra 1. Soybean and corn grain yields in the 1976 complete were taken from the 1976 complete treatment data presented in Tables 2.2:2 and 2.2:3.

The data presented in Table 2.2:7 do not include inputs such as seeds, weeding, and insecticides, which are considered to be equal for all treatments. A higher hand labor requirement is recognized to be needed at harvesting time, as the yields increase, but is not taken into account. The table was made using the 1976 subsidized prices for fertilizers. Results clearly demonstrated the profitability of the new 1976 complete treatment. The profitability could be even higher if dolomitic lime is used as the Mg source.

All of this data can be used to fit the economic models that are presently being developed by Drs. Cate and Coutu, so a more integrated approach will be given in the near future.

## 2.3 FALLOW WITH KUDZU STUDY

D. E. Bandy

The traditional slash-and-burn system needs a 20-year fallow for the recycling of nutrients to regenerate an exhausted soil of the Amazon jungle basin near Yurimaguas, Peru. This extended time period makes it impossible for any type of a permanent agriculture system to become established. If, for example, the fallow period could be reduced to three or four years, a small farmer could permanently farm a five-hectare piece of land, rotating a one-hectare cropping area per year with four hectares in different stages of fallow.

To investigate the possibilities of using a shorter fallow period, a 5-year experiment was initiated in 1975 at Yurimaguas using kudzu instead of forest for the soil regenerator. Each year a piece of previously farmed land, approximately 1200 $M^2$, is placed into kudzu fallow so that at the end of five years we will have a chacra which has been in kudzu fallow for 4, 3, 2, and 1 years.

At the start of the fifth year, the kudzu will be prepared for soil incorporation via several methods as compared to a 20-year old forest fallow parcel of land. The ultimate objective

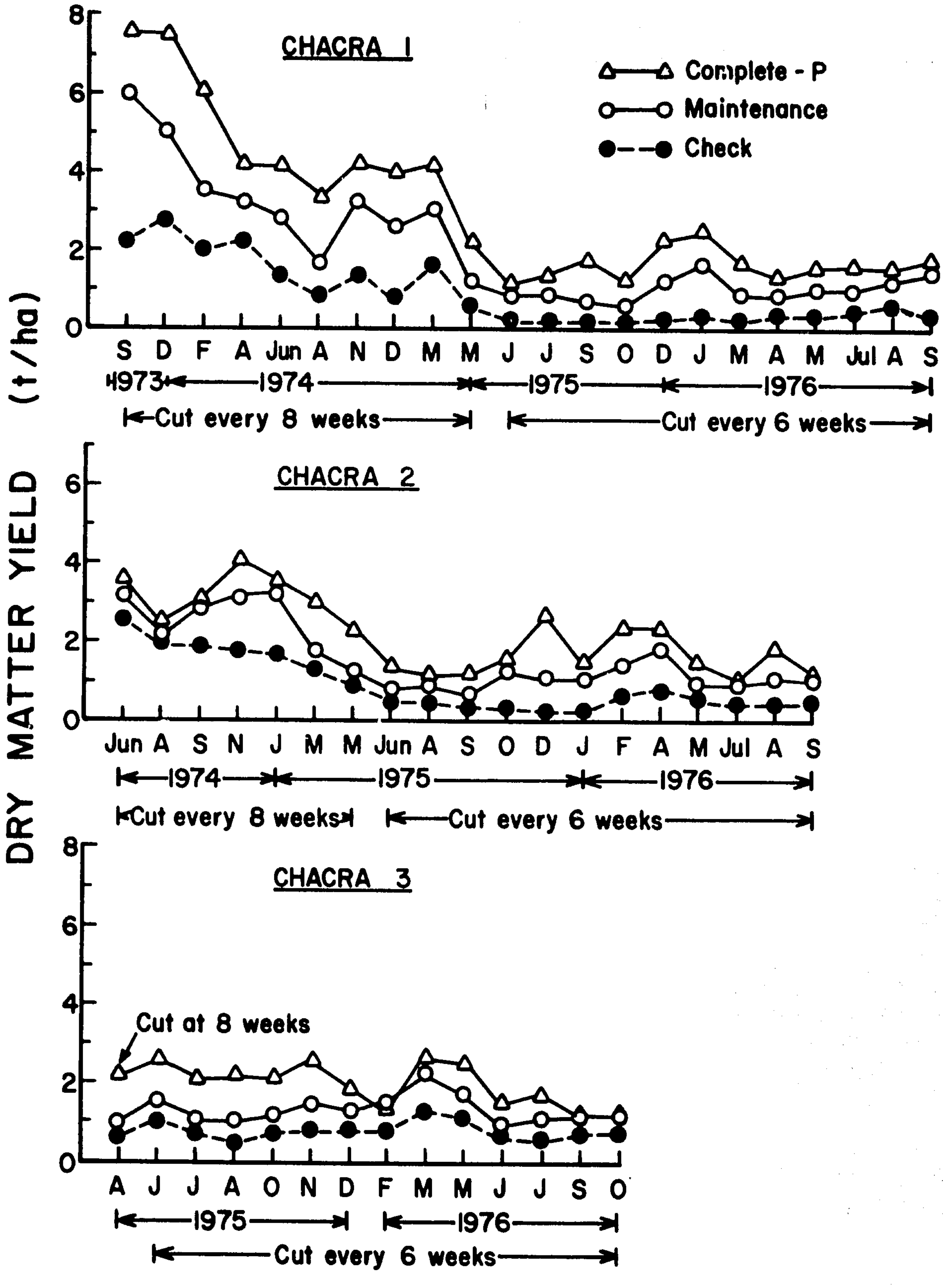



Figure 2.2:3. Production of guinea grass cuts in the rice-guinea grass system in Chacras 1, 2, and 3. Average of four replications. Yurimaguas, 1976.

Table 2.2:7. Economic analysis of new fertilization strategy developed in 1976 applied to the rice-corn-soybean rotation. Costs in 1976 soles at Yurimaguas converted to US$ at the rate of S/.45 per dollar.

| | Unfertilized | 1974 strategy | 1976 strategy |
|---|---|---|---|
| | Fertilization (kg/ha/yr): | | |
| N-P-K | None | 240-79-240 | 350-211-333 |
| Mg-Cu-B-Zn-Mo | None | None | 81-3-3-3-0.3 |
| Extra lime (tons/ha) | None | 1 | 1 |
| | Grain Yields (tons/ha): | | |
| Rice | 0.5 | 1.5 | 3.6 |
| Corn | 0.3 | 1.2 | 3.6 |
| Soybean | 0.4 | 1.6 | 2.6 |
| | Value of Crops (US$/ha/yr): | | |
| Rice | 128 | 383 | 920 |
| Corn | 61 | 245 | 736 |
| Soybean | 157 | 629 | 1023 |
| Total Income | 346 | 1257 | 2679 |
| | Expenditures (US$/ha/yr): | | |
| N, P, K fertilizers | 0 | 225 | 371 |
| Mg + micronutrients | 0 | 0 | 96 |
| Lime | 0 | 111 | 111 |
| Total fertilization | 0 | 336 | 578 |
| Cultural practices | 170 | 170 | 170 |
| Harvesting, threshing | 34 | 120 | 274 |
| Crop transport to market | 14 | 52 | 118 |
| Total costs | 218 | 678 | 1140 |
| | Profit | | |
| Net Profit (US$/ha/yr) | 128 | 579 | 1539 |
| $ Profit/$ invested in fertilizers and lime | -- | 1.72 | 2.66 |

is to learn whether kudzu fallow can replace a 20-year old forest fallow, and if so, how many years of kudzu fallow are needed.

Another kudzu fallow system was initiated in 1976 where a newly cleared chacra was intensively farmed for one year, using very low rates of fertilization, then placed one year in kudzu fallow. After one year of kudzu fallow, the area would again be intensively farmed for one year using the same low rates of fertilization. This experiment is expected to last for at least six years, which would allow sufficient time to study the changes in the physical and chemical properties of the soil after three years of farming interspaced with three years of kudzu fallow.

## 2.4 VARIETIES AND SOME AGRONOMIC FACTORS OF CORN PRODUCTION STUDIES

J. R. Benites and G. C. Naderman

Prior to the initiation of the intercropping-N experiment, it was necessary to obtain consistent information on the corn crop, since at the early stage of the research in Yurimaguas corn was identified as a problem crop. After evaluating corn yield data obtained in the different experiments conducted from 1972 through 1975, it was decided to try those corn varieties and hybrids obtained by the Corn Program of the National Agrarian University (UNA) and CIMMYT for tropical areas. Together with the study of genetic material (considered to be the first limitation) an attempt was made to learn about the response of these varieties to fertilization, plant population and other agronomic factors.

Summary of Previous Corn Yields (1972-1975)

During 1973-1975, corn yields were extremely low. In 1973, the local variety "Cuban Yellow," planted in a continuous cropping experiment, only yielded an average of 0.5 tons/ha. Severe attacks of pests and diseases as well as low levels of S, B, and Mo in the soil were observed.

In 1974 the average yield was 1.94 tons/ha. The corn variety Carimagua planted in the continuous cropping experiment, yielded an average of 1.7 tons/ha and a maximum yield of 3.1 tons/ha using the following fertilizer rates: 80-44-66 kg/ha of N, P, K plus 0.5 kg/ha of B and Mo, and 3.5 tons/ha of lime. These mediocre yields were attributed to the low genetic potential of the variety utilized and to pest and disease problems. In 1974, the best average yield was obtained with the variety Amarillo Planta Baja (3.2 tons/ha), planted in the N x spacing experiment, and a maximum yield of 4.0 tons/ha was obtained with the following fertilizer rates: 180-51-120 kg/ha of N, P, K plus 10 kg/ha of S, 0.5 kg/ha of B, 0.53 kg/ha of Mo, and 0.9 tons/ha of lime.

In 1975 the mean yield was 2.0 tons/ha. The variety PD $(MS)_6$ planted in continuous cropping experiment, yielded an average of 0.7 tons/ha and a maximum of 1.9 tons/ha. The climatic conditions during this planting season were not favorable, and the availability of soil nutrients was low. A yield of 5.8 tons/ha was obtained during 1975 with the hybrid PM-211 in the macro- and micronutrients experiment.

But the same hybrid planted in the same season in the P–S interaction experiment, only reached a mean yield of 0.7 tons/ha, and a maximum of 1.5 tons/ha obtained with the formula 120-53-100 kg/ha of N, P, K plus 60 kg/ha of S and 1.4 tons/ha of lime.

In summary, all possible factors that could have influenced corn yields during 1973-1975 did. These were genetic, agronomic, climatic, and pests.

Corn Varietal Response to Liming and Fertilization

Objectives and design. In earlier experiments maximum yields generally have been associated with the high fertility levels but there was no certainty that genetic material with the highest yield potential was used. This experiment consisted of a test of 22 tropical varieties and hybrids from the germplasm bank of the corn program of the National Agrarian University.

Before treatment the first 15 cm of soil contained 2.24 me and 3.03 me of Al and Ca + Mg, respectively, per 100g of soil and 43% Al saturation. Each variety was planted at two fertility levels (indicated as lime–N–P–K in kg/ha):

1. 500-0-0-0
2. 1500-180-66-83

Lime and P were applied during soil preparation 15 days before planting. The N was banded beside the plants and was split into three equal portions at 15, 30 and 45 days after planting. Applications of K and Mg were made at 15 days after planting. Atrazine was applied at 2 kg/ha for weed control. The crop was planted April 21 and harvested after 102-114 days.

Results. Table 2.4:1 presents yields of the varieties that reached more than 1.5 tons/ha, including the local variety for comparison. Yields of all varieties increased with fertilization and liming; the varieties Amarillo Planta Baja, PM-211, 1268 x 1273 ($C_{11}$ x $C_{16}$), and Tuxpeño Braquitico Blanco responded most to fertilization and liming with yield increases of 46%, 56%, 55%, and 56%, respectively. The local variety gave only a 17% yield response to liming and fertilization.

The highest yield at both fertility levels was obtained with the variety Amarillo Planta Baja. This variety also gave one of the highest responses to liming and fertilization with a 46% yield response. By comparing the yields of improved varieties with the local variety in the higher fertility treatment, it can be observed that Amarillo Planta Baja, 1268 x 1273, PM-211 and PMS-264 were superior producing respective yield increases of 113%, 88%, 74% and 70%.

During the experiment a strong insect, disease and bird attack occurred and it was observed (Table 2.4:2) that the highest proportion of damage occurred in low-lime plots, although in both cases the proportion was high. Table 2.4:3 shows some growth variables, such as plant height, precocity and susceptibility to lodging. The tallest plants were PMS-264 (2.83 m) and the local variety Cuban Yellow (2.87 m). The medium-height varieties were PM-211 (2.64 m), and Hibrido Tropical (2.67 m). The shorter varieties were Amarillo Planta Baja and Tuxpeño Braquitico Blanco with 2.33 m and 2.18 m, respectively. The hybrid PM-211 showed lodging

Table 2.4:1. Yield response of 10 corn varieties to lime and fertilization, Yurimaguas, 1976.

| Variety | Corn grain yield | | Yield response to lime and fertilization | Comparison with local variety (both rec'd fertil.) |
|---|---|---|---|---|
| | Low Lime Only | Lime + Fert. | | |
| | ---------- tons/ha -------- | | % | % increase |
| POB II | 1.73 | 2.60 | 33 | 44 |
| PMS-264 | 1.85 | 3.07 | 40 | 70 |
| Amarillo Planta Baja | 2.09 | 3.86 | 46 | 113 |
| $PD(MS)_6$ | 1.79 | 2.48 | 28 | 37 |
| PM-211 | 1.39 | 3.14 | 56 | 74 |
| PMC-747 | 2.03 | 2.88 | 30 | 59 |
| Hibrido Tropical | 1.51 | 2.59 | 42 | 43 |
| Tuxpeño Braquitico Blanco | 1.01 | 2.32 | 56 | 28 |
| 1268 x 1273 ($C_{11}$ x $C_{16}$) | 1.52 | 3.40 | 55 | 88 |
| Cuban Yellow (local variety) | 1.51 | 1.81 | 17 | -- |

$LSD_{.05}$ Between varieties at the same fertility level: 1.08

$LSD_{.05}$ For one variety at different fertility levels: 1.62

CV: 38%

Table 2.4:2. Relationship between fertilization and corn ear damage.

| Ear Damege | Low Lime Only | Lime & Fert. Plots |
|---|---|---|
| Healthy ears ( ) | 38 | 46 |
| Insect and disease damage ( ) | 36 | 33 |
| Bird damage ( ) | 26 | 21 |

Drs. George Naderman (center) and Dale Bandy (right) confer with Ing. Jose Benites regarding his experiment with N fertilization of corn, peanuts and rice. Yurimaguas, Peru. March, 1977.

Table 2.4:3. Some phenotypic variables of corn in the variety x fertilization experiment (mean of all plots).

| Variety | Plant Height | Total lodged at silking | Cumulative heat units at silking* |
|---|---|---|---|
| | m | % | |
| POB II | 2.55 | 1.53 | -- |
| PMS-264 | 2.83 | 5.31 | 1631 |
| Amarillo Planta Baja | 2.33 | 0.00 | 1521 |
| PD $(MS)_6$ | 2.47 | 3.04 | 1439 |
| PM-211 | 2.64 | 8.71 | 1631 |
| PMC-747 | 2.52 | 0.39 | -- |
| Hibrido Tropical | 2.67 | 1.90 | -- |
| Tuxpeño Braquitico Blanco | 2.18 | 0.00 | 1742 |
| 1268 x 1273 $(C_{11} \times C_{16})$ | 2.81 | 2.66 | -- |
| Cuban Yellow (local variety) | 2.87 | 3.03 | 1687 |

*Cumulative heat units at silking stage were calculated according to the formula of Gilmore and Rogers, $\left(\frac{\text{Max. temp °F + Min. temp °F}}{2} - 50\ \text{°F}\right)$ correction for temperature above 86 °F was made.

susceptibility with 9% of the plants lodged at 73 days after planting and 50% at harvest time. In contrast were the varieties Amarillo Planta Baja and Tuxpeño Braquitico Blanco, which showed zero lodging both at 73 days and at harvest time. Finally, the earliest maturing varieties were PD $(MS)_6$ and Amarillo Planta Baja and the latest maturing varieties were Cuban Yellow and Tuxpeño Braquitico Blanco as determined by cumulative heat units at silking.

## Varieties and Plant Population Studies with Corn

Objectives and design. The experiment on varieties and plant population conducted in 1975 showed that as plant population was increased from 55,000 to 66,000 per hectare, yields tended to diminish, both in the fertilized + limed and low limed treatments. For this reason in 1976, an experiment was installed, which had 44,000 and 53,000 plants per hectare as population treatments. Both populations were planted at the same fertilization level (160-66-125 kg/ha of N–P–K plus 18 kg/ha of Mg and 2 tons/ha of lime). The most promising corn varieties from the variety and fertilization experiment were utilized, including the local variety Cuban Yellow as check. Corn was planted in September in Chacra IV.

The population of 44,000 was obtained by planting rows of 0.90 with 0.25 m between plants. The 53,000 population was obtained with rows at 0.75 cm and 0.25 cm between plants. Half of the N was applied 10 days after planting with the balance at 30 days. Lime and P were applied during land preparation prior to planting. All K and Mg were applied together with the first half of N. Harvest was 126 days after planting.

Results. Table 2.4:4 shows that yields of all varieties but one increased as the population increased from 44,000 to 53,000 plants per hectare. The varieties PMS-264, PD $(MS)_6$ and PMC-747 significantly responded to the higher population with yield increases at 35%, 27%, and 25%, respectively. However, the yield of Tuxpeño Braquitico Blanco decreased by 69% as plant population increased.

With respect to variety effect, Hibrido Tropical had an exceptionally high yield of 6.49 tons/ha which greatly exceeded yields of the other varieties. However, Hibrido Tropical and other corn hybrids were badly affected during the dry season, especially at the low fertility level. Due to this consideration, for further studies we preferred the composite variety Amarillo Planta Baja which exhibited a tolerance to dry season and wet seasons in low and high fertility levels.

## Planting Date Effect on Corn Grain Yield

The influence of planting date and associated environmental factors is apparent by comparison of the yields of two experiments previously reported. The variety x fertilization study was planted in April, and the variety x plant population study was planted in September 1976.

Results of this comparison are presented in Fig. 2.4:1. Yields of corn planted in September were 43% greater than those of corn planted in April. Varieties having the greater yield increases from September planting were Hibrido Tropical, PD $(MS)_6$, PMC-747, POB-11 and PMS-264.

Table 2.4:4. Plant population effect on grain yield of 10 corn varieties planted in September 1976. Yurimaguas.

| | Plant population, plants/ha | | | | |
|---|---|---|---|---|---|
| | 40,000 | | 50,000 | | |
| Variety | Grain yield | Yield compared with local variety | Grain yield | Yield compared with local variety | Yield response to high population |
| | tons/ha | % change | tons/ha | % change | % change |
| POB II | 4.24 | 8.7 | 4.81 | 20.3 | 11.9 |
| PMS-264 | 3.51 | -10.0 | 5.42 | 35.5 | 35.2 |
| Amarillo Planta Baja | 4.14 | 6.2 | 4.72 | 18.0 | 12.5 |
| PD $(MS)_6$ | 3.74 | - 4.1 | 5.09 | 27.3 | 26.5 |
| PM 211 | 4.57 | 17.2 | 5.02 | 25.5 | 9.0 |
| PMC-747 | 4.17 | 6.9 | 5.52 | 38.0 | 24.5 |
| Hibrido Tropical | 5.94 | 52.3 | 6.49 | 62.3 | 8.5 |
| Tuxpeño Braquitico Blanco | 5.34 | 36.9 | 3.16 | -21.0 | -69.0 |
| 1268 x 1273 ($C_{11}$ x $C_{16}$) | 4.07 | 4.4 | 4.81 | 20.3 | 15.4 |
| Cuban Yellow (local variety) | 3.90 | -- | 4.00 | -- | 2.5 |
| Mean | 4.30 | | 4.91 | | |

$LSD_{.05}$ Plant population: 1.34 tons/ha

$LSD_{.05}$ Varieties: 0.95 ton/ha

CV: 15%

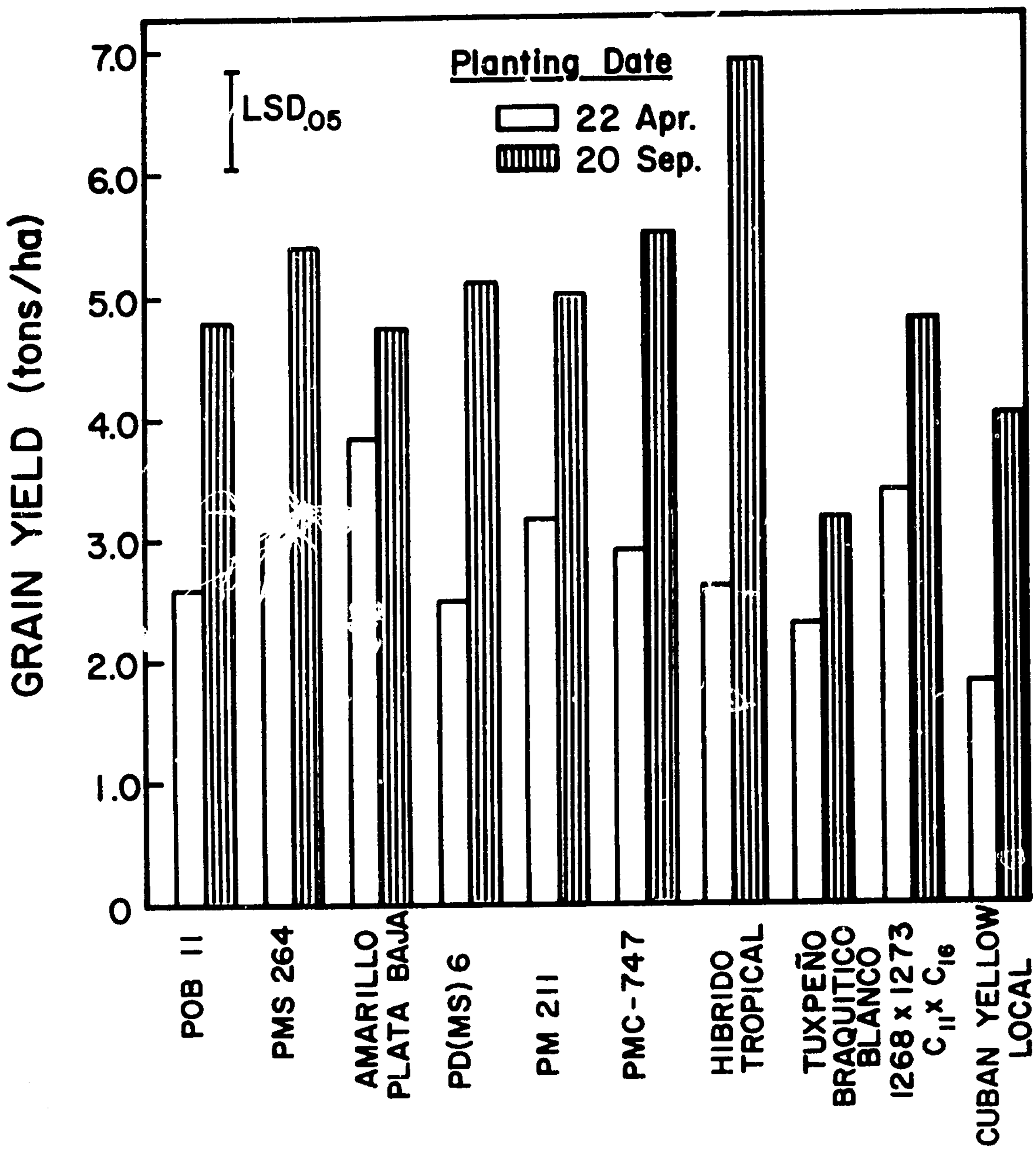



Figure 2.4:1. The effect of planting date and associated environmental factors on corn yields in Yurimaguas, 1976.

Table 2.4:5 shows some of the average results of various climatic observations during the growth of both crops. In September, the precipitation more than doubled that of the April planting; furthermore, between June and July, 51 cumulative days and more than 10 consecutive days without rain were reported. It appears that this dry period during the first planting favored the increase of corn pests (Table 2.4:6), especially during the flowering and maturation process, which affected yields adversely. On the other hand, during the September planting there was sufficient precipitation with normal distribution patterns.

Cumulative solar radiation was higher in the September than in the April planting. This factor may have influenced the yield-producing potential per hectare in September because this period received more solar radiation available for photosynthesis.

All these data demonstrated that the planting date had a large influence on corn yield. Good varieties with an adequate level of fertilization may fail if planted during the wrong planting season.

Planting System, Row Spacing and Hilling

Objectives and design. The objective of this experiment was to determine if the utilization of hilling and a better distribution of plants in the land could increase the efficiency of fertilization, as well as to determine if they could reduce plant lodging.

This experiment was installed in Chacra III. The varieties Amarillo Planta Baja and the hybrid PM-211 were utilized. The treatments for each variety were row spacings of 0.90 or 0.75 m, planting systems of "drilling hill" (one plant each 0.25 m) or "dropped hill" (three plants each 0.75 m), and no, one or two hillings. The combination of these factors gave 12 treatments for each variety. For all treatments, the following fertilization formula was utilized: 160-66-83 kg/ha of N–P–K plus 18 kg/ha of Mg and 2 tons/ha of lime. Planting was according to treatment. First and second hillings were 15 and 30 days after planting. Nitrogen was split into two equal applications, and in each case before the hilling process. Harvest was 120 days after planting.

Results. Table 2.4:7 shows the yields obtained with the variety Amarillo Planta Baja. It can be noted that the hilling practice increased the yields from 4.90 tons/ha (without hilling) to 6.60 tons/ha (with one hilling), utilizing a row spacing of 0.75 m. With a row spacing of 0.90 m there were no differences in yields between one-hilling and no-hilling, but with two-hillings there was a significant increase in yields. There were no differences found between planting systems and row spacings.

The hybrid PM-211 had a mean yield lower than that of Amarillo Planta Baja. None of the factors being studied significantly affected the yields of this hybrid and thus, the results obtained with this hybrid are not presented in this report.

Stalk-Doubled Over Effect on Corn Grain Yields

Objectives and design. During the drier season, there is a high incidence of bird and insect damage to corn. In the rainier season, damage is caused by disease. In both cases, yields can be reduced up to 50%. A common practice utilized

Table 2.4:5. Some climatic observations at the two growing periods.

| Growing Parameter | Growing Period April 20 to August 12 | Growing Period September 20 to January 24 |
|---|---|---|
| Cumulative precipitation (mm) | 489.1 | 1043.7 |
| Cumulative solar radiation $kCal/gr^1/cm^{-2}$ | 39.9 | 49.8 |
| Average temperature[1/] (°C) | 25.2 | 26.5 |
| Average maximum temperature (°C) | 30.5 | 32.2 |
| Average minimum temperature (°C) | 20.9 | 20.5 |
| Average relative humidity[1/] (%) | 83.3 | 78.8 |
| Average standard P.A.N. evaporation (mm) | 3.4 | 2.5 |

[1/] Average temperature and average relative humidity are based on the daily averages from readings taken 07:00, 13:00 and 19:00 hours.

Table 2.4:6. Insect and disease damaged corn ears at two planting dates

| Planting date | Healthy ears | Insect and disease damaged ears | Bird damaged ears |
|---|---|---|---|
| | % | | |
| April 20 | 42 | 34.5 | 23.5 |
| September 20 | 67 | 28.0 | 5.2 |

Mr. Jose Benites takes notes regarding his N fertilization experiment with corn, peanuts and rice.

Table 2.4:7. Planting system, row spacing and hilling effects on corn grain yield of Amarillo Planta Baja. September, 1976. Yurimaguas.

| Row Spacing | | Planting system: Dropped | Planting system: Drilling | Mean: Hilling Practice | Mean: Row Spacing |
|---|---|---|---|---|---|
| cm | | ton/ha | | | |
| 75 | No hilling | 5.54 | 4.25 | 4.90 | |
| | One hilling | 6.60 | 6.60 | 6.60 | |
| | Two hilling | 5.18 | 6.16 | 5.67 | |
| | Mean | 5.77 | 5.67 | | 5.72 |
| 90 | No hilling | 4.74 | 3.85 | 4.30 | |
| | One hilling | 6.37 | 3.64 | 5.01 | |
| | Two hilling | 5.99 | 5.84 | 5.92 | |
| | Mean | 5.70 | 4.44 | | 5.08 |
| Mean Row Spacing | No hilling | 5.14 | 4.05 | 4.60 | |
| | One hilling | 6.49 | 5.12 | 5.81 | |
| | Two hilling | 5.59 | 6.00 | 5.80 | |
| | Mean | 5.74 | 5.06 | | 5.40 |

$LSD_{.05}$ Hilling Practice: 1.99

Method of planting and row spacing were not significant.

CV: 21%

by small farmers of the tropics in order to avoid these problems is "stalk doubling." The objective of this experiment was to determine if this is an agronomically sound practice and to determine which is the best time to perform it. The stalks were doubled at four weekly intervals, with the first beginning 20 days after silking.

This experiment was installed with a Cuban Yellow seed planted in June. The plot received only 50 kg/ha of N and 500 kg/ha of lime. The stalk doubling was made below the principal ear. Harvest was 41 days after silking.

Results. In Table 2.4:8 it can be noted that stalk doubling did not affect the yields even though stalks were doubled beginning 20 days after the beginning of the silking stage. The humidity percentage was 60.1% at the time of the first stalk doubling, and 23% at harvest. It is possible that the early utilization of this practice could help corn avoid the consequences of adverse climatic conditions which may favor pest and disease infestation and also may reduce the negative effect on shorter plants (rice, peanuts, soybeans) that may grow intercropped with corn. However, this supposition must be further tested before a conclusive statement can be made.

Tropical Corn Varieties and Hybrid Trials from CIMMYT

Objectives and design. In August 1976 corn seeds were received from CIMMYT which were planted in September in Chacra IV, with the purpose of expanding the information on genetic material adapted to the tropics.

This experiment was fertilized with 160-44-83-18 kg/ha of N–P–K–Mg. The soil was not limed since 1.5 tons/ha of lime had been applied at the previous planting. Planting was at a population of 50,000 plants per hectare (0.90 m between rows and 0.60 m/3 plants).

Results. The varieties Mezcla Tropical Blanca, (Ver. 181-Ant. Gpo. 2) $O_2$, and La Posta were the only ones that significantly out-yielded the check variety Cuban Yellow (Table 2.4:9). The varieties Tuxpeño 1, Braquitico, Yellow H.E.$O_2$ and Tuxpeño Caribe-1 yielded less, but not significantly than the local variety.

General Conclusions. Genetic material has a great influence on corn yield. However, good varieties with adequate fertilization may fail if planted during the wrong planting season.

The corn variety Amarillo Planta Baja had the best overall yields in the various trials. It ranked first in the fertilizer and liming treatments (3.86 tons/ha), as well as in the treatment without fertilizer and low-levels of liming (2.09 tons/ha). Yields obtained in the dry season (April planting) and the rainy season (September planting) were favorable compared to those of hybrids and other varieties which were badly affected during the dry season. In addition, the relative shortness of this variety (2.3 m) makes it resistant to lodging. On the other hand, Amarillo Planta Baja is an early variety, which silks in 50 to 58 days, and matures in 90 to 100 days, making it possible to harvest with a 20-25% grain humidity. Due to its earliness, this variety can be planted up to three times a year, with a potential grain yield of more than 10 tons/ha/ year.

Table 2.4:8. Effect of stalk doubling on corn grain yield of the Cuban Yellow variety. 1976. Yurimaguas.

| Date of Doubling | Days after silking | Grain Humidity | Grain Yield |
|---|---|---|---|
| | | % | tons/ha |
| September 4 | 20 | 60.1 | 1.49 |
| September 11 | 27 | 48.0 | 1.57 |
| September 18 | 34 | 26.4 | 1.55 |
| September 25 (harvest) | 41 | 23.0 | 1.66 |

$LSD_{.05}$: 1.03

CV: 30%

Table 2.4:9. Yield parameters of 22 CIMMYT tropical corn varieties. September, 1976. Yurimaguas.

| Varieties | Grain | Stover | Dry Matter | Grain Stover Ratio |
|---|---|---|---|---|
| | tons/ha | | | |
| Tuxpeño-1 | 2.74 | 3.53 | 6.27 | 0.75 |
| Mezcla Tropical Blanca | 4.84 | 5.28 | 10.13 | 0.94 |
| Blanco Cristalino-1 | 4.33 | 3.84 | 8.17 | 1.23 |
| (Ver. 181 x Ant. Gpo. 2) Ven. 1$O_2$ | 4.04 | 5.26 | 9.30 | 0.77 |
| (Mix. 1 - Col. Gpo. 1) Eto | 3.65 | 5.99 | 9.63 | 0.62 |
| Mezcla Amarilla | 3.69 | 5.25 | 8.94 | 0.81 |
| Amarillo Cristalino-1 | 4.01 | 6.50 | 10.52 | 0.62 |
| Amarillo Dentado-2 | 4.17 | 4.55 | 8.73 | 0.92 |
| Tuxpeño Caribe-2 | 4.82 | 5.46 | 10.28 | 0.91 |
| Amarillo Dentado-1 | 4.54 | 5.71 | 10.24 | 0.83 |
| Braquitico | 2.75 | 5.61 | 8.36 | 0.48 |
| Tuxpeño Caribe-1 | 3.03 | 4.14 | 7.17 | 0.99 |
| Cogollero | 3.67 | 4.46 | 8.13 | 0.84 |
| Tuxpeño $O_2$ | 3.71 | 5.48 | 9.19 | 0.69 |
| (Ver. 181-Ant. Gpo. 2) $O_2$ | 4.97 | 7.07 | 12.05 | 0.71 |
| Yellow H.E. $O_2$ | 3.30 | 5.02 | 8.05 | 0.66 |
| White H.E. $O_2$ | 3.17 | 3.54 | 6.71 | 0.89 |
| La Posta | 4.88 | 7.31 | 12.18 | 0.66 |
| Eto Blanco | 4.24 | 4.72 | 8.96 | 0.91 |
| Ant. x Rep. Dominicana | 3.92 | 2.95 | 6.87 | 1.39 |
| Eto x Tuxpeño | 4.51 | 5.16 | 9.67 | 0.88 |
| Cuban Yellow Local | 3.32 | 4.82 | 8.13 | 0.59 |
| Mean | 3.92 | 5.08 | 8.98 | 0.82 |
| $LSD_{.05}$ | 1.52 | 1.89 | 2.89 | 0.44 |
| CV (%) | 22.8 | 22.0 | 18.9 | 31.3 |

## 2.5 PHOSPHORUS AND SULFUR STUDIES

J. H. Villachica and P. A. Sanchez

Objectives and design. The basic idea for performing this research was outlined in the 1975 Annual Report. First crop yields (corn) were reported at that time. The same plots were used to study residual effects of the lime, P, and S initially applied. Rice was used as the test crop, and following its harvest, new rates of superphosphate and rock phosphate were applied prior to soybean planting. Table 2.5:1 shows the distribution of rice treatments. Treatments 1 through 15 were used to test the residual effect of P, employing three and two rates of rock phosphate (RP) and triple superphosphate (TSP), respectively. Treatments 16 and 17 were used to determine whether the S contained in the superphosphate (SSP) would provide the S needed by the plants. Treatment 18 was a check. Treatments 19 and 20 were used to test if RP applications prior to those of SSP would compensate for the use of lime in this very acid soil. All treatments were applied prior to corn planting, as reported in the 1975 Annual Report. After corn was harvested, rice (cv. IR-4-2) was planted on November 29, 1975, with no additional P, S, or lime. Following the rice harvest of April 14, 1976, new levels of RP, TSP, SSP, and lime were applied on April 25, as described in Table 2.5:1. Soybeans (cv. XLM) were planted on May 11, 1976. A basal application of 120 kg N/ha and 100 kg K/ha was applied for rice. Soybeans received only 30 kg N/ha and 100 kg K/ha. Soybeans were harvested on August 30.

Results. Table 2.5:1 also presents yields of rice and soybeans harvested during 1976. Rice yields with the first nine treatments, fertilized with RP, but no lime, were very low. In all of the first nine treatments except those of 7 and 9, yields were 0.5 ton grain/ha or less. Data presented in Table 2.5:2, with soil samples taken before planting, indicate that these very low yields were limited by the high amounts of exchangeable Al and the high percentage of Al saturation in the soil. In fact, Al toxicity symptoms were easily identified on rice plants growing on these plots. These high Al contents were explained by the lack of lime application to the soil and by the history of the field. All three replications were former bulldozed plots which received no lime initially, neither from ash nor from liming material. Data presented in Table 2.5:1 indicated that even though a high available P content (Olsen method) was built up in the soil, such as in treatments 7, 8, and 9, rice would not grow adequately unless Al toxicity was neutralized. As it will be discussed later, this was noted also for soybeans.

Figure 2.5:1 shows the difference between rice yields as determined by residual effects of RP and those of TSP plus 1.4 tons lime/ha. Yields of rice averaged over 1.3 tons/ha in the treatments where residual effect of the two levels of TSP was noted. Differences due to the residual effect of S were not significant.

Rice yields on residual SSP plots (treatments 16 and 17) were similar to those on all residual TSP plots, both with and without S. Thus, a response to residual S was not evident in the rice

Table 2.5:1. Corn, rice, and soybean yields as affected by P sources and rates. Average of three replications. Yurimaguas, 1975-1976.

| | | Rate Prior to Corn Planting | | | Rate Prior to Soybean Planting | | Grain Yields.*/ | | |
|---|---|---|---|---|---|---|---|---|---|
| | P | P | S | Lime | P | Lime | Corn | Rice | Soybean |
| Tmt | Source | -----kg/ha----- | | t/ha | kg/ha | t/ha | -------kg/ha--------- | | |
| 1 | RP | 26 | 0 | 0 | 218 | 0 | 48 | 237 | 240 |
| 2 | RP | 26 | 30 | 0 | 218 | 0 | 10 | 302 | 308 |
| 3 | RP | 26 | 60 | 0 | 218 | 0 | 130 | 449 | 352 |
| 4 | RP | 52 | 0 | 0 | 327 | 0 | 330 | 215 | 299 |
| 5 | RP | 52 | 30 | 0 | 327 | 0 | 95 | 121 | 419 |
| 6 | RP | 52 | 60 | 0 | 327 | 0 | 14 | 167 | 417 |
| 7 | RP | 208 | 0 | 0 | 436 | 0 | 1,280 | 956 | 793 |
| 8 | RP | 208 | 30 | 0 | 436 | 0 | 911 | 309 | 480 |
| 9 | RP | 208 | 60 | 0 | 436 | 0 | 624 | 556 | 841 |
| 10 | TSP | 26 | 0 | 1.4 | 26 | 1.0 | 1,068 | 1,229 | 1,262 |
| 11 | TSP | 26 | 30 | 1.4 | 26 | 1.0 | 1,300 | 1,793 | 1,255 |
| 12 | TSP | 26 | 60 | 1.4 | 26 | 1.0 | 531 | 1,538 | 1,037 |
| 13 | TSP | 52 | 0 | 1.4 | 52 | 1.0 | 1,055 | 1,567 | 1,258 |
| 14 | TSP | 52 | 30 | 1.4 | 52 | 1.0 | 1,330 | 1,538 | 1,202 |
| 15 | TSP | 52 | 60 | 1.4 | 52 | 1.0 | 1,540 | 1,751 | 1,262 |
| 16 | SSP | 26 | 0 | 1.4 | 26 | 1.0 | 1,324 | 1,583 | 1,085 |
| 17 | SSP | 52 | 0 | 1.4 | 52 | 1.0 | 1,430 | 1,542 | 1,217 |
| 18 | NONE | 0 | 0 | 0 | 52 | 2.0 | 0 | 349 | 857 |
| 19 | SS+RP | 26SSP+26RP | 0 | 0 | 26SS+436RP | 0 | 210 | 609 | 551 |
| 20 | SS+RP | 26SS+183RP | 0 | 0 | 52SS+436RP | 0 | 1,203 | 709 | 629 |
| $LSD_{.05}$ | | | | | | | 461 | 709 | 358 |

*/ Planting dates for corn, rice, and soybean were July 1975, November 1975, and May 1976, respectively.

Table 2.5:2. Some soil chemical properties on P and S plots sampled in November 1975. (Average of two replications)

| Tmt | Mod. Olsen P | 6N $H_2SO_4$ K | pH | O.M. | 1N KCl extract. Al | 1N KCl extract. Ca | Al Sat. |
|---|---|---|---|---|---|---|---|
| | ppm | ppm | | % | ----me/100g---- | | % |
| 1 | 6 | 52 | 4.0 | 2.5 | 2.1 | 0.7 | 64 |
| 2 | 4 | 50 | 4.3 | 2.2 | 3.0 | 1.8 | 57 |
| 3 | 6 | 58 | 4.0 | 2.5 | 2.9 | 0.9 | 67 |
| 4 | 10 | 55 | 4.0 | 2.4 | 2.6 | 1.3 | 59 |
| 5 | 8 | 48 | 4.0 | 2.6 | 2.9 | 1.0 | 66 |
| 6 | 7 | 65 | 3.9 | 2.1 | 3.1 | 0.8 | 70 |
| 7 | 24 | 44 | 4.4 | 2.5 | 3.1 | 1.2 | 65 |
| 8 | 28 | 52 | 4.2 | 2.8 | 2.2 | 1.4 | 54 |
| 9 | 27 | 65 | 4.3 | 2.5 | 1.7 | 1.8 | 43 |
| 10 | 5 | 52 | 4.7 | 2.7 | 1.0 | 3.0 | 22 |
| 11 | 5 | 65 | 4.7 | 2.4 | 0.7 | 2.9 | 17 |
| 12 | 4 | 52 | 4.4 | 2.2 | 2.5 | 2.3 | 50 |
| 13 | 8 | 52 | 4.7 | 2.0 | 2.1 | 2.5 | 41 |
| 14 | 7 | 65 | 4.4 | 2.3 | 2.3 | 2.7 | 42 |
| 15 | 12 | 44 | 4.7 | 2.8 | 0.5 | 3.3 | 12 |
| 16 | 3 | 39 | 4.6 | 2.5 | 1.3 | 3.1 | 27 |
| 17 | 6 | 44 | 4.7 | 2.3 | 0.9 | 3.2 | 20 |
| 18 | 4 | 65 | 4.1 | 2.4 | 2.2 | 1.5 | 52 |
| 19 | 11 | 65 | 4.1 | 2.5 | 2.4 | 1.6 | 53 |
| 20 | 27 | 50 | 4.2 | 2.6 | 1.4 | 1.5 | 41 |

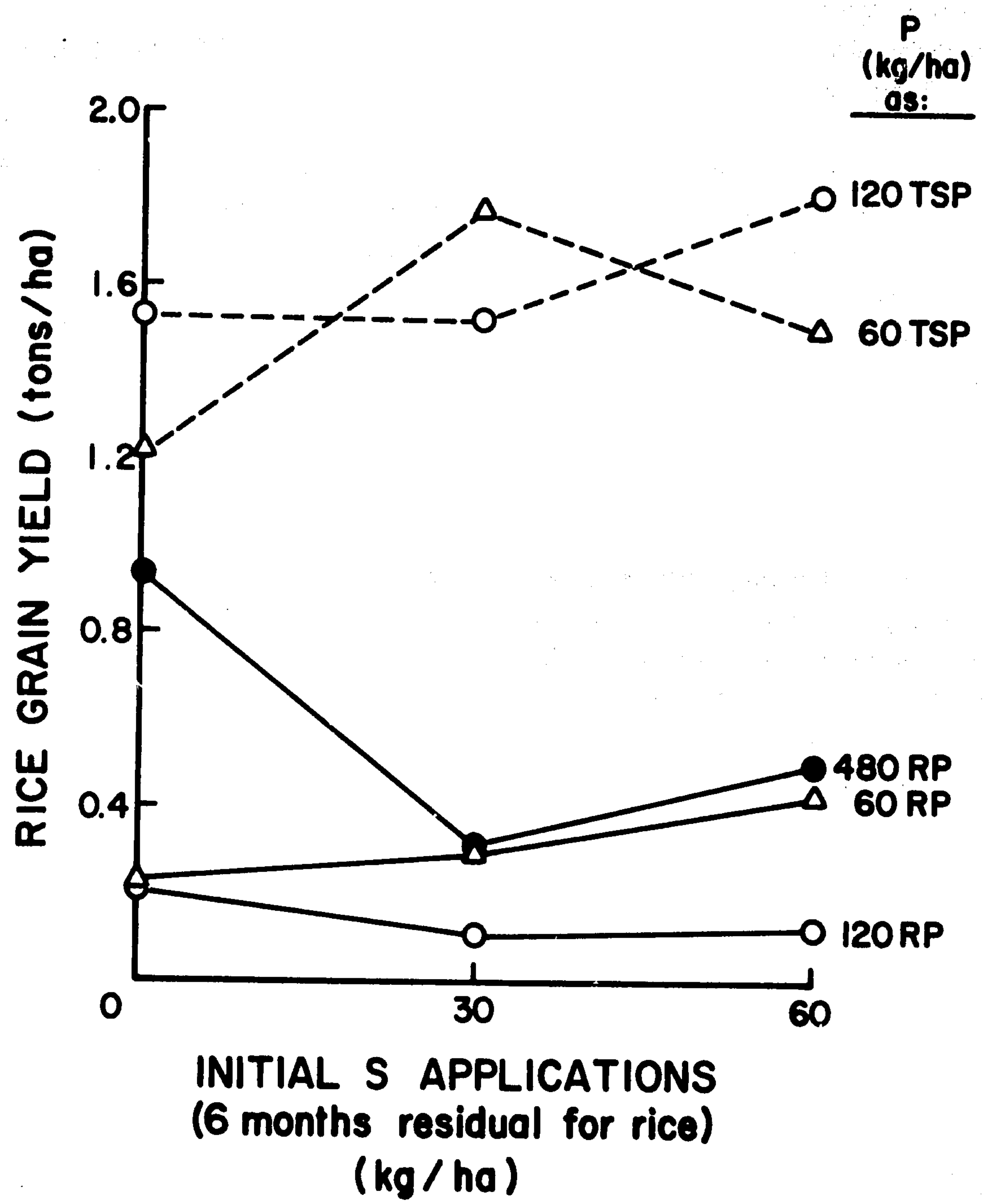



Figure 2.5:1. Effect of residual P and S on rice yields in Yurimaguas, 1976. Average of 3 replications. Triple superphosphate = TSP; rock phosphate = RP.

yields. Neither did the following crop of soybeans show a response to the residual S of SSP.

Considering the low rice yields obtained with the RP treatments, higher levels of RP were used (Table 2.5:1) to determine if Al toxicity problems could be alleviated in this way. Fifteen days prior to soybean planting, RP or TSP plus 1 ton lime/ha were applied. No further additions of S were made except where SSP was applied with lime or with RP (treatments 16-20).

Soybean grain yields follow a similar pattern to that described for rice (Table 2.5:1). Thus, yields on the plots that received lime plus either TSP or SSP were higher than those that received only RP. However, soybean yields on plots 7 and 9, where a total of 644 kg P/ha as RP were applied during the entire study, were not too different from those of the plots that received TSP or SSP, i.e., treatments 12 or 16.

Lack of difference between treatments 16 and 17 (those that received SSP) and treatments 10-15 (those that received TSP) indicated that S was not limiting yields at this time. It should be pointed out that in addition to Al, other limiting problems in this experiment were believed to be Mg deficiency and the low amount of N applied for rice. Magnesium deficiency was proved to be a limiting factor on soils of the area at the time soybeans were planted, but it could not be corrected because the only two available Mg fertilizers were Mg sulfate and K-Mg sulfate, both of which are also sources of S.

## 2.6 MICRONUTRIENT RESEARCH

J. H. Villachica and P. A. Sanchez

Experiment 1. Responses to Lime, K, Mg and Micronutrients.

Objectives and design. Preliminary results on secondary and micronutrient studies reported in the 1975 Annual Report showed a strong response of corn and soybeans to lime and magnesium and a good response of soybeans to foliarly-applied micronutrients. Both studies were continued to determine the residual effect of lime and Mg and the effect of new applications of K and micronutrients. Both crop sequences (soybeans–rice–corn and corn–rice–soybeans) were planted with rice (cv. IR-4-2) on November 24, 1975, and harvested on April 7, 1976. Corn (cv. PM-211) and soybeans (cv. National) were planted on April 23, 1976, after rice was harvested. Soybeans were lost due to herbicide residual effect. Corn was harvested on August 23, 1976. Before each sowing of rice or corn, K was applied in the amounts shown in Table 2.6:1. A basal application of 150, 70, and 22 kg N, P, S/ha, respectively, was made in all plots. Micronutrients were twice sprayed on the leaves: at 45 and 67 days for rice, and at 20 and 40 days for corn. Residual effects of lime (applied May 23, 1975) and Mg (applied June 25, 1975) were studied. A composite rotable design of treatments as presented in Table 2.6:1 was used.

Table 2.6:1. Rice and corn yields as affected by the application of K, microelements, and the residual effect of lime and Mg. Yurimaguas, 1976[1].

| Treatment[2] | | | | | Grain Yields | | |
|---|---|---|---|---|---|---|---|
| | | | | | Corn-Rice-Soybean Sequence | Soybean-Rice-Corn Sequence | |
| No. | Lime | K | Mg | Micro-nutrient Level[3] | Rice | Rice | Corn |
| | t/ha | --kg/ha-- | | | kg/ha | | |
| 1 | 1 | 83 | 9 | 1 | 3112 | 2644 | 1656 |
| 2 | 3 | 83 | 9 | 3 | 3538 | 2882 | 5239 |
| 3 | 1 | 166 | 9 | 3 | 3224 | 1516 | 148 |
| 4 | 3 | 166 | 9 | 1 | 4190 | 3462 | 3529 |
| 5 | 1 | 83 | 27 | 3 | 4117 | 822 | 3224 |
| 6 | 3 | 83 | 27 | 1 | 4880 | 2536 | 4056 |
| 7 | 1 | 166 | 27 | 1 | 2731 | 2940 | 2075 |
| 8 | 3 | 166 | 27 | 3 | 3187 | 3530 | 4309 |
| 9 | 1 | 83 | 9 | 3 | 3336 | 3094 | 428 |
| 10 | 3 | 83 | 9 | 1 | 4060 | 4262 | 3926 |
| 11 | 1 | 166 | 9 | 1 | 2964 | 2948 | 148 |
| 12 | 3 | 166 | 9 | 3 | 4638 | 4322 | 3650 |
| 13 | 1 | 83 | 27 | 1 | 3603 | 2552 | 1524 |
| 14 | 3 | 83 | 27 | 3 | 3496 | 4328 | 4890 |
| 15 | 1 | 166 | 27 | 3 | 3244 | 2912 | 1192 |
| 16 | 3 | 166 | 27 | 1 | 4544 | 2986 | 2779 |
| 17 | 0 | 0 | 0 | 0 | 802 | 380 | 1 |
| 18 | 2 | 125 | 18 | 2 | 3670 | 3662 | 3281 |
| 19 | 0 | 125 | 18 | 2 | 3236 | 2162 | 138 |
| 20 | 4 | 125 | 18 | 2 | 3726 | 3796 | 5273 |
| 21 | 2 | 41 | 18 | 2 | 3100 | 2814 | 3529 |
| 22 | 2 | 208 | 18 | 2 | 3384 | 3804 | 3592 |
| 23 | 2 | 125 | 0 | 2 | 3562 | 2910 | 1617 |
| 24 | 2 | 125 | 36 | 2 | 3502 | 2787 | 3658 |
| 25 | 2 | 125 | 18 | 0 | 3974 | 2678 | 1278 |
| 26 | 2 | 125 | 18 | 4 | 3586 | 3270 | 5301 |

[1] Basal rate of 150 kg N/ha, 70 kg P/ha, and 22 kg S/ha was applied.

[2] Lime and Mg were applied on May 23 and June 25, 1975; K was applied before each planting. Micronutrients were applied two times as spray during the growing period.

[3] Micronutrient level 1 was: two sprays of a solution of 22 g zinc sulfate, 21 g manganese sulfate, 25 g iron sulfate, 7 g copper sulfate, 11 g borax, 1 g ammonium molybdate, and 43 g lime, all for 11 liters of water, applied at a rate of 600 liters/ha. Levels 2, 3, and 4 of micronutrients were 2, 3, and 4 times level 1, respectively.

Results. Yield response of rice to the different treatments and in both crop sequences is shown in Fig. 2.6:1. A response to the residual lime can be observed in the experiment where rice was planted after soybeans. The response was lower in the companion experiment. From the data of Fig. 2.6:1, it seems that lime and K were the most limiting factors for rice production in this soil.

Table 2.6:2 presents some soil chemical properties in soil samples taken before rice was planted (corn–rice–soybeans sequence). It can be observed that pH was 4.3 in the unlimed plot, 4.6 where 2 tons lime/ha were applied five months earlier, and 5.6 where 4 tons lime/ha were applied also five months earlier. Similarly, Al saturation decreased from 48% to 24% and 9%, respectively. This evidence indicated that even though pH was low in the plots that received 2 tons lime/ha initially, Al saturation was not sufficiently high to cause problems for rice. Yields of rice on the fertilized plots that were limed initially with 2 tons lime/ha or more averaged 3.5 tons grain/ha. This yield was considered excellent for upland rice growing in this old abandoned soil with very low native soil fertility.

Response to K of rice following corn exhibited the same pattern as did the previous crop. Thus, the maximum response was to 83 kg K/ha. When rice was planted after soybeans, the highest yield was observed with 125 kg K/ha. No clear response to the residual effect of Mg was found. Rice growing after soybeans (SAM experiment) showed only small yield response to residual Mg. Rice planted after maize (MAS experiment) did not show response to residual Mg.

Rice yield response to micronutrients was found only on those plots that had a previous crop of soybeans. In these cases, the yield difference between the treatment that received micronutrient level 2 and that not receiving micronutrients was 984 kg/ha.

To continue studying the residual effect of lime and magnesium, corn was planted next in the sequence soybeans–rice–corn. Potassium was applied before planting and micronutrients were applied foliarly at 15 and 35 days at rates given in Table 2.6:1. Corn (cv. PM-211) was used.

Corn yields as influenced by treatment are given in Table 2.6:1 and Fig. 2.6:2. A very dramatic response of corn to the residual effect of lime can be observed in Fig. 2.6:2. Corn yields were almost nil in the unlimed plots but followed a linear response to the residual effect of the lime initially applied. No yield plateau was reached. The initially-applied 1 ton lime/ha level which gave those good soybean yields eight months earlier no longer provided adequate soil conditions for corn growth. Yields over 4 tons grain/ha were obtained only with the residual effect of 3 or 4 tons lime/ha applied at the beginning of the experiment. The experiment was limed on May 23, 1975, and then soybeans and rice were grown successfully up to April 1976. Thus, the residual effect of 1 ton lime/ha lasted only about ten months. The residual effect of 2 tons lime/ha was noticeable, but reduced. This fast depreciation of the residual effect of lime can be explained by the high leaching conditions in Yurimaguas which moved Ca into the subsoil (Villachica, Ph.D. Dissertation, 1978) and on the lime source used. Lime source used was calcium

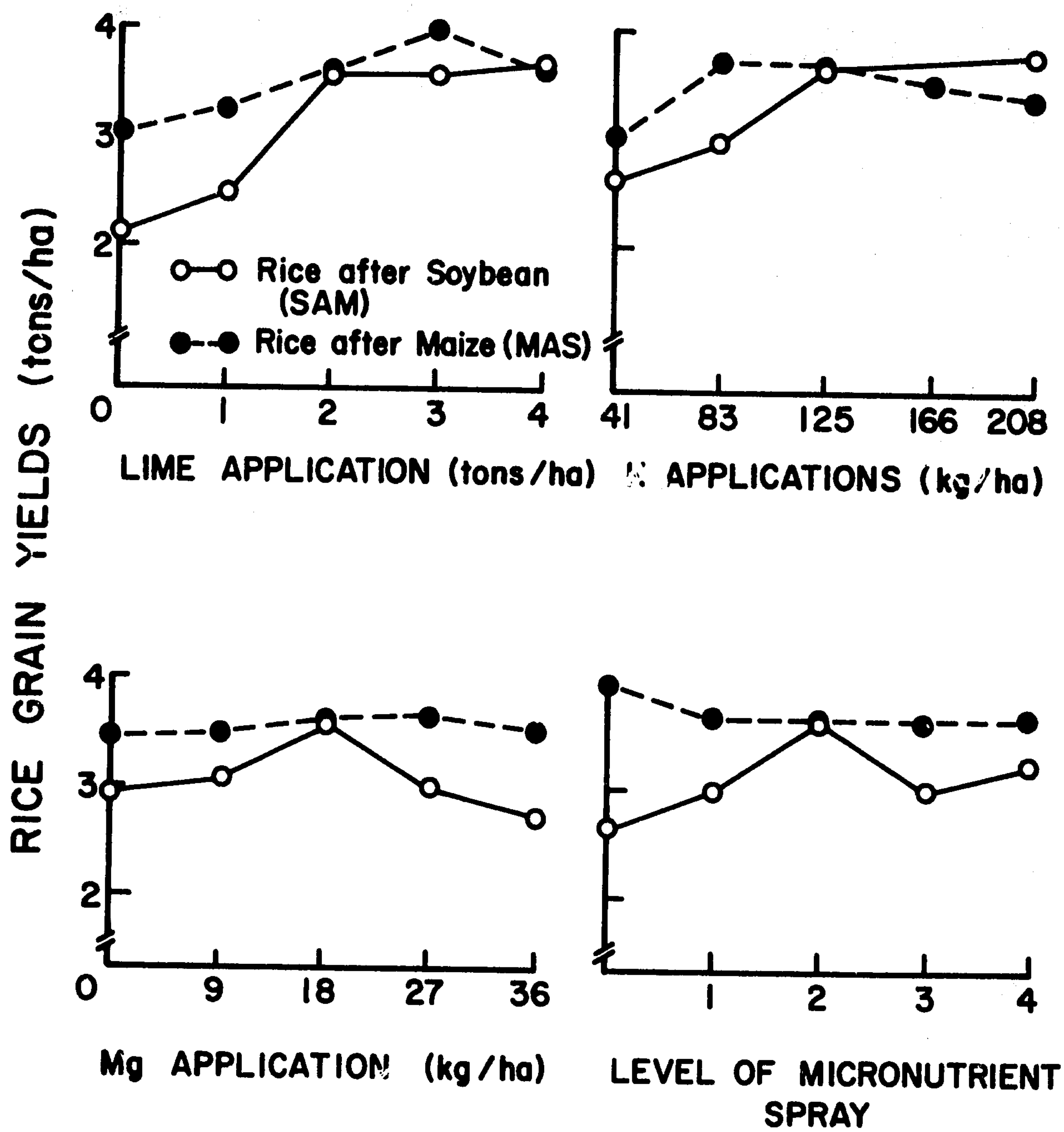



Figure 2.6:1. Rice grain yields following soybeans (o—o SAM experiment) or maize (o—o MAS experiment), as affected by the application of K and micronutrients and the residual effects of lime and Mg. Yurimaguas, 1976.

Table 2.6:2. Some soil chemical properties on the secondary and micronutrient experiment with the corn-rice-soybean sequence. Yurimaguas, October 1975.

| | Amounts Applied[1] | | | | Available[2] | | | Exchangeable | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Tmt. | Lime | K | Mg | Micro. spray | P | K | pH | K | Ca | Al |
| | T/ha | --kg/ha-- | | | --ppm--- | | | ----me/100g-------- | | |
| 1 | 1 | 83 | 9 | 1 | 11 | 65 | 4.4 | .11 | 2.2 | .70 |
| 2 | 3 | 83 | 9 | 3 | 8 | 65 | 4.7 | .11 | 2.8 | 1.20 |
| 3 | 1 | 166 | 9 | 3 | 16 | 137 | 4.8 | .30 | 2.2 | .90 |
| 4 | 3 | 166 | 9 | 1 | 13 | 156 | 5.2 | .30 | 2.8 | .20 |
| 5 | 1 | 83 | 27 | 3 | 12 | 91 | 4.7 | .20 | 2.6 | .60 |
| 6 | 3 | 83 | 27 | 1 | 6 | 65 | 5.3 | .12 | 4.0 | .20 |
| 7 | 1 | 166 | 27 | 1 | 6 | 72 | 4.4 | .16 | 2.6 | 1.10 |
| 8 | 3 | 166 | 27 | 3 | 6 | 78 | 4.8 | .16 | 3.8 | 1.00 |
| 9 | 1 | 83 | 9 | 3 | 11 | 59 | 4.8 | .13 | 2.0 | .50 |
| 10 | 3 | 83 | 9 | 1 | 7 | 78 | 5.0 | .14 | 3.2 | 1.30 |
| 11 | 1 | 166 | 9 | 1 | 6 | 78 | 4.6 | .19 | 2.0 | .40 |
| 12 | 3 | 166 | 9 | 3 | 10 | 98 | 5.2 | .22 | 2.6 | .50 |
| 13 | 1 | 83 | 27 | 1 | 8 | 65 | 4.6 | .14 | 2.0 | 1.00 |
| 14 | 3 | 83 | 27 | 3 | 5 | 65 | 4.8 | .13 | 3.3 | .90 |
| 15 | 1 | 166 | 27 | 3 | 8 | 91 | 4.6 | .17 | 2.0 | .40 |
| 16 | 3 | 166 | 27 | 1 | | | | | | |
| 17 | 0 | 0 | 0 | 0 | 10 | 65 | 4.4 | .16 | 1.6 | 1.50 |
| 18 | 2 | 125 | 18 | 2 | 7 | 56 | 4.8 | .14 | 2.0 | .90 |
| 19 | 0 | 125 | 18 | 2 | 6 | 78 | 4.3 | .14 | 1.4 | 2.00 |
| 20 | 4 | 125 | 18 | 2 | 7 | 78 | 5.6 | .14 | 4.2 | .50 |
| 21 | 2 | 41 | 18 | 2 | 8 | 65 | 5.0 | .15 | 3.0 | .50 |
| 22 | 2 | 208 | 18 | 2 | 4 | 98 | 5.0 | .28 | 3.0 | .60 |
| 23 | 2 | 125 | 0 | 2 | 12 | 130 | 5.1 | .35 | 2.8 | .40 |
| 24 | 2 | 125 | 36 | 2 | 11 | 98 | 4.9 | .18 | 2.6 | .70 |
| 25 | 2 | 125 | 18 | 0 | 4 | 65 | 4.9 | .11 | 2.2 | 1.00 |
| 26 | 2 | 125 | 18 | 4 | 5 | 65 | 4.6 | .14 | 2.4 | 1.00 |

[1] Amounts of amendments applied in June 1975. Micronutrients refers to foliar spray of micronutrients as explained in Table 2.6:1.

[2] P was extracted with 0.5M $NaHCO_3$; K by 6N $H_2SO_4$; exchangeable K by 1N $NH_4OAc$ at pH 7.0, and Ca and Al with 1N KCl.

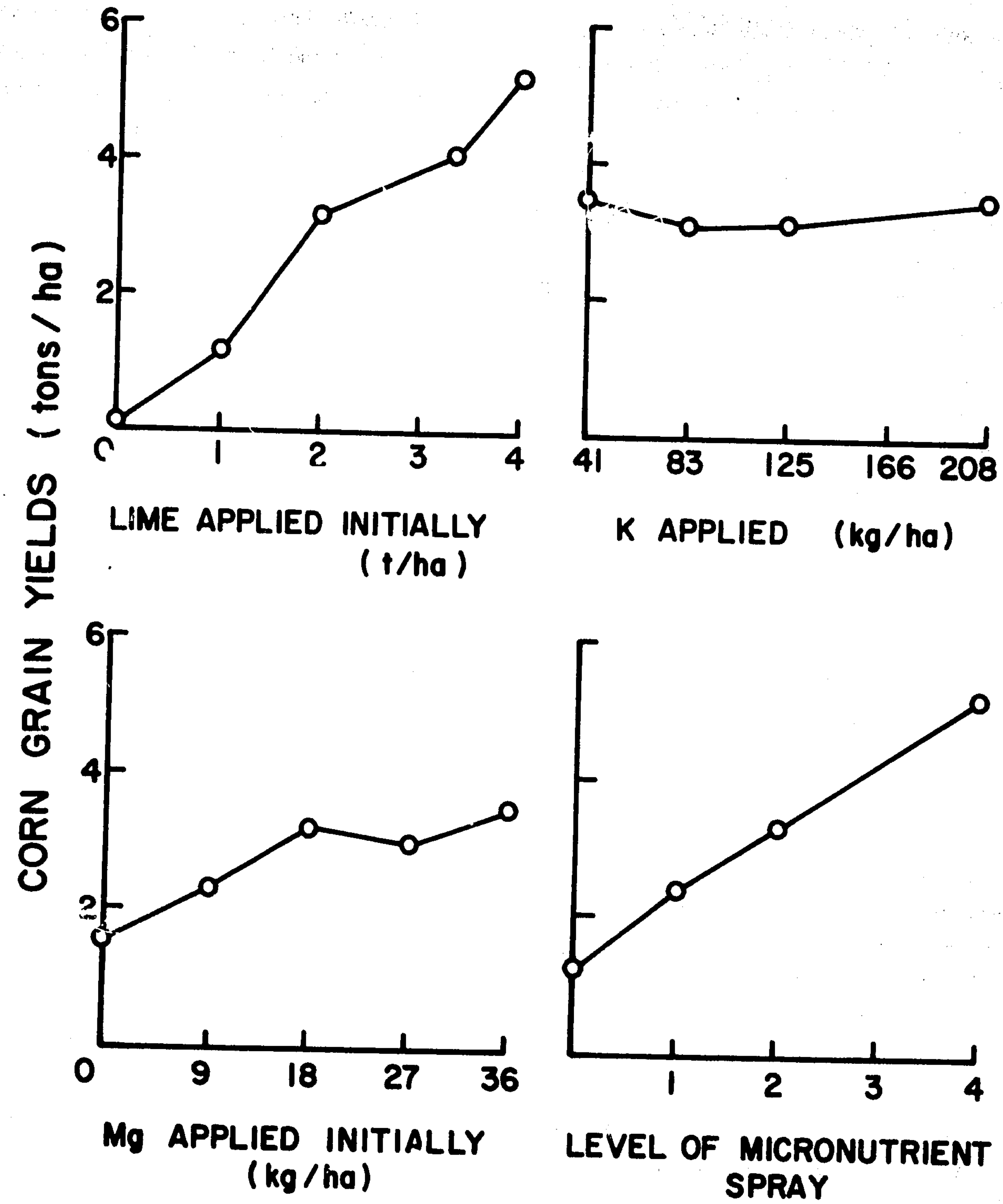



Figure 2.6:2. Corn grain yields when planted after soybeans and rice, as affected by K and micronutrient applications and the residual effect of lime and Mg. Yurimaguas, 1976.

hydroxide of which 100% passed through a 2 mm sieve. Calcium hydroxide is known to be very reactive in the soil and to have a short residual effect.

The next most limiting factor for corn grain yield was micronutrients. Fig. 2.6:2 shows that when micronutrients were not applied, corn grain yields were slightly over 1 ton/ha, and with the application of two foliar micronutrient sprays, increased up to 5 tons/ha. That corn responded more dramatically to micronutrients than did soybeans could be due to differential crop species response and to a decrease in the amounts of micronutrients originally present in the soil. Thus, it is expected that when the soil is under continuous cropping, micronutrient responses or deficiencies will be bigger after several crops have been harvested.

No corn response was observed between 42 to 208 kg K/ha. This result, when compared with those obtained in the first crops, suggested that K was not a limiting element in this range of application, although it was found in very low levels in the soil (0.15 me K/100 ml). Magnesium residual effects were more limiting than K. Yields of corn increased up to 3.1 tons grain/ha with the residual effect of 18 kg Mg/ha. Soils and plants have been sampled, and chemical analyses are being performed. These data will help to explain some of the responses observed.

A very important conclusion drawn from these experiments is that 1 ton lime/ha did not last more than ten months; 2 tons lime had a little higher residual effect, but yields were lower than those obtained with 3 tons lime/ha. The best yield results for all crops were obtained with 4 tons/ha lime as $Ca(OH)_2$. For practical considerations and for a 13-month cropping sequence of soybeans–rice–corn or any combination thereof, an initial application of 3 to 4 tons lime should be considered. Since the residual effect of lime is lost so quickly, soil acidity should be checked at least once a year in order to consider application of additional lime. It was also pointed out that Mg and micronutrients became more limiting after two crops had been removed from the field. These data partially explained the rapid yield decline in the continuous cropping experiments. It also was suggested that yields in the continuous cropping experiments would not have been improved as well this year if only the new levels of lime and NPK were applied. Magnesium and micronutrients were needed also. The need for the study of new liming materials that carry Mg and will have higher residual effects is emphasized.

Experiment 2. Soybean Responses to Lime, Mn, B and Mo.

Objectives and design. Soybean response to micronutrients was observed in the experiments conducted during 1975 and early 1976 in an old abandoned field (1975 Annual Report). However, all micronutrients were applied as a foliar spray. There was no information on which of the elements was or were responsible for the increase in yields. Soybeans growing during 1975 in Chacra 3 showed symptoms that resembled Mn deficiency. Foliar analysis of soybean samples taken from this field indicated low levels of Mn, B, Fe, Mg, and Ca in the leaves. For this reason, a portion of Chacra 3 that was burned in 1974 and then abandoned again was cleared and planted with soybeans (cv. XLM) in July 1976. Five levels of lime, Mn, B, and Mo were studied. The amounts of nutrients studied are presented in Table 2.6:3.

Results. Table 2.6:3 and Fig. 2.6:3 present soybean grain yield as affected by the application of the different treatments. There was a response to 1 ton lime/ha as soybean yields increased from 1.5 ton/ha to 2.5 tons/ha (Fig. 2.6:3). No further response was found to additional lime applications up to 4 tons lime/ha. This result differed somewhat from that reported last year in the secondary and micronutrients study, where soybeans were reported to respond up to 2 tons lime/ha. This could be explained by the low Al saturation of the soil in Chacra 3, possibly due to some liming effect from the ash (1974 Annual Report).

No positive response was observed to either foliar Mn applications or Mo seed treatment, indicating that both elements were present in adequate amounts in the soil or that some other factor was more limiting to yields. With respect to B, soybean grain yields increased about 0.5 ton/ha when the first 0.5 kg B/ha were applied. However, when additional 0.5 kg B/ha rates were applied, soybean yields dropped to those of the zero B level. Research in Georgia on similar soils has indicated B toxicity to soybeans at rates greater than 1 kg/ha.

Additional treatments of soil-applied Zn and foliar applications of Fe were used to test the response of soybeans to these elements. Table 2.6:3 shows that there was no response to either one of these treatments (treatments 27 and 28). However, when Cu was not applied as basal (treatment 17), soybean yield was only 1.5 ton/ha, even though all other micronutrients were applied. This result agreed with that found in greenhouse experiments and reported in the 1974 Annual Report that Cu is limiting crop yields in soils of Yurimaguas.

In summary, the evidence indicated that in a newly cleared and burned chacra that has not been cropped, Mo, Mn, Zn, and Fe were adequately supplied to the plant. Boron seemed to be needed in low amounts (0.5 kg B/ha), and applications of 2 kg Cu/ha were also necessary.

Experiment 3. Peanut Response to Cu, Mn, B and Mo.

Objectives and design. Secondary and micronutrient studies reported in 1975 showed a soybean response to foliar applications of microelements. The soil in which soybeans were grown was a very low fertility soil from an old abandoned pasture. No beneficial effect of ash was expected here. As previously emphasized, the experiments with foliar micronutrients were designed only to detect whether there was response to microelements. No information was obtained at that time with respect to which micronutrient was deficient and what should be the amount to be applied to the soil.

Peanuts were incorporated into the crop sequences being studied in continuous cropping experiment, since they have a high cash value and are very promising in the area. However, in almost all of the experiments in which peanuts were studied, plants were characterized by a high number of empty pods at harvesting time. Empty pods are known to be one of the symptoms of B deficiency. Chemical analysis indi-

Table 2.6:3. Soybean grain yields as affected by lime, Mn, B and Mo applications[1/].

| Tmt. | Amounts Applied | | | | Remarks[2/] | Soybean Yield |
|---|---|---|---|---|---|---|
| | Lime | Mn | B | Mo | | |
| | T/ha | kg/1000 l/ha | kg/ha | g/kg seed | | kg/ha |
| 1 | 1 | 0.5 | 0.5 | 1.5 | | 2333 |
| 2 | 3 | 0.5 | 0.5 | 4.5 | | 1845 |
| 3 | 1 | 1.5 | 0.5 | 4.5 | | 2591 |
| 4 | 3 | 1.5 | 0.5 | 1.5 | | 2493 |
| 5 | 1 | 0.5 | 1.5 | 4.5 | | 2602 |
| 6 | 3 | 0.5 | 1.5 | 1.5 | | 2426 |
| 7 | 1 | 1.5 | 1.5 | 1.5 | | 2941 |
| 8 | 3 | 1.5 | 1.5 | 4.5 | | 2131 |
| 9 | 1 | 0.5 | 0.5 | 4.5 | | 2808 |
| 10 | 3 | 0.5 | 0.5 | 1.5 | | 2283 |
| 11 | 1 | 1.5 | 0.5 | 1.5 | | 2823 |
| 12 | 3 | 1.5 | 0.5 | 4.5 | | 2720 |
| 13 | 1 | 0.5 | 1.5 | 1.5 | | 2051 |
| 14 | 3 | 0.5 | 1.5 | 4.5 | | 1767 |
| 15 | 1 | 1.5 | 1.5 | 4.5 | | 2230 |
| 16 | 3 | 1.5 | 1.5 | 1.5 | | 2567 |
| 17 | 2 | 1.0 | 1.0 | 3.0 | Minus Cu | 1587 |
| 18 | 2 | 1.0 | 1.0 | 3.0 | | 2190 |
| 19 | 0 | 1.0 | 1.0 | 3.0 | | 1535 |
| 20 | 4 | 1.0 | 1.0 | 3.0 | | 2758 |
| 21 | 2 | 0 | 1.0 | 3.0 | | 2420 |
| 22 | 2 | 2.0 | 1.0 | 3.0 | | 1545 |
| 23 | 2 | 1.0 | 0 | 3.0 | | 2182 |
| 24 | 2 | 1.0 | 2.0 | 3.0 | | 2233 |
| 25 | 2 | 1.0 | 1.0 | 0 | | 2257 |
| 26 | 2 | 1.0 | 1.0 | 6.0 | | 2667 |
| 27 | 2 | 1.0 | 1.0 | 3.0 | Plus Zn | 1965 |
| 28 | 2 | 1.0 | 1.0 | 3.0 | Plus Fe | 2000 |

[1/] A basal application of 70 kg P/ha, 102 kg K/ha, 30 kg Mg/ha, and 2 kg Cu/ha was made.

[2/] Four kg Zn/ha and 0.5 kg Fe/1000 l/ha were applied in treatments 27 and 28, respectively. Iron was sprayed together with Mn at 30, 45, and 55 days after planting.

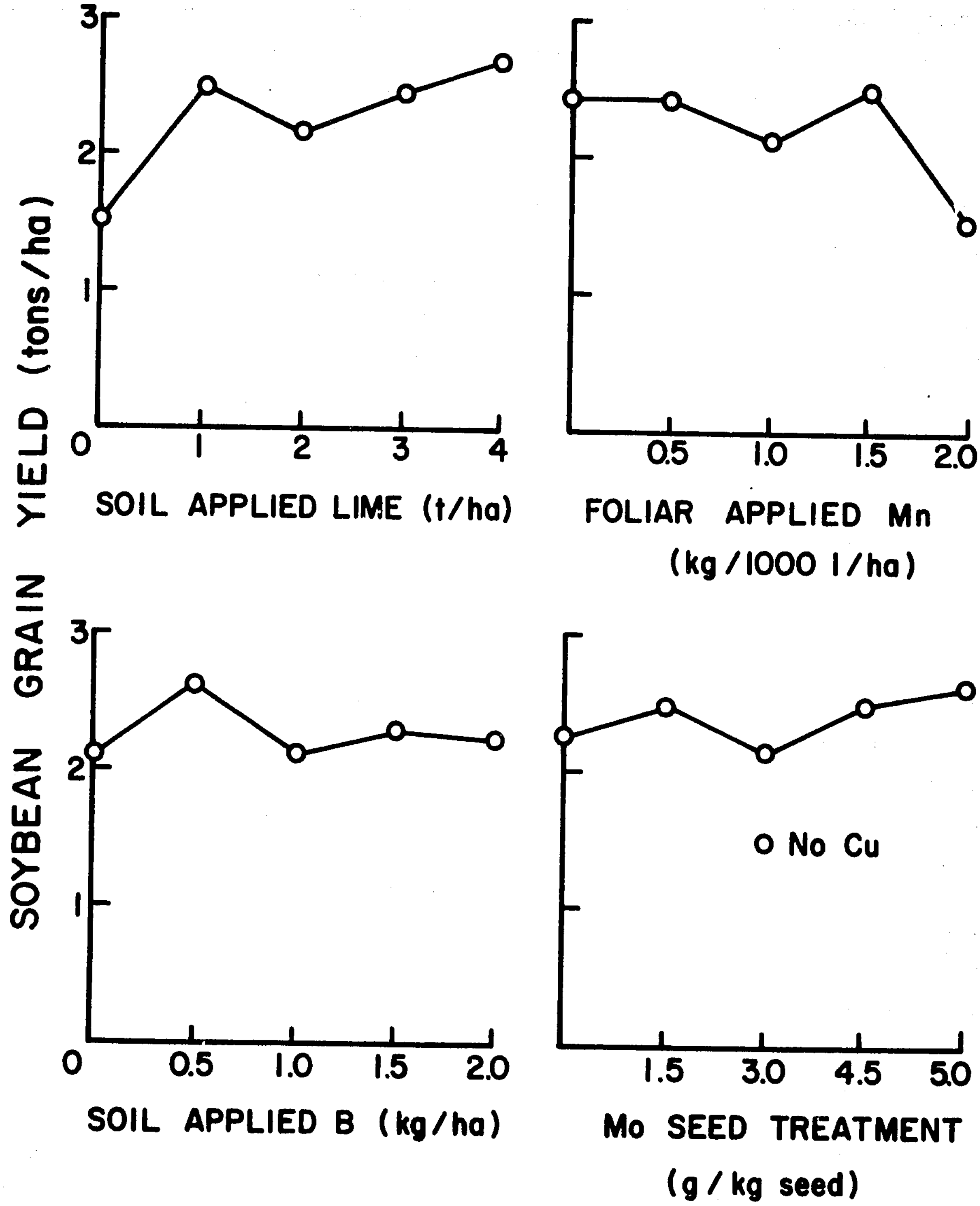



Figure 2.6:3. Soybean yields as affected by lime, Mn, B, Mo applications. Yurimaguas, 1976.

cated that B content in the soils of the Yurimaguas Experimental Station is very low and not measurable in most of the cases.

For these reasons, it was necessary to determine the effect of five levels of Cu, Mn, B, and Mo on soybeans (cv. National) and peanuts (cv. Blanco Tarapoto) growing simultaneously on two different experiments. Both crops were planted in a field adjacent to the one where secondary and micronutrient studies were conducted. Thus, the soil was acid (pH 4.2), had 2.3 me Al/100 g soil, and was low in N, P, and K. A central composite rotatable design was used on both experiments. Peanuts were planted on August 3, 1976, and harvested on November 18. Soybeans were planted also on August 3, 1976, but seedlings did not emerge well, due to low seed quality. A new planting was on September 3 and was harvested at the time that this report was being written. Only results on peanuts will be presented at this time. Treatments and nutrient levels applied are presented in Table 2.6:4.

Results. Results of peanut yields are presented in Table 2.6:4. It can be observed that yields were generally over 4,000 kg/ha, which is excellent for the zone. As indicated in Table 2.6:4, no N was applied to the plots. The idea was to test peanut response to Mo in the presence of only the native soil N. Yields were remarkably good, indicating that peanuts can be grown with only the native soil N where the proper Rhizobia inoculum is used. Fig. 2.6:4 indicates that there was no response of peanuts to copper applied to the soil or to manganese applied to the leaves. However, a high response to boron was observed. As in the case of soybeans described earlier, the biggest response was to the first 0.5 kg B/ha. An additional response was observed with the last 0.5 kg B/ha increment. This last yield increment is difficult to interpret.

A response to Mo applied to the seeds was also observed. The results indicated that when 1.5 g Mo/kg of seeds were applied as a slurry, yields of peanuts increased from 3.8 tons/ha to 4.5 tons/ha, with no further increments with additional Mo dosages. However, the high yield with the check (3.8 tons/ha) also indicated a good N fixation when Mo was not applied. A survey of the roots of the peanuts showed that nodulation in all plots was very good with most of the nodules pink in color.

Additional treatments showed that when none of the microelements (Cu, Mn, B, and Mo) was applied, peanuts yielded only 3.0 tons/ha (treatment 17). This was the same amount obtained in the zero B plots. No peanut yield response to the application of 4 kg Zn/ha was noted. It will be remembered that corn also failed to respond to Zn applied to the same soil (1974 Annual Report).

From the last two microelement experiments, it can be indicated that B, Mo, and Cu deficiencies can be expected in Yurimaguas Paleudults when they are continuously cropped. No response to Zn or Mn was found with soybeans or peanuts. Initially reported low levels of Mn in soybean leaves are thought to be related to other nutrient deficiencies. The question remains on how this response or lack of responses will change after plants use the native micronutrients in the soil. Thus, the need for long-term

Table 2.6:4. Peanut yields as affected by Cu, Mn, B, and Mo applications.

| Tmt. | Cu | Mn | B | Mo | Remarks[2/] | Peanut Yield |
|---|---|---|---|---|---|---|
| | Amounts Applied | | | | | |
| | kg/ha | kg/1000 1/ha | kg/ha | g/kg seed | | kg/ha |
| 1 | 1 | 0.5 | 0.5 | 1.5 | | 4707 |
| 2 | 3 | 0.5 | 0.5 | 4.5 | | 4375 |
| 3 | 1 | 1.5 | 0.5 | 4.5 | | 5208 |
| 4 | 3 | 1.5 | 0.5 | 1.5 | | 4083 |
| 5 | 1 | 0.5 | 1.5 | 4.5 | | 4041 |
| 6 | 3 | 0.5 | 1.5 | 1.5 | | 4333 |
| 7 | 1 | 1.5 | 1.5 | 1.5 | | 4833 |
| 8 | 3 | 1.5 | 1.5 | 4.5 | | 3875 |
| 9 | 1 | 0.5 | 0.5 | 4.5 | | 3625 |
| 10 | 3 | 0.5 | 0.5 | 1.5 | | 4750 |
| 11 | 1 | 1.5 | 0.5 | 1.5 | | 4916 |
| 12 | 3 | 1.5 | 0.5 | 4.5 | | 4250 |
| 13 | 1 | 0.5 | 1.5 | 1.5 | | 3875 |
| 14 | 3 | 0.5 | 1.5 | 4.5 | | 3625 |
| 15 | 1 | 1.5 | 1.5 | 4.5 | | 4541 |
| 16 | 3 | 1.5 | 1.5 | 1.5 | | 4333 |
| 17 | 0 | 0 | 0 | 0 | Check | 3041 |
| 18 | 2 | 1.0 | 1.0 | 3.0 | | 4381 |
| 19 | 0 | 1.0 | 1.0 | 3.0 | | 4291 |
| 20 | 4 | 1.0 | 1.0 | 3.0 | | 4416 |
| 21 | 2 | 0 | 1.0 | 3.0 | | 4374 |
| 22 | 2 | 2.0 | 1.0 | 3.0 | | 4458 |
| 23 | 2 | 1.0 | 0 | 3.0 | | 3401 |
| 24 | 2 | 1.0 | 2.0 | 3.0 | | 5291 |
| 25 | 2 | 1.0 | 1.0 | 0 | | 3791 |
| 26 | 2 | 1.0 | 1.0 | 6.0 | | 4458 |
| 27 | 2 | 1.0 | 1.0 | 3.0 | Plus Zn | 4124 |
| 28 | 2 | 1.0 | 1.0 | 3.0 | Plus Fe | 4042 |

[1/] A basal application of 2 tons lime/ha, 70 kg P/ha, 102 kg K/ha, and 30 kg Mg/ha was made. No N was applied.

[2/] Four kg Zn/ha and 1 kg Fe/1000 1/ha were applied in each treatment. Iron was sprayed together with Mn at 25, 36, and 50 days after planting.

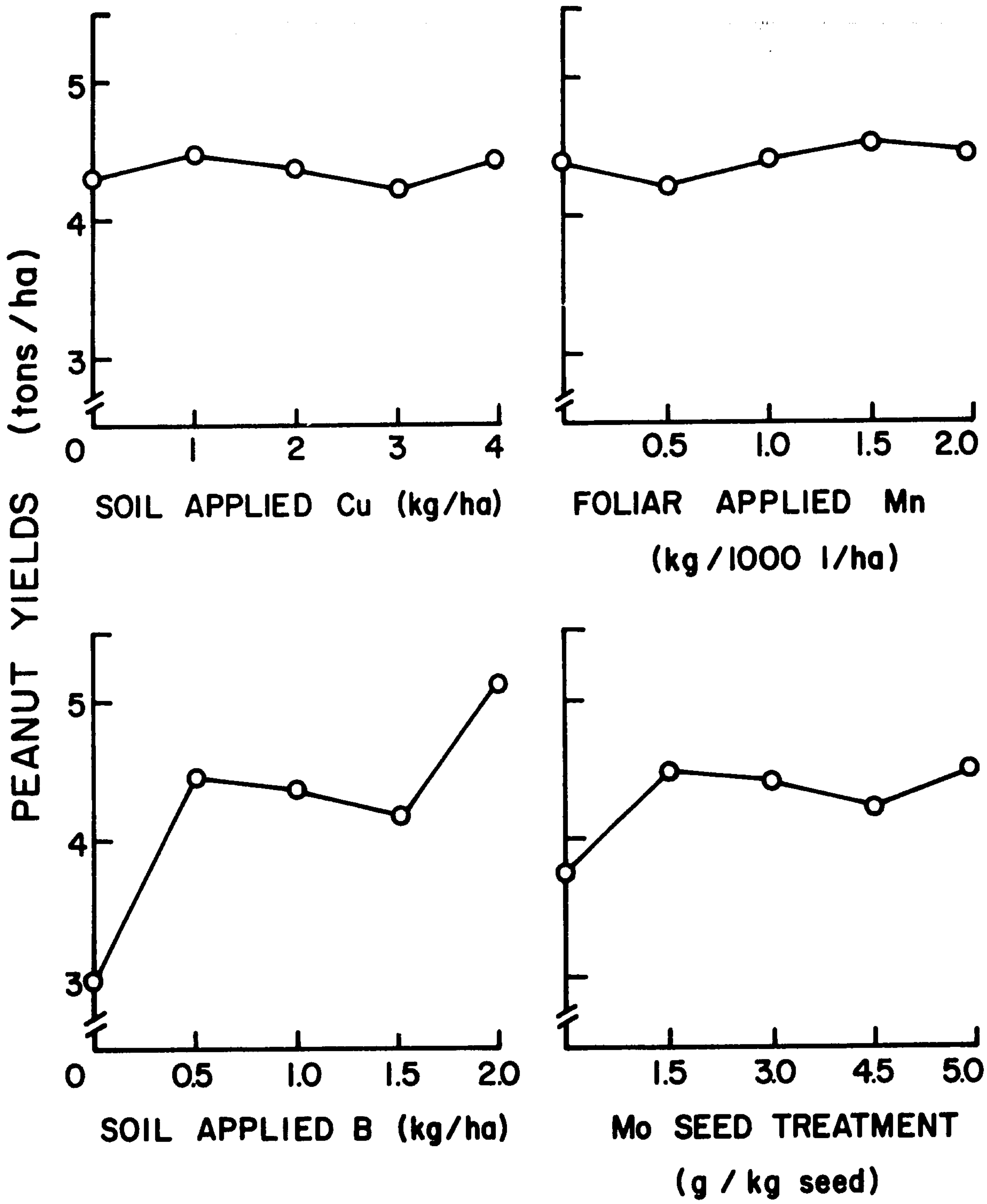



Figure 2.6:4. Peanut yields as affected by Cu, Mn, B and Mo applications. Yurimaguas, 1976.

micronutrient studies is evident. The data indicate that in order to continue obtaining good yields in the continuous cropping experiments, the next micronutrients should be applied in the following amounts per crop: 0.5 kg B/ha (as Borax), 1.5 g Mo/kg seed (as ammonium molybdate), and 1 kg Cu/ha (as copper sulfate).

## 2.7 INTEGRATED CROPPING SYSTEMS

D. E. Bandy

In December 1976 an experiment was initiated in a new chacra (Chacra 5) that was recently prepared for planting by the traditional slash-and-burn method. The experiment is designed to confirm or integrate results that have been previously shown at the station.

The experiment used low levels of fertilizer and lime since previous Annual Reports (1973 and 1974) have documented well that newly cleared land has only enough nutrients in the ash from the burn to produce fairly decent yields for one or two crops, but not enough for a whole year of intensive cropping. With the proper selection of crop species and agronomic practices it is possible to grow three crops a year with very low levels of technical inputs and still gain respectable yields. The Annual Reports of 1974 and 1975 have shown that a certain type of intercropping, i.e., relay cropping, is best suited for this area. Fertilizer rates were NPK at 0-35-66 kg/ha, Mg at 18 kg/ha, and the micronutrients Cu, Zn, B and Mo at 3, 3, 1, and 0.1 kg/ha, respectively. In addition, lime at 650 kg/ha ($CaCO_3$ equivalent) was applied. All soil amendments were applied as basal applications at the beginning of the experiment.

No nitrogen was applied since, from previous experience, the ash should supply enough N for the first crop. Succeeding crops were legumes or non-nitrogen responsive crops (Fig. 2.7:1). Magnesium was applied since it has been shown (Annual Report 1975) that Mg deficiency was probably one of the main reasons for the declining yields in the rotation experiment of Chacras 1, 2, and 3. Micronutrients were applied as insurance since it was still not known for sure if one year of cropping will use up all the micronutrients from the ash. It has been shown in Annual Reports 1974-1975 that micronutrient deficiencies of Mo and possibly Cu have appeared after an area has been intensively cropped for two to three years.

Lime was necessary to apply since these Ultisols of the Yurimaguas soil series, are too acidic and too Al saturated (Annual Report 1973) for most crops to produce any reasonable yield unless the exchangeable Al has been neutralized to a minimum of 30-40% Al saturation, depending on crop tolerance to Al.

Preliminary results showed no negative effects of the low fertilizer and lime rates for rice, cowpeas, soybeans, peanuts, sugar cane or cassava. Corn did show nitrogen deficiency symptoms. Complete yield data will be reported in the 1977-1978 Annual Report.

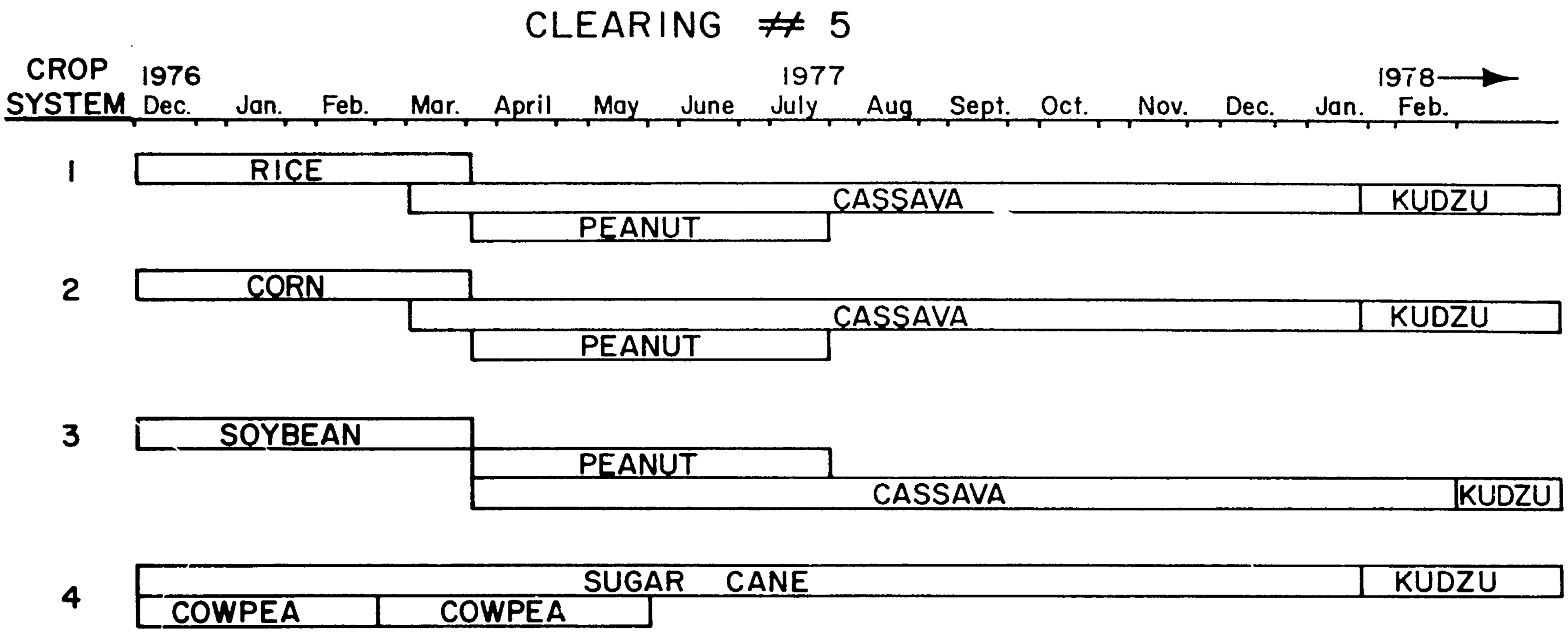



Figure 2.7:1. Schematic diagram of the integrated cropping experiment with low inputs begun in December, 1976.

Aerial view of small farms in area surrounding Yurimaguas, Peru.

Rice, peanut and corn fertilization study at the Yurimaguas Agricultural Experiment Station.

# CERRADO OF BRAZIL

(Joint NCSU/Cornell Research)

Sr. Luis Souza-Lima (with moustache), a farmer in the Cerrado, talks with Dr. Elmar Wagner, Director of CPAC, about current developments in the agronomic research developed by the cooperative CPAC/Cornell/NCSU program at Brasilia. Unaí, Minas Gerais. March, 1977.

This report covers agronomic research conducted cooperatively by scientists from Brazil's Centro de Pesquisa Agropecuaria dos Cerrados (CPAC), Cornell and North Carolina State Universities. It includes field work conducted from October 1975 through September 1976, encompassing a full agricultural year with the 1975-1976 rainy season and the 1976 dry season. Research conducted independently of seasons is also reported.

This report will center on studies which evaluated effects on crops of residual lime, Ca and Mg downward movement, residual P, residual Zn, K and Mg fertilization, and N fertilization. Also discussed are crop species and varietal tolerances to Al toxicity and low available P, effects of P, lime and Si on soil properties and plant growth, and an outreach study of Cerrado soil properties.

Unless otherwise specified, all field experiments were conducted on a clayey Dark Red Latosol (Typic Haplustox, fine, kaolinitic, isohyperthermic) located on a second erosion surface at CPAC near Brasilia. Properties of this soil were described in previous Annual Reports and are typical of acid Oxisols of tropical savannas. Generally speaking, these soils are well-drained, relatively deep, acid, low in organic matter, P, K, Ca, Mg, with a relatively high P retention capacity. These Oxisols are not as susceptible to soil compaction as are the sandier Ultisols of the Amazon Jungle.

## 3.1 CROP WEATHER

W. Espinosa and M. Jarreta Junior

Meterological data for the 1975-1976 agricultural year at CPAC are given in Table 3.1:1. Average values for 35 years at nearby Formosa are presented in Table 3.1:2.

The temperature the morning of July 7, 1975, at CPAC was unusually low ($4^{o}C$) as a consequence of a cold wave which covered the southern part of Brazil, causing great agricultural losses, particularly in the state of Paraná.

Precipitation during this year (1243 mm) was considerably lower than the average of 1580 mm, due to reduced rainfall in the months of December, January, March and April. Four dry spells (veranicos) occurred as shown in Fig. 3.1:1.

Fig. 3.1:2 shows the 1975-1976 meteorological water balance for CPAC using Class A pan evaporation. For comparison, the water balance based on solar radiation calculated according to Hargreaves method and using 35 years of data collected at Formosa is presented in Fig. 3.1:3.

## 3.2 RESIDUAL LIME EFFECTS

### A. RESIDUAL EFFECTS OF LIME ON THE CLAYEY DARK RED LATOSOL

E. Gonzalez, E. Lobato and W. Soares

The effect of liming acid soils is usually expected to last for several years. It is also expected that this effect will be shorter in the

Table 3.1:1. Meteorological data for the agricultural year 1975/1976,CPAC, (15° 36'S, 47° 42'W, altitude 1010 meters).

| Month | Temperature (°C) Max. | Min. | Avg. | Precipitation | Evaporation | Wind | Relative Humidity | Solar Radiation |
|---|---|---|---|---|---|---|---|---|
| | | | | (mm) | (mm) | (m/s) | (%) | (cal/cm$^2$/day) |
| July | 23.7 | 12.5 | 18.4 | 8.2 | 170.5 | 1.3 | 66.5 | 412.9 |
| August | 27.2 | 14.8 | 21.0 | 0 | 213.6 | 1.1 | 56.0 | 480.7 |
| September | 28.5 | 16.6 | 22.6 | 3.0 | 242.2 | 1.1 | 55.5 | -- |
| October | 28.3 | 17.3 | 22.8 | 104.3 | 169.9 | 0.8 | 58.4 | 416.3 |
| November | 26.4 | 17.6 | 22.0 | 254.3 | 141.2 | 0.8 | 64.7 | 421.6 |
| December | 27.0 | 16.8 | 21.9 | 156.3 | 166.5 | 0.6 | 60.2 | 468.0 |
| January | 27.8 | 16.7 | 22.2 | 146.9 | 167.8 | -- | 59.2 | 484.0 |
| February | 26.6 | 17.8 | 22.2 | 311.8 | 132.7 | 0.8 | 63.1 | 419.4 |
| March | 27.4 | 17.7 | 22.6 | 186.2 | 146.3 | 0.8 | 61.3 | -- |
| April | 27.9 | 16.9 | 22.4 | 12.2 | 155.8 | 0.9 | 57.2 | -- |
| May | 26.7 | 15.3 | 21.0 | 59.4 | 134.6 | 0.7 | 58.7 | -- |
| June | 26.7 | 13.6 | 20.1 | 0 | 166.9 | 0.8 | 51.0 | -- |

Source: Relatório Técnico Anual, CPAC, 1976, Brasilia D. F.

Table 3.1:2. Average of 35 years of meteorological data for Formosa, GO (15° 32'S, 47° 18'W, altitude 912 m).

| Month | Atmospheric pressure | Avg. Temp. | Min. Temp. | Max. Temp. | Relative Humidity | Cloudiness | Average monthly precipitation | Maximum precipitation in 24 hours | Evaporation | Insolation |
|---|---|---|---|---|---|---|---|---|---|---|
| | (mm) | (°C) | (°C) | (°C) | (%) | (1-10) | (mm) | (mm) | (mm) | (hrs) |
| Jan | 909.5 | 22.0 | 17.8 | 27.4 | 80.2 | 7.7 | 271.9 | 100.7 | 73.2 | 180.5 |
| Feb | 909.6 | 22.1 | 18.0 | 27.8 | 80.8 | 7.7 | 204.2 | 85.0 | 63.7 | 159.3 |
| Mar | 909.8 | 21.9 | 17.9 | 27.6 | 81.5 | 7.5 | 220.6 | 92.5 | 67.1 | 186.8 |
| Apr | 910.9 | 21.5 | 17.0 | 27.6 | 77.3 | 6.2 | 42.7 | 77.8 | 75.3 | 222.2 |
| May | 912.2 | 20.1 | 14.8 | 27.0 | 71.4 | 4.8 | 17.0 | 41.8 | 97.8 | 270.3 |
| June | 913.6 | 19.0 | 13.1 | 26.4 | 66.0 | 3.8 | 3.2 | 18.0 | 113.0 | 279.9 |
| July | 914.1 | 18.9 | 12.6 | 26.3 | 59.4 | 3.4 | 5.5 | 25.2 | 141.3 | 278.0 |
| Aug | 913.2 | 20.7 | 13.7 | 28.4 | 49.6 | 2.7 | 2.5 | 45.8 | 188.3 | 303.2 |
| Sept | 911.5 | 22.8 | 16.2 | 30.1 | 51.7 | 4.0 | 30.0 | 63.6 | 189.2 | 236.2 |
| Oct | 910.1 | 22.9 | 17.8 | 29.2 | 66.0 | 6.7 | 127.1 | 103.4 | 138.1 | 200.7 |
| Nov | 908.8 | 21.6 | 18.0 | 27.4 | 79.3 | 8.3 | 255.3 | 107.5 | 75.2 | 142.7 |
| Dec | 908.8 | 21.9 | 18.1 | 26.6 | 83.0 | 8.5 | 342.5 | 124.9 | 60.8 | 125.1 |
| Year | 911 | 21.3 | 16.2 | 27.6 | 70.6 | 5.9 | 1,572.5 | | 1,283.0 | 2,614.9 |

Source: Relatorio Técnico Anual, CPAC, 1976. Brasilia D.F.

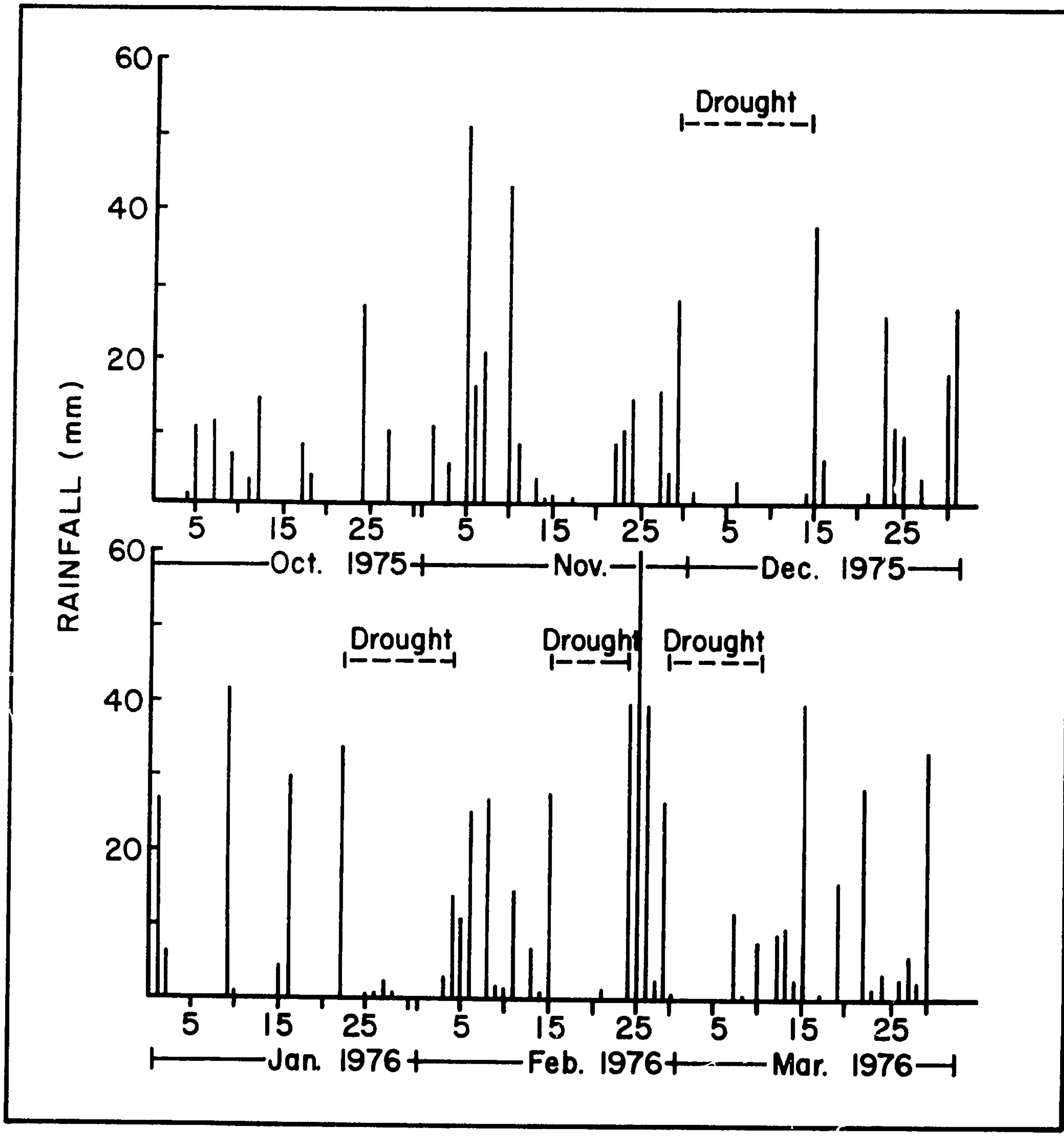



Figure 3.1:1. Daily rainfall at CPAC during the wet season 1975-1976.

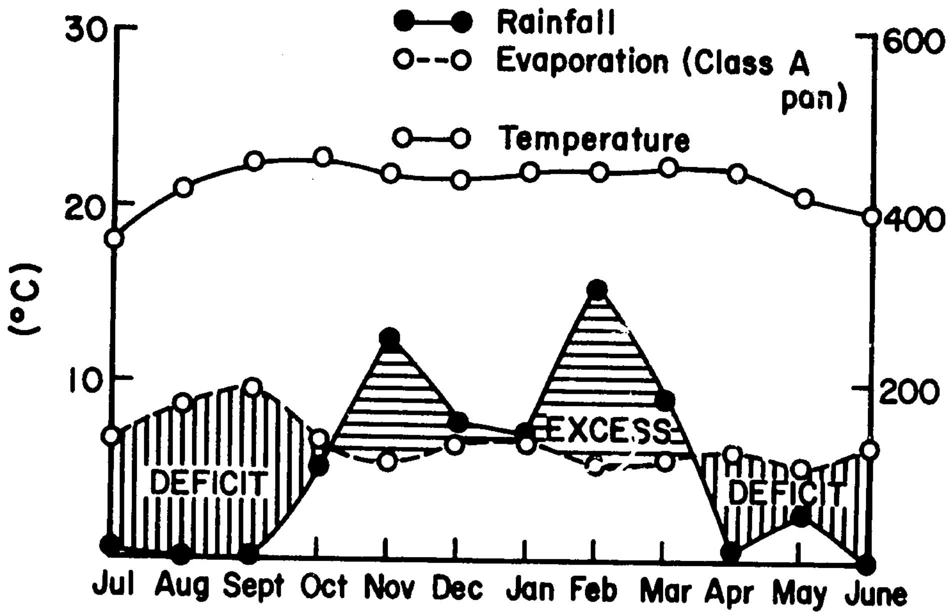



Figure 3.1:2. Meteorological water balance for agricultural year 1975-1976 for CPAC based on class A pan evaporation.

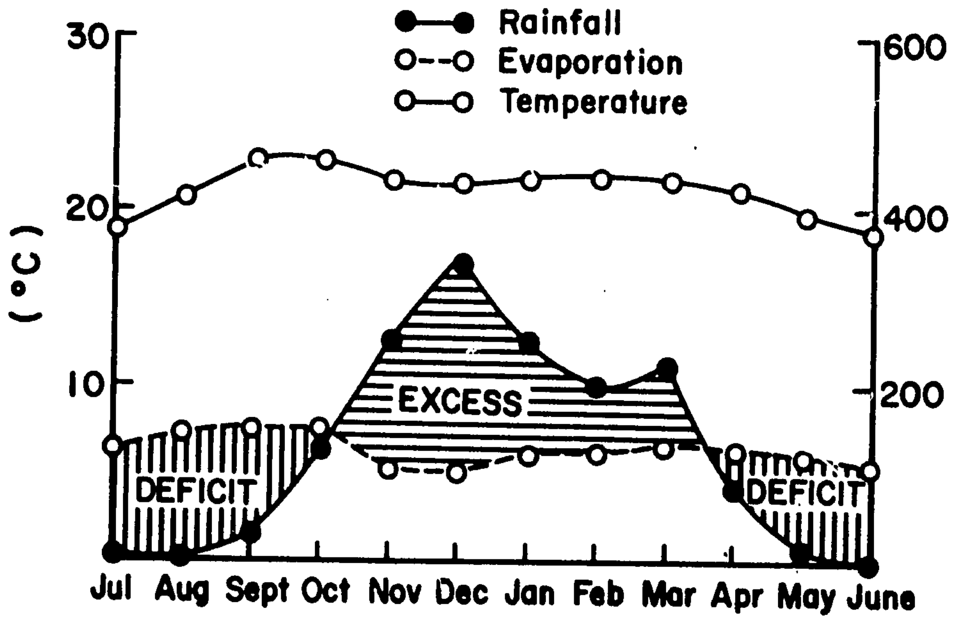



Figure 3.1:3. Meteorological water balance for 35 years of data collected at nearby Formosa, GO, based on solar radiation (according to Hargreaves).

tropical region than in the temperate region because of more intensive climatic conditions of high rainfall and high temperature. In the humid tropical areas, leaching of basic cations becomes important because it not only reduces the residual effect of lime but affects the depth below the zone of lime incorporation. This is particularly important where subsoil acidity is a problem for root development.

The first part of this discussion deals with a soybean experiment conducted at the station to test the residual effect of various lime levels. The second part treats the movement and implications of base movement in the profile from plots limed & fertilized in different years.

Soybean Growth Under Various Residual Levels of Lime

This residual study of lime was conducted in the wet season 1973-1974 on an acid soil where lime had been applied in November 1970 and *Stylosanthes* was planted during that time. Soil samples taken before the application of lime indicated that the soil was very acid (pH around 4.6) with a high Al saturation in the topsoil and subsoil (80 to 90 percent). The amount of exchangeable Al was around 1.5 me/100 cc with the exchangeable Ca + Mg around 0.2 me/100 in the top 30 cm of soil. Different levels of calcitic limestone were incorporated to a depth of about 20 cm. These levels of lime were effective in increasing *Stylosanthes* growth. The highest dry matter production was obtained with 4, 6, and 8 tons of lime [no statistical lime (1 ton)]. Two harvests were made before the residual study was established. Tops were removed from the fields at each harvest. Grain yields of two varieties of soybeans planted on these 3-year old plots are presented in Table 3.2:1. As with the *Stylosanthes*, there was a significant increase in yields of both varieties with the first increment of lime. With rates greater than 1 ton there were further increases in yields, but this benefit was only significant at the 6 ton level with the Viçosa variety. The other variety, IAC-2, did not respond as well at the highest level of lime. Overall, yields obtained in this study may be considered somewhat low for experimental conditions. Both varieties showed an impressive vegetative and reproductive growth at all levels of lime. Grain yields, however, were not as markedly increased because of a long rainy period which delayed harvest and reduced yields by damaging some of the pods.

There are important features of the effect of the various residual lime levels on soybean yields. The increase in yields obtained with the first increment of lime was considerable, in the order of 800 kg/ha for both varieties. The interesting point is that this increase occurred when the soil was still very acid (Table 3.2:2). The second soil sampling which was made after the harvest of the soybean crop showed that Al saturation was around 50 percent at the 0-15 cm depth and 63 percent at the 15-30 cm. This indicated that these two varieties were relatively tolerant to Al and responded well to small additions of lime.

Table 3.2:1. Residual effect of various levels of lime on grain yields (14% moisture) of two soybean varieties in the LE soil[1].

| Previous Lime rates | Variety | |
|---|---|---|
| | Viçosa | IAC-2 |
| ton/ha | ------- kg/ha -------- | |
| 0 | 1095 | 1059 |
| 1 | 1902 | 1868 |
| 2 | 2137 | 1919 |
| 4 | 2139 | 2294 |
| 6 | 2695 | 2405 |
| 8 | 2729 | 2259 |

$LSD_{.05}$ Lime = 545

$LSD_{.05}$ Var. = 467

[1]Values are mean of 4 replications.

Table 3.2:2. The residual effect of liming in the Dark Red Latosol as measured by soil analysis. The first sampling was done on December 1970, one month after lime application. The second one in March 1974, after harvesting the soybean.

| Lime Levels | Depth of Sampling | pH | Exchangeable Al | Exchangeable Ca+Mg | Al satur. |
|---|---|---|---|---|---|
| ton/ha | cm | | ---me/100cc | --- | % |
| | | First Sampling | | | |
| 0 | 0-20 | 4.2 | 1.76 | 0.32 | 85 |
| | 20-40 | 4.1 | 1.37 | 0.27 | 84 |
| 1 | 0-20 | 4.5 | 1.22 | 0.77 | 61 |
| | 20-40 | 4.3 | 1.32 | 0.29 | 82 |
| 2 | 0-20 | 4.5 | 1.22 | 0.95 | 56 |
| | 20-40 | 4.4 | 1.25 | 0.37 | 77 |
| 4 | 0-20 | 4.7 | 0.82 | 1.57 | 34 |
| | 20-40 | 4.4 | 1.17 | 0.37 | 76 |
| 6 | 0-20 | 5.1 | 0.32 | 2.85 | 12 |
| | 20-40 | 4.7 | 1.10 | 0.63 | 64 |
| 8 | 0-20 | 5.3 | 0.10 | 3.60 | 3 |
| | 20-40 | 4.6 | 1.05 | 0.72 | 59 |
| | | Second Sampling | | | |
| 0 | 0-15 | 4.7 | 1.34 | 0.57 | 70 |
| | 15-30 | 4.8 | 1.32 | 0.51 | 72 |
| 1 | 0-15 | 4.8 | 1.25 | 1.29 | 49 |
| | 15-30 | 4.8 | 1.23 | 0.73 | 63 |
| 2 | 0-15 | 5.0 | 0.95 | 2.36 | 29 |
| | 15-30 | 4.8 | 1.12 | 1.00 | 53 |
| 4 | 0-15 | 5.1 | 0.56 | 2.23 | 20 |
| | 15-30 | 4.9 | 0.92 | 0.99 | 48 |
| 6 | 0-15 | 5.4 | 0.21 | 2.91 | 7 |
| | 15-30 | 5.1 | 0.52 | 1.91 | 21 |
| 8 | 0-15 | 5.6 | 0.15 | 3.70 | 4 |
| | 15-30 | 5.1 | 0.51 | 1.90 | 36 |

Another important aspect is that a further response was obtained with the 6 tons of lime after a plateau was reached at the 2 and 4 ton/ha level. The Al saturation at the 6 ton level was less than 10 percent in the 0-15 cm depth and around 20 percent in the 15-30 cm. This is more in agreement with the results of Soares et al., in 1974 on two Dark Red Latosols where soybean yields increased sharply with 5 tons/ha of lime, which had reduced Al saturation to 10 percent. They, however, did not have any rates less than 5 tons/ha. Spain et al., also in 1974 found that soybeans responded to lime applications up to 6 tons/ha on an acid Colombian Oxisol, but most of the response occurred with an application of 2 tons/ha. The Viçosa and IAC-2 varieties yielded an additional 800 and 550 kg/ha, respectively, as lime rates were increased from 1 to 6 tons/ha. There was no further increase at the 8 ton level and with the IAC-2 there was a slight reduction in yield. This increase in yields with the 6 ton/ha rate represented a response to a diminished Al saturation (about 10 percent) or may have been due to greater availability of Mo. No Mo was applied with the soybeans, and the only Mo that had been applied previously was before planting the Stylosanthes. Nutrient concentration of the trifoliates of the two varieties (Table 3.2:3) showed Ca to be in the sufficiency range of 0.36-2.00 percent even in the check treatment. The concentration of Ca increased with increasing levels of lime but all were within the above range. The concentration of Mg may also be considered adequate. Nitrogen concentration was increased with the higher lime rates suggesting that nodulation was more effective when soil acidity was reduced further.

After three years of cropping there was a considerable residual effect of liming in this soil. Soil analysis showed that most of the Al was still neutralized at the end of three years where 6 tons of lime/ha were initially applied. Results of the first sampling suggested that lime was still reacting with the soil one month after application.

Even though 1 ton of lime increased yields considerably, it still was not sufficient for maximum growth and for efficient nitrogen utilization. It was necessary to reduce Al saturation to less than 10 percent to obtain the highest yields in this experiment. This corresponded to a soil pH of about 5.4 and is also the pH at which Al was reduced to minimal levels in the LE soil.

Cation Movement from Limed Plots

Natural downward movement of Ca and Mg was studied on certain plots of the Dark Red Latosol. These plots had been limed with calcitic limestone in different years and received different fertilization practices. Results from the oldest limed plots sampled for this particular study are reported in Table 3.2:4. This was an experiment established in 1967, with Stylosanthes under different rates of lime and P. The lowest level of P (33 kg/ha as triple superphosphate) applied in that year with no additional P in subsequent years was selected in order to avoid other sources of Ca besides the lime

Table 3.2:3. Nutrient concentrations of the uppermost trifoliate in the late blooming stage of two soybean varieties grown under various residual levels of lime in the Dark Red Latosol. Wet season, 1973-74.

| Lime added | Variety | N | P | K | Ca | Mg | Mn | Zn |
|---|---|---|---|---|---|---|---|---|
| ton/ha | | ------------ | ------------ | % | ------------ | ------------ | --µg/cc--- | |
| 0 | Viçosa | 3.77 | .19 | 1.9 | .67 | .27 | 121 | 177 |
| 1 | Viçosa | 4.04 | .20 | 1.9 | .95 | .27 | 87 | 116 |
| 2 | Viçosa | 3.93 | .19 | 1.7 | 1.01 | .27 | 76 | 95 |
| 4 | Viçosa | 4.39 | .21 | 1.8 | 1.17 | .32 | 71 | 94 |
| 6 | Viçosa | 4.19 | .21 | 1.7 | 1.19 | .28 | 70 | 96 |
| 8 | Viçosa | 4.46 | .21 | 1.6 | 1.27 | .29 | 57 | 87 |
| 0 | IAC-2 | 3.79 | .19 | 1.9 | .59 | .23 | 134 | 178 |
| 1 | IAC-2 | 3.83 | .19 | 1.9 | .63 | .24 | 103 | 133 |
| 2 | IAC-2 | 3.31 | .16 | 1.8 | .89 | .24 | 95 | 124 |
| 4 | IAC-2 | 4.00 | .20 | 1.8 | 1.19 | .30 | 93 | 87 |
| 6 | IAC-2 | 4.22 | .20 | 1.7 | 1.28 | .28 | 66 | 57 |
| 8 | IAC-2 | 4.04 | .21 | 1.8 | 1.42 | .32 | 75 | 88 |

Table 3.2:4. Soil analysis of limed plots (1967) in the LE soil that were planted to *Stylosanthes*. Samples were taken at 7.5 cm increments in April 1974.[1]

| Lime added in 1967 | Depth of sampling | pH | Exchangeable Al | Exchangeable Ca | Exchangeable Mg | Al satur. |
|---|---|---|---|---|---|---|
| ton/ha | cm | | --- me/100cc --- | | | % |
| 0 | 0.0- 7.5 | 4.67 | 1.04 | 0.25 | 0.05 | 78 |
| | 7.5-15.0 | 4.60 | 1.18 | 0.24 | 0.05 | 79 |
| | 15.0-22.5 | 4.80 | 1.12 | 0.25 | 0.05 | 79 |
| | 22.5-30.0 | 4.80 | 0.96 | 0.25 | 0.05 | 78 |
| | 30.0-37.5 | 4.90 | 0.81 | 0.28 | 0.03 | 72 |
| | 37.5-45.0 | 5.00 | 0.61 | 0.29 | 0.02 | 66 |
| | 45.0-52.5 | 5.00 | 0.51 | 0.25 | 0.03 | 63 |
| | 52.5-60.0 | 5.10 | 0.44 | 0.25 | 0.03 | 61 |
| | 60.0-67.5 | 5.10 | 0.45 | 0.30 | 0.03 | 56 |
| | 67.5-75.0 | 5.10 | 0.46 | 0.35 | 0.03 | 55 |
| 5 | 0.0- 7.5 | 6.20 | 0.06 | 5.98 | 0.17 | 1 |
| | 7.5-15.0 | 5.45 | 0.33 | 2.50 | 0.07 | 11 |
| | 15.0-22.5 | 4.90 | 0.86 | 0.65 | 0.05 | 55 |
| | 22.5-30.0 | 4.90 | 0.84 | 0.35 | 0.04 | 68 |
| | 30.0-37.5 | 4.93 | 0.88 | 0.25 | 0.04 | 75 |
| | 37.5-45.0 | 4.95 | 0.72 | 0.25 | 0.04 | 71 |
| | 45.0-52.5 | 4.97 | 0.59 | 0.28 | 0.02 | 66 |
| | 52.5-60.0 | 4.95 | 0.57 | 0.25 | 0.02 | 68 |
| | 60.0-67.5 | 5.10 | 0.50 | 0.30 | 0.02 | 61 |
| | 67.5-75.0 | 5.10 | 0.28 | 0.25 | 0.03 | 50 |
| 10 | 0.0- 7.5 | 6.45 | 0.05 | 6.32 | 0.21 | 1 |
| | 7.5-15.0 | 6.65 | 0.04 | 5.91 | 0.15 | 1 |
| | 15.0-22.5 | 5.70 | 0.04 | 3.88 | 0.07 | 1 |
| | 22.5-30.0 | 5.06 | 0.57 | 0.72 | 0.05 | 43 |
| | 30.0-37.5 | 5.04 | 0.56 | 0.53 | 0.03 | 50 |
| | 37.5-45.0 | 5.07 | 0.47 | 0.47 | 0.03 | 48 |
| | 45.0-52.5 | 5.09 | 0.51 | 0.38 | 0.03 | 55 |
| | 52.5-60.0 | 5.10 | 0.39 | 0.38 | 0.03 | 48 |
| | 60.0-67.5 | 5.10 | 0.51 | 0.45 | 0.03 | 51 |
| | 67.5-75.0 | 5.10 | 0.31 | 0.40 | 0.02 | 43 |

[1]Values are mean of 2 plots. Each plot sample was a composite of 3 subsamples.

material. Thus, it is estimated that lime was the only source of Ca since the triple superphosphate would have provided very little but a uniform basal amount of Ca to the soil. The only source of Mg was 200 kg $MgSO_4$/ha also applied in 1967 with no further application in later years.

Not much movement of cations occurred below the zone of lime incorporation with the 5 ton level. It is assumed that lime was not physically incorporated below 15 cm depth. A small rotovator was used to incorporate this lime and good mixing with the soil was accomplished. Some Ca seems to have moved into the 15.0-22.5 cm depth, but insignificant amounts of Ca moved below 22.5 cm. With the 10 ton level a considerable amount of Ca moved into the 15.0-22.5 cm, a much lower quantity moved below that zone into the 22.5-45.0 cm depth, and insignificant amounts below 45.0 cm. For all practical purposes, the effective depth of movement was limited to 22.5 cm where most of the Al was neutralized. Below that depth, Al saturation was still high, being around 50 percent, which may be toxic for many crops. The data also showed that essentially all the Mg applied as $MgSO_4$ was lost, most probably by plant uptake (there were 6 cuttings of the Stylosanthes). Only a small portion was retained in the limed zone by pH-dependent charges.

In a more recent experiment (Zn II experiment) where high rates of lime were incorporated to about 20-25 cm in November 1972 and the soil sampled in April 1974, there was marked downward movement of Ca to about 15 cm below the depth of incorporations (Table 3.2:5). This caused the decrease of Al saturation in the 30-45 cm zone from 70-75% initially to about 50% or less within 1½ years after liming.

Since no $MgSO_4$ was applied, there was little Mg in the profile. The Mg in the top cm came mostly from the calcitic limestone. This was the same material as that applied in the depth of liming experiment.

In the Zn II experiment, several anions were incorporated along with the limestone. These included chlorides (from KCl), nitrates (from nitrification of $NH_3$ of the urea) and some sulfate (from $ZnSO_4$). These anions may have enhanced Ca movement acting as the accompanying ion in the leaching process. Work in South Africa by Reeve and Sumner in 1972 reported that heavy fertilization and high rates of lime increased the rate of cation movement, but the Ca had little effect on exchangeable Ca and Al below a depth of 45 cm in a typical Natal Oxisol after 14 years. Dolomitic limestone was applied in the top 15 cm.

In the Stylosanthes study there was no source of anions as in the Zn II experiment, and very little Ca actually moved from the zone of application. Besides the need of anions for cation movement in the soil, a high rate of lime is also important. The literature on this subject indicates that movement occurred only at high rates of lime, and this rate has been related to the texture of the soil.

Table 3.2:5. Soil analysis of limed plots (1972) in the LE soil (Zn II experiment). Samples were taken at 7.5 cm increments in April 1974.[1]

| Lime added in 1972 | Depth of sampling | pH | Exchangeable Al | Exchangeable Ca | Exchangeable Mg | Al satur. |
|---|---|---|---|---|---|---|
| ton/ha | cm | | --- me/100cc --- | | | % |
| 24 | 0.0- 7.5 | 7.68 | tr. | 8.13 | 0.12 | 0 |
| | 7.5-15.0 | 7.65 | tr. | 7.45 | 0.08 | 0 |
| | 15.0-22.5 | 7.44 | tr. | 6.88 | 0.07 | 0 |
| | 22.5-30.0 | 5.62 | 0.06 | 4.38 | 0.07 | 1 |
| | 30.0-37.5 | 4.98 | 0.62 | 1.38 | 0.05 | 44 |
| | 37.5-45.0 | 4.83 | 0.67 | 0.59 | 0.02 | 53 |
| | 45.0-52.5 | 4.73 | 0.63 | 0.38 | 0.03 | 63 |
| | 52.5-60.0 | 4.54 | 0.65 | 0.35 | 0.04 | 63 |
| | 60.0-67.5 | 4.46 | 0.63 | 0.30 | 0.04 | 65 |
| | 67.5-75.0 | 4.41 | 0.65 | 0.25 | 0.03 | 70 |
| 16 | 0.0- 7.5 | 7.02 | tr. | 6.95 | 0.13 | 0 |
| | 7.5-15.0 | 7.35 | tr. | 7.50 | 0.13 | 0 |
| | 15.0-22.5 | 7.15 | tr. | 7.25 | 0.08 | 0 |
| | 22.5-30.0 | 6.12 | tr. | 3.70 | 0.07 | 0 |
| | 30.0-37.5 | 5.07 | 0.67 | 1.21 | 0.03 | 35 |
| | 37.5-45.0 | 4.97 | 0.68 | 0.76 | 0.03 | 46 |
| | 45.0-52.5 | 4.80 | 0.63 | 0.45 | 0.03 | 57 |
| | 52.5-60.0 | 4.75 | 0.61 | 0.43 | 0.02 | 58 |
| | 60.0-67.5 | 4.52 | 0.63 | 0.35 | 0.03 | 63 |
| | 67.5-75.0 | 4.50 | 0.90 | 0.30 | 0.03 | 73 |
| 8 | 0.0- 7.5 | 7.15 | tr. | 6.02 | 0.18 | 0 |
| | 7.5-15.0 | 7.30 | tr. | 6.13 | 0.14 | 0 |
| | 15.0-22.5 | 7.35 | tr. | 6.35 | 0.10 | 0 |
| | 22.5-30.0 | 6.60 | tr. | 4.73 | 0.08 | 0 |
| | 30.0-37.5 | 5.10 | 0.64 | 1.09 | 0.07 | 36 |
| | 37.5-45.0 | 5.10 | 0.67 | 0.94 | 0.04 | 41 |
| | 45.0-52.5 | 4.75 | 0.70 | 0.39 | 0.03 | 62 |
| | 52.5-60.0 | 4.60 | 0.74 | 0.30 | 0.02 | 70 |
| | 60.0-67.5 | 4.55 | 0.76 | 0.30 | 0.03 | 70 |
| | 67.5-75.0 | 4.35 | 0.74 | 0.25 | 0.02 | 73 |

[1]Values are mean of 3 replications at each lime level. Each replication is a composite of 4 subsamples.

## B. RESIDUAL EFFECTS OF LIME RATE AND INCORPORATION DEPTHS

J. G. Salinas, E. Gonzalez, E. J. Kamprath and P. A. Sanchez

A fifth crop of corn was grown during the 1975-1976 rainy season in order to continue evaluating the residual effects of lime applications and changes in soil properties. The experimental design and methodology has been reported in previous annual reports. Besides the evaluation of annual, cumulative and residual effects of liming on the grain production as well as its effects on the soil properties to the depth of lime incorporation, a decision was made to study the soil properties in terms of downward movement of basic cations and root development as deep root proliferation. The N, P and K applications continued this season with a broadcast application of 124 kg K/ha as KCl, a banded application of 44 kg P/ha as triple superphosphate (TSP) and 20 kg N /ha as urea followed by three side-dressed applications totaling 200 kg N/ha as urea. As in earlier experiments, the same corn variety Cargill-111 was planted in 80 cm rows at an approximate population of 50,000 plants/ha. The experiment was planted on October 31, 1975, and harvested on March 20, 1976.

Yields

Results of the fifth corn crop are shown in Fig. 3.2:1. As in previous crops, significant yield increases were produced by the residual effect of only 1 ton lime/ha incorporated to either depth. The yields from rates of 2 and 4 tons/ha at either depth were not significantly different from the same depth at 1 ton/ha. At 8 tons/ha, however, both depths of this lime rate yielded significantly more than all lower rates. This yield increase could be explained by the very low Al saturation maintained over time on the surface and subsurface. On the other hand, the non-significant difference between shallow and deep application at this highest rate essentially was due to the fact that in the subsurface (15-30 cm) at the shallow application, the Al saturation was quite low (less than 20% Al saturation) which indicated no toxic effect on root growth.

Effects on Soil Properties

The Table 3.2:6 shows the change in soil pH, exchangeable Al and percent Al saturation in samples taken after each crop harvest from May 1973 to April 1976. Soil pH at two depths for all lime rates after each of five crops is shown in Fig. 3.2:2. In general, the pH gradually decreased in both shallow and deep incorporations. With time the pH values for both shallow and deep placement of 1, 2 and 4 tons lime/ha decreased to similar values. Although there was a decline in pH at the rate of 8 tons/ha incorporated to 30 cm depth, this high rate of lime still maintained substantial residual effect after five years. In addition, the pH values at 15-30 cm depth in shallow treatments showed increases with time even though no lime was applied at this depth.

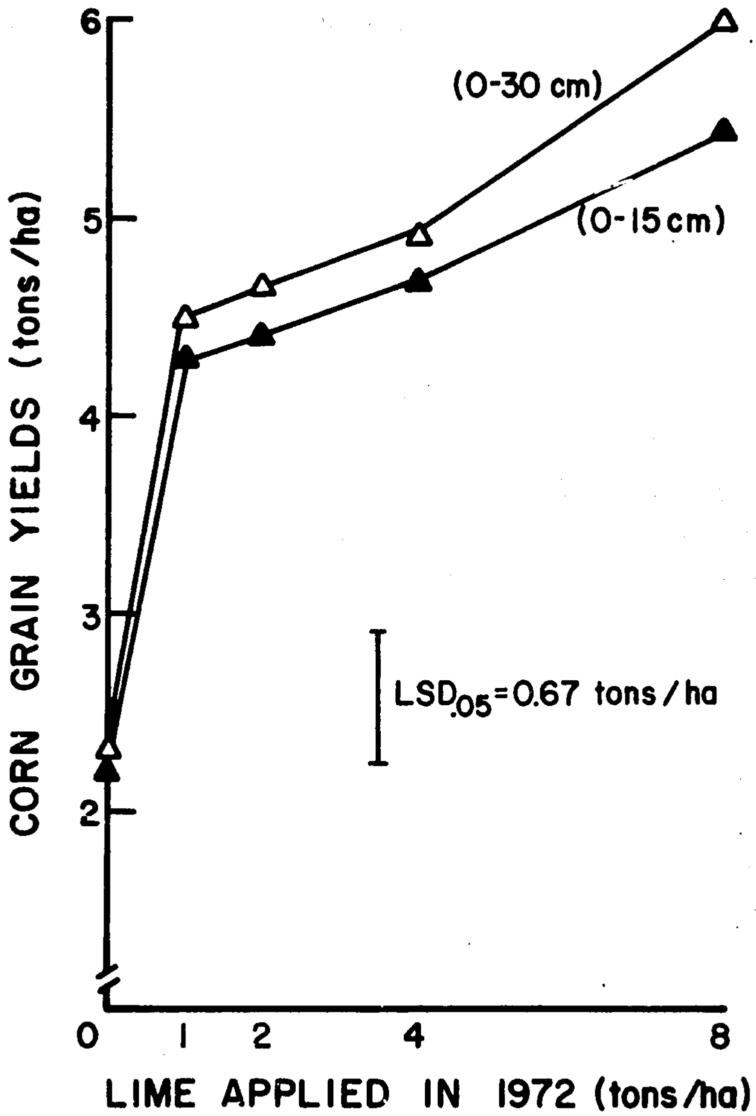



Figure 3.2:1. Corn yields of the fifth crop (1976) as affected by lime applied in 1972. Brasilia.

Table 3.2:6. Soil pH, exchangeable Al, and percent Al saturation of the five crops as affected by depth and rate of lime applications in 1972.

| Depth of lime incorp. | Lime rate | Soil depth | Soil pH | | | | | Exchangeable Al | | | | | Al Saturation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | May 1973 | Nov 1973 | May 1974 | Mar 1975 | Apr 1976 | May 1973 | Nov 1973 | May 1974 | Mar 1975 | Apr 1976 | May 1973 | Nov 1973 | May 1974 | Mar 1975 | Apr 1976 |
| --cm-- | ton/ha | -cm-- | --------- 1:1 $H_2O$ ---------- | | | | | --------- me/100cc---------- | | | | | ------------ % ------------ | | | | |
| No Lime | 0 | 0-15 | 4.7 | 4.6 | 4.5 | 4.4 | 4.2 | 1.10 | 1.03 | 1.14 | 1.41 | 1.48 | 71 | 72 | 68 | 78 | 78 |
| | | 15-30 | 4.7 | 4.5 | 4.4 | 4.3 | 4.1 | 1.16 | 1.01 | 1.18 | 1.25 | 1.25 | 68 | 68 | 73 | 81 | 71 |
| Shallow | 1 | 0-15 | 5.0 | 4.9 | 4.9 | 4.9 | 4.4 | 0.85 | 0.55 | 0.62 | 0.66 | 0.89 | 43 | 28 | 30 | 41 | 44 |
| | | 15-30 | 4.8 | 4.7 | 4.6 | 4.6 | 4.4 | 0.98 | 1.00 | 0.99 | 0.97 | 0.90 | 61 | 69 | 60 | 62 | 51 |
| | 2 | 0-15 | 5.1 | 5.3 | 5.2 | 5.0 | 4.8 | 0.52 | 0.16 | 0.35 | 0.56 | 0.64 | 22 | 7 | 15 | 24 | 25 |
| | | 15-30 | 4.8 | 4.8 | 4.6 | 4.7 | 4.6 | 0.97 | 0.97 | 1.08 | 0.99 | 0.80 | 65 | 61 | 63 | 57 | 44 |
| | 4 | 0-15 | 5.6 | 5.7 | 5.6 | 5.2 | 4.9 | 0.18 | 0.08 | 0.08 | 0.33 | 0.36 | 6 | 2 | 3 | 12 | 13 |
| | | 15-30 | 4.8 | 4.8 | 4.8 | 4.8 | 4.7 | 0.92 | 0.79 | 0.92 | 0.93 | 0.69 | 61 | 45 | 50 | 50 | 33 |
| | 8 | 0-15 | 6.4 | 6.4 | 6.5 | 6.1 | 5.7 | 0.07 | 0.03 | 0.07 | 0.08 | 0.02 | 2 | 1 | 1 | 1 | 1 |
| | | 15-30 | 4.9 | 4.9 | 4.9 | 5.3 | 4.9 | 0.74 | 0.76 | 0.68 | 0.55 | 0.36 | 47 | 35 | 20 | 27 | 15 |
| Deep (0-30) | 1 | 0-15 | 5.1 | 4.9 | 4.9 | 4.7 | 4.4 | 0.79 | 0.66 | 0.89 | 0.99 | 1.25 | 39 | 35 | 48 | 32 | 63 |
| | | 15-30 | 5.0 | 4.9 | 4.8 | 4.6 | 4.4 | 0.88 | 0.86 | 1.03 | 1.04 | 1.07 | 46 | 58 | 58 | 66 | 62 |
| | 2 | 0-15 | 5.4 | 5.2 | 5.4 | 5.1 | 4.6 | 0.25 | 0.28 | 0.33 | 0.50 | 0.73 | 11 | 12 | 12 | 23 | 31 |
| | | 15-30 | 5.2 | 5.1 | 4.9 | 4.8 | 4.6 | 0.66 | 0.40 | 0.73 | 0.78 | 0.66 | 31 | 20 | 40 | 51 | 33 |
| | 4 | 0-15 | 5.9 | 5.4 | 5.5 | 5.4 | 5.2 | 0.17 | 0.17 | 0.21 | 0.26 | 0.18 | 4 | 6 | 9 | 10 | 6 |
| | | 15-30 | 5.4 | 5.1 | 5.1 | 5.0 | 4.8 | 0.34 | 0.33 | 0.51 | 0.66 | 0.43 | 13 | 16 | 25 | 35 | 19 |
| | 8 | 0-15 | 6.5 | 6.1 | 5.9 | 5.9 | 5.7 | 0.06 | 0.07 | 0.06 | 0.07 | 0.05 | 1 | 1 | 1 | 1 | 1 |
| | | 15-30 | 5.9 | 5.5 | 5.2 | 5.3 | 5.2 | 0.16 | 0.11 | 0.14 | 0.13 | 0.15 | 5 | 3 | 5 | 5 | 5 |

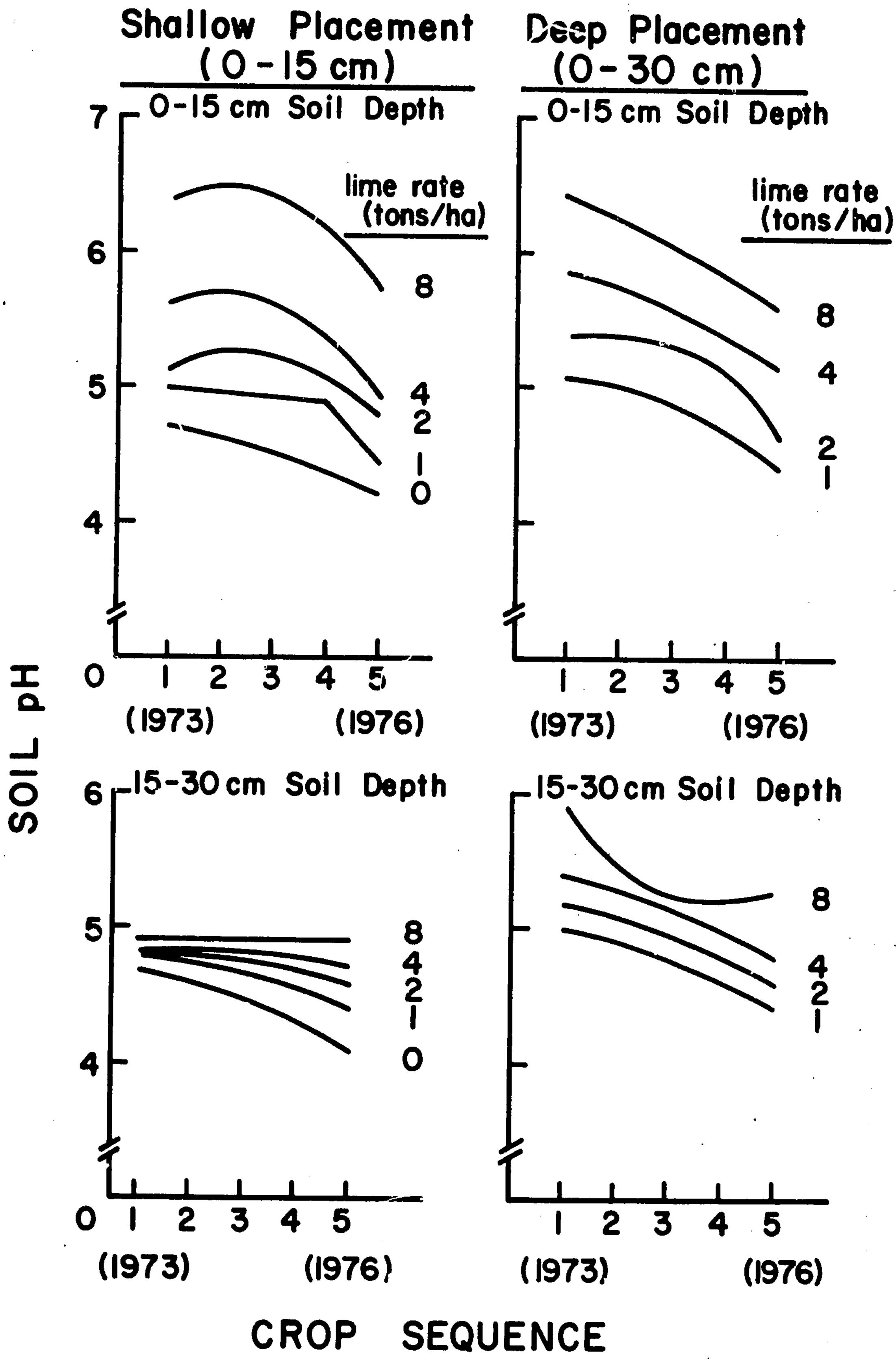



Figure 3.2:2. Residual effects of lime rates and depth of incorporation on the soil pH at two depths after each of five crops. Brasilia, 1972-1976.

Perhaps a better picture of these differences is given by consideration of change of percent Al saturation. Fig. 3.2:3 shows a progressive decrease in percent Al saturation in the 15-30 cm layer of shallow applications which was associated with downward movement of basic cations. Thus, five years after lime applications in the Dark Red Latosol, the additional benefit of deep incorporation of lime which was obtained during the first three crops started to decrease in the fourth crop and was almost negligible after the fifth crop. However, from the economical point of view, the superior performance of deep application is still evident since deep lime placement produced the same yield with half the rate of lime as did shallow application. It is important to remark that the fifth crop was planted on the date in which the probability was high to escape from a severe "veranico" during the grain formation stage. In addition, a severe veranico did not occur during this wet season. The only slight drought period within the 1975-1976 rainy season occurred for 8 days at the beginning of January 1976, 65 days after planting this experiment and which did not cause serious plant water stress due to cloudiness and high humidity.

Cumulative and Residual Effects of Liming

The seasonal and cumulative yields of the five crops are presented in Table 3.2:7. Although there was no difference between shallow and deep applications in the fifth crop, the overall trend still showed that deep lime application had a positive effect after five years. From observation of the cumulative yields, one notes equal yields from one-half as much lime when incorporated to 30 cm as compared with incorporation to 15 cm.

The residual effects of the original lime treatments applied in 1972 are shown in Fig. 3.2:4. These effects are expressed as percent of maximum yield relative to the highest absolute yield which was always produced by 8 tons/ha of lime incorporated to 30 cm. After five years, 1, 2 and 4 tons/ha lime at shallow and deep incorporations produced similar yields. However, the lack of differences between shallow and deep placement might be atttributable, in part, to the lack of natural drought period in this wet season. The shallow incorporation of 8 tons lime/ha produced 90% of the maximum yield and its residual effect was still considerable. This experiment will be continued by CPAC staff members in order to fully evaluate the residual effects.

Yields of the five crops expressed as percent of the maximum yield (8 tons lime/ha incorporated to 30 cm) as a function of the soil pH are given in Fig. 3.2:5. In general, after each crop the curves representing shallow and deep applications shifted to the left indicating a decrease of pH values at all lime rates. Thus, the residual effect of lime diminished with cropping. Significant differences occurred between shallow and deep incorporations of lime with the first three crops in which the differences in pH values at 15-30 cm soil layers were large. With time, these differences became smaller and practically

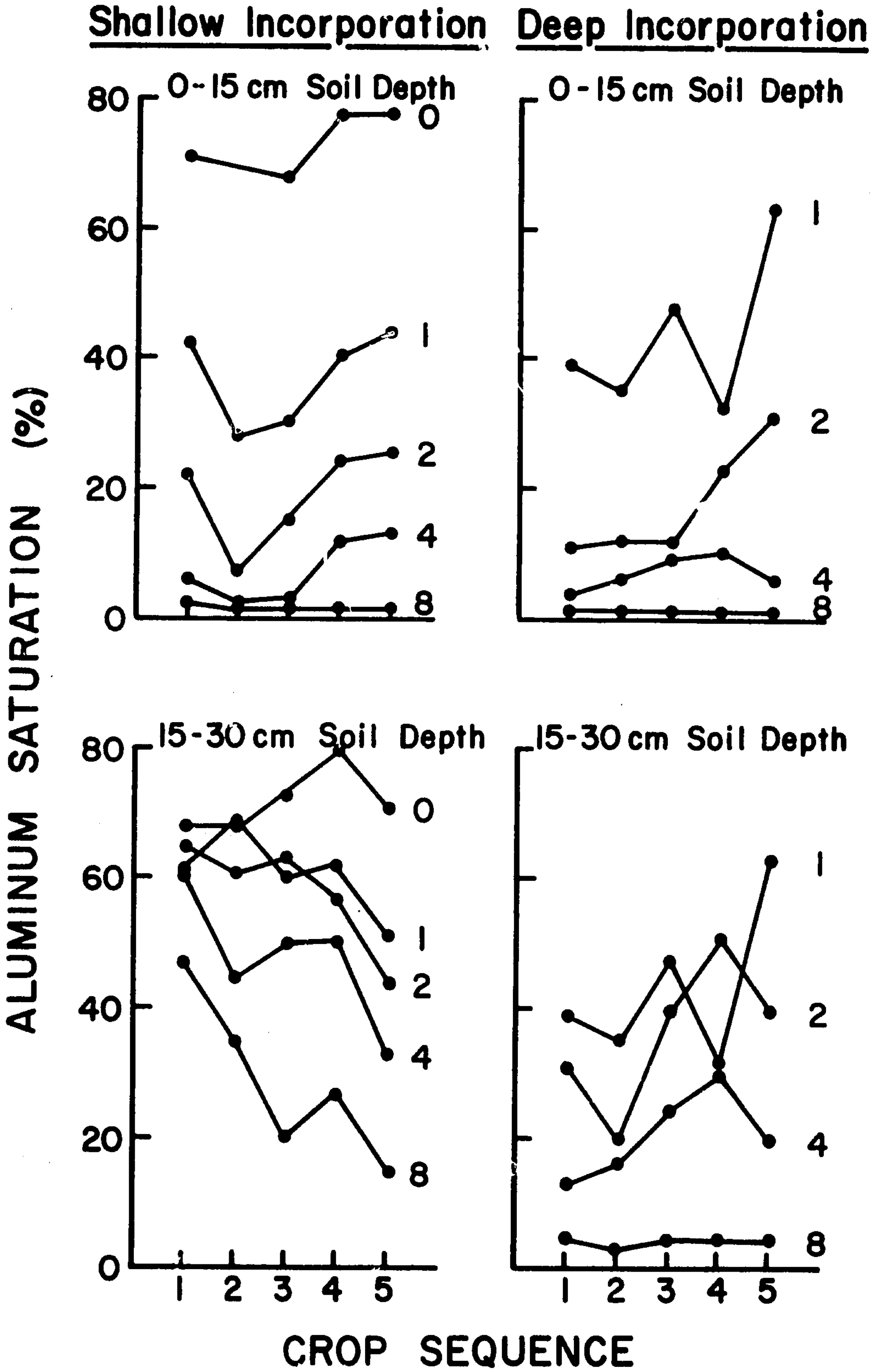



Figure 3.2:3. Residual effects of lime rates and depth incorporation on the Al saturation after five crops. Brasilia, 1972-1976.

Table 3.2:7. Seasonal and cumulative gran yields of five crops (4 for corn and 1 for sorghum*) as affected by shallow and deep lime applications.

| Depth of lime incorp. | Lime rates applied in 1972 | Seasonal Grain Yields 1 Rainy 72-73 | 2 Dry 73 | 3 Rainy 73-74 | 4 Rainy 74-75 | 5 Rainy 75-76 | Cumu-lative yield | Maximum yields |
|---|---|---|---|---|---|---|---|---|
| cm | ton/ha | tons/ha | | | | | | % |
| No Lime | 0 | 2.11 | 4.57 | 0.88 | 1.48 | 2.36 | 11.40 | 41 |
| Shallow (0-15) | 1 | 3.42 | 5.28 | 1.47 | 3.52 | 4.28 | 17.97 | 64 |
| | 2 | 3.53 | 5.69 | 1.86 | 5.58 | 4.32 | 20.98 | 75 |
| | 4 | 4.00 | 5.90 | 2.27 | 6.23 | 4.62 | 23.02 | 82 |
| | 8 | 3.72 | 5.96 | 2.05 | 6.88 | 5.41 | 24.02 | 85 |
| Deep (0-30) | 1 | 4.02 | 5.88 | 2.09 | 4.57 | 4.43 | 20.99 | 75 |
| | 2 | 4.34 | 5.68 | 2.59 | 5.86 | 4.60 | 23.07 | 82 |
| | 4 | 4.80 | 5.86 | 3.06 | 6.42 | 4.81 | 24.95 | 89 |
| | 8 | 4.80 | 6.68 | 3.60 | 7.06 | 5.97 | 28.11 | 100 |
| $LSD_{.05}$ | | 0.57 | 0.55 | 0.76 | 0.64 | 0.67 | | |
| CV (%) | | 26 | 13 | 28 | 10 | 12 | | |

*Sorghum yield is an average of two sorghum varieties.

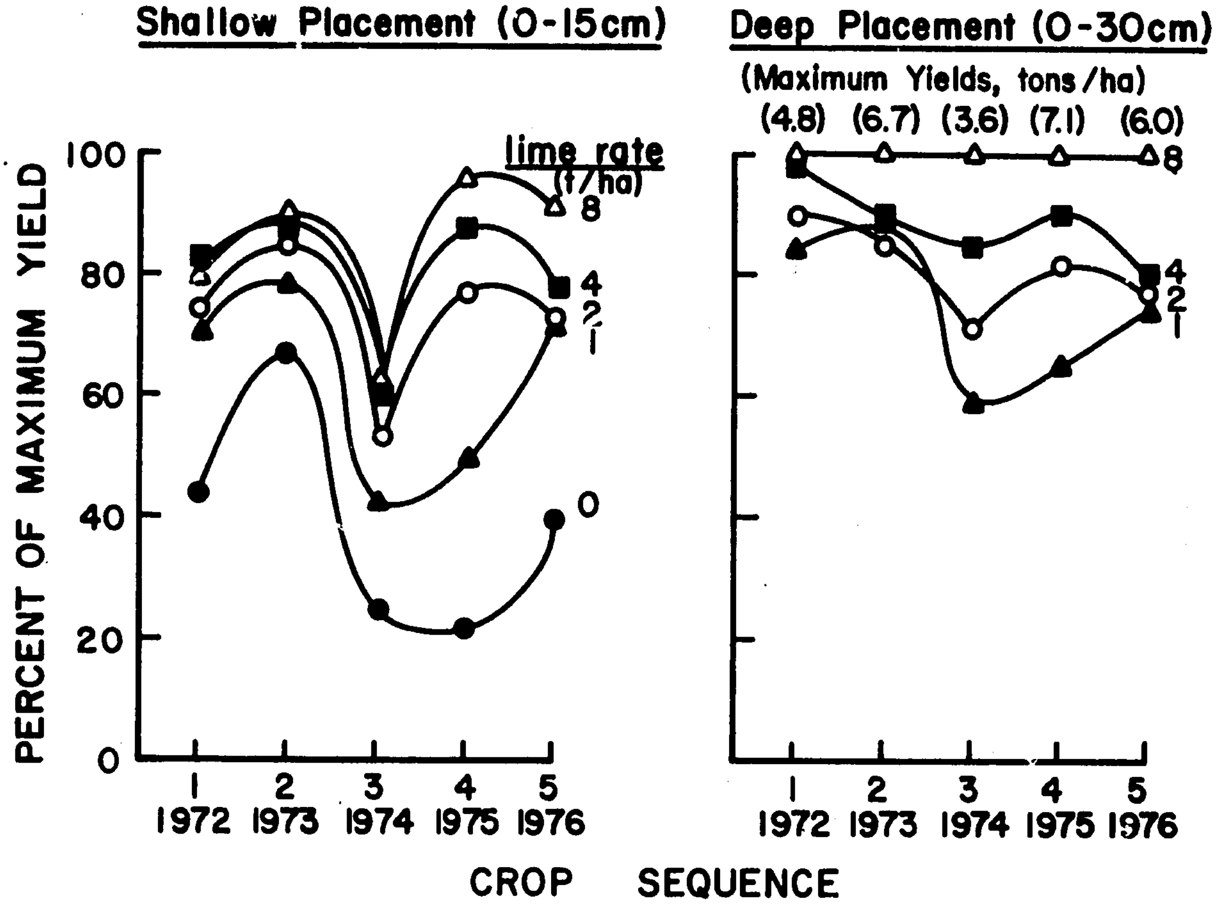



Figure 3.2:4. Corn grain yields over time as influenced by various residual lime rates at two placements. 1972-1976. Brasilia.

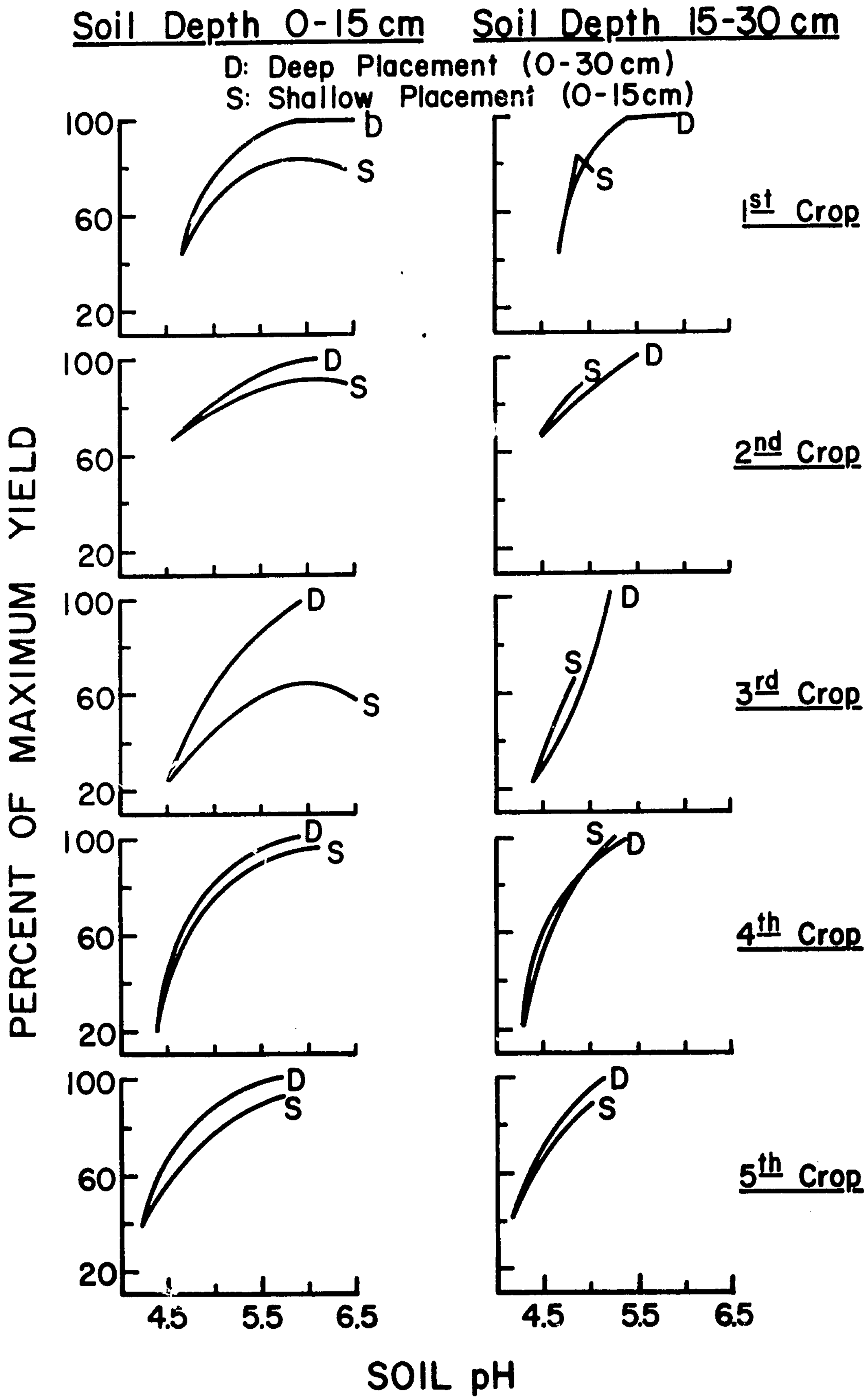



Figure 3.2:5. Corn grain yields over time as influenced by residual lime placement and plotted as a function of soil pH. 1972-1976. Brasilia, Brazil.

disappeared in the fourth and fifth crops. The main reasons seemed to be a result of the decrease in the residual effect of lime incorporated to a 30 cm depth and the decrease in Al saturation in the shallow lime treatments at the 15-30 cm depth due to a downward movement of Ca and Mg into this soil depth.

Root Depth and Downward Movement of Basic Cations

Eighty days after planting, three pits were dug and opened to 100 cm in plots which received no lime and 4 tons lime/ha shallow and deep incorporation, respectively. As expected, depth and proliferation of roots increased with increasing depth of liming (Fig. 3.2:6). Where no lime was applied most of the roots were concentrated close to the row and just in the 0-15 cm soil layer. This type of rooting distribution could be related to the banded P application. At 4 tons lime/ha shallow application a high concentration of roots still were observed in the 15 cm soil layer but their distribution covered all this layer, with some of them having passed 20-30 cm below the level to which lime had been incorporated. Deep liming resulted in a fairly uniform rooting distribution in the 0-15 cm soil layer with considerable roots irregularly distributed to a 50 cm depth. This differential distribution of roots emphasized the necessity for a more detailed soil sampling to deeper layers in order to evaluate the effects on soil properties of lime rates and depth of incorporation. After harvest of the fifth corn crop, soil samples were taken in several layers to a 90 cm depth. Changes in pH, exchangeable Al, Ca, Mg and percent Al saturation are shown in Figs. 3.2:7-3.2:10. The results indicated clearly that a factor other than simple pH effect was involved. As lime rates were increased, notable differences in pH values at least until 45 cm depth were noted. The greatest difference was found between 0 and 8 tons/ha shallow and deep incorporation. The data strongly indicate that after five years substantial Ca and Mg have moved through the profile to depths of 45 to 50 cm.

Proportional to the lime rate, Ca and Mg concentrations increased and Al saturation decreased through the profile. Considering 50% Al saturation as a critical value for adequate corn growth, the results showed that five years after shallow applications at the rates of 2 and 4 tons/ha this critical Al saturation value is found at 30 cm deep. With deep placement (0-30 cm) of 2 tons/ha the critical value is found around 35 cm deep and for 4 tons/ha near 45 cm deep. With the highest lime rate (8 tons/ha) it is interesting to observe that 50% Al saturation was encountered somewhere between 50 and 70 cm deep under both shallow and deep incorporation. In addition, at these highest rates of lime incorporated at 0-15 and 0-30 cm the neutralization of aluminum in the sublayers was quite similar. Small differences were observed with exchangeable Al and Ca + Mg under both shallow and deep placement at the highest lime rates. All these results are showing the benefit of movement of basic cations

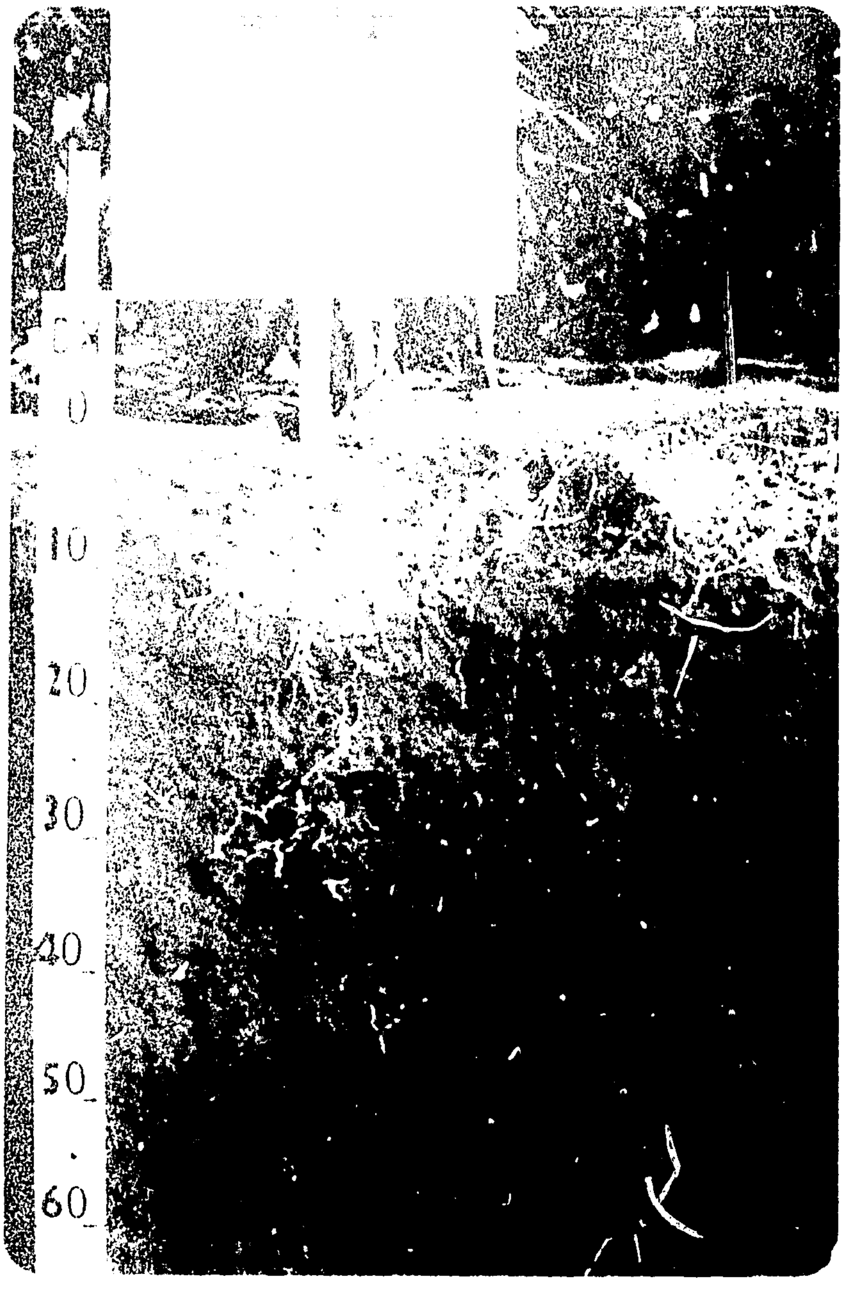



Figure 3.2.6a. Corn root distribution as a function of depth in the zero lime treatment of the experiment on lime rates and depth of incorporation. Concentrated root zones correspond to regions of banded P applications. Fifth crop. Brasilia, 1976.

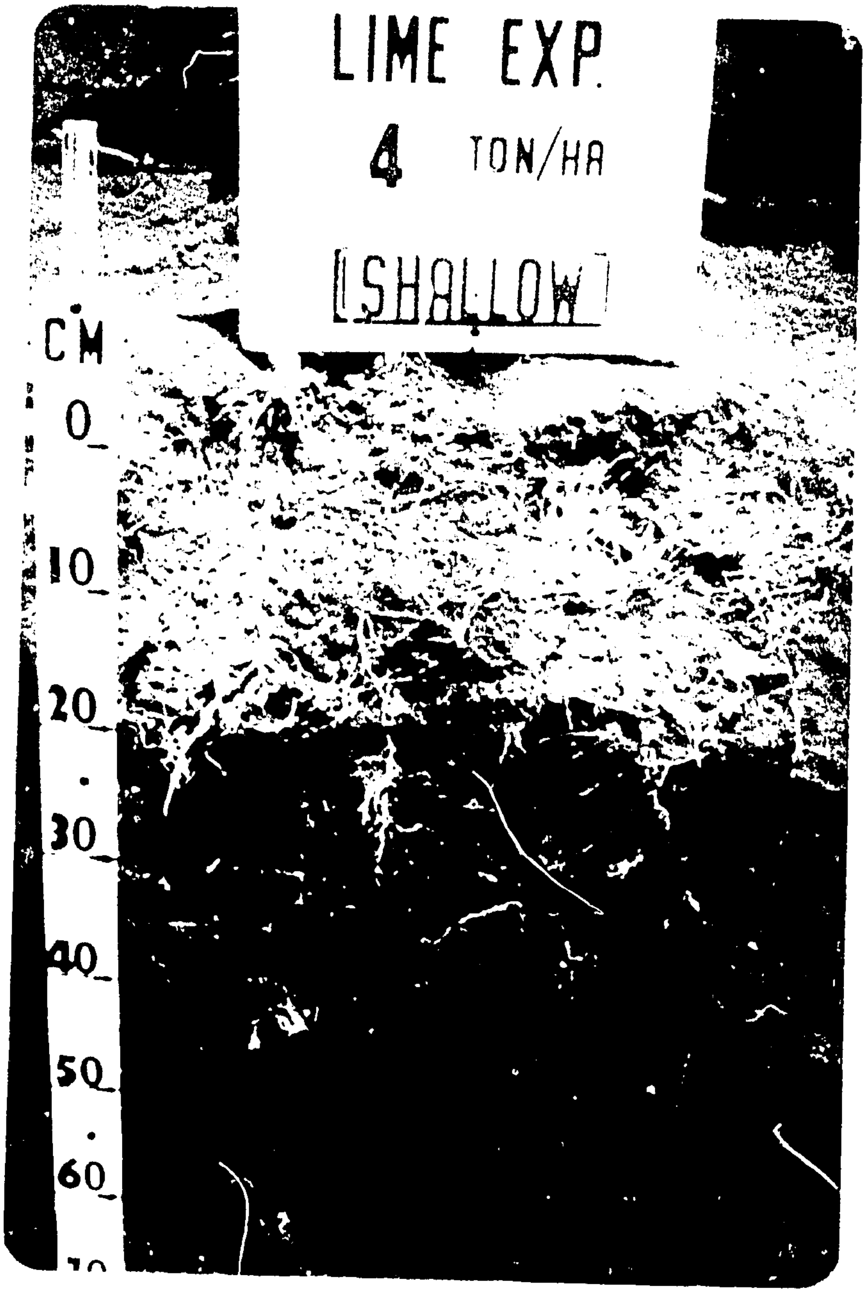



Figure 3.2:6b. Corn root distribution as a function of depth in the residual 4 ton/ha lime treatment with shallow (0-15 cm) incorporation. Fifth crop after liming. Brasilia, 1976.

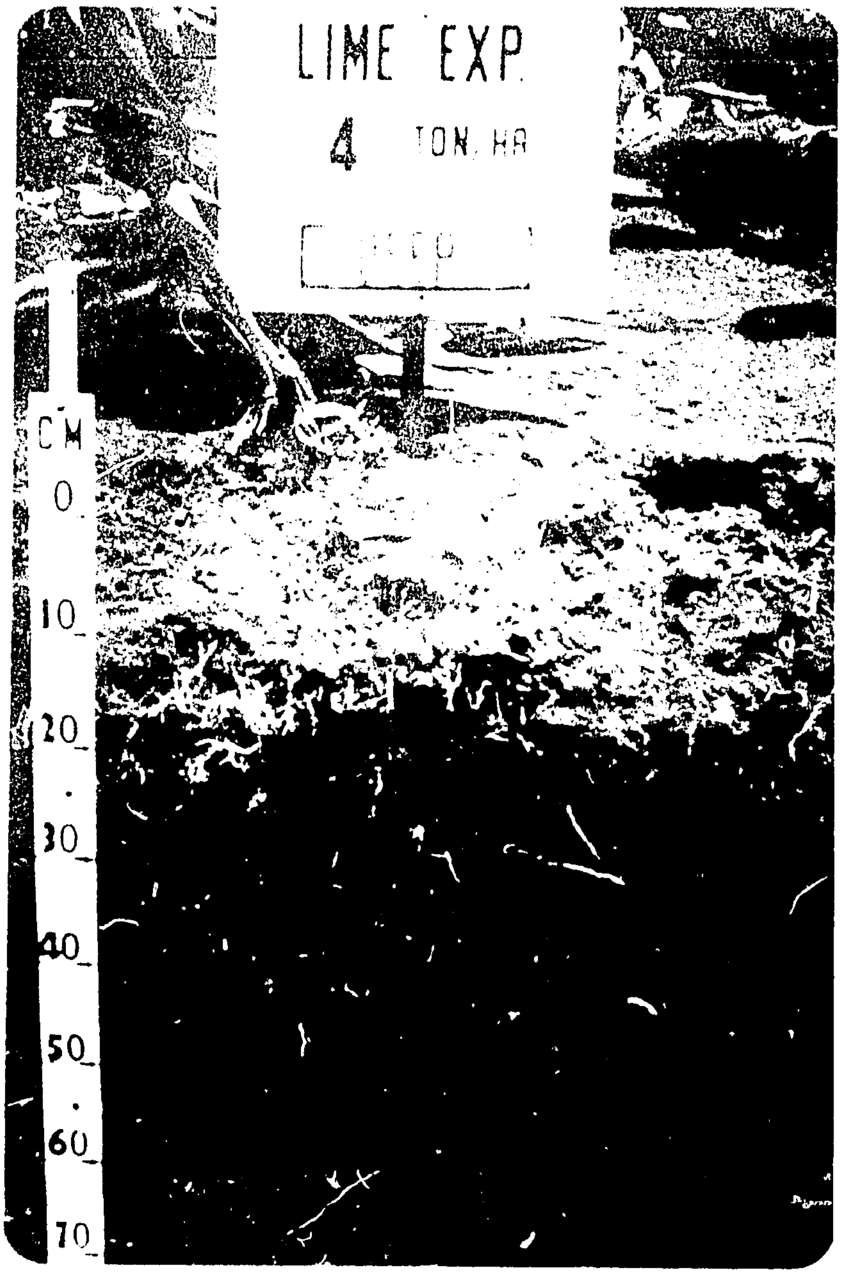



Figure 3.2:6c. Corn root distribution with depth in the residual 4 ton/ha lime treatment with deep (0-30 cm) incorporation. Fifth crop after liming. Brasilia, 1976.

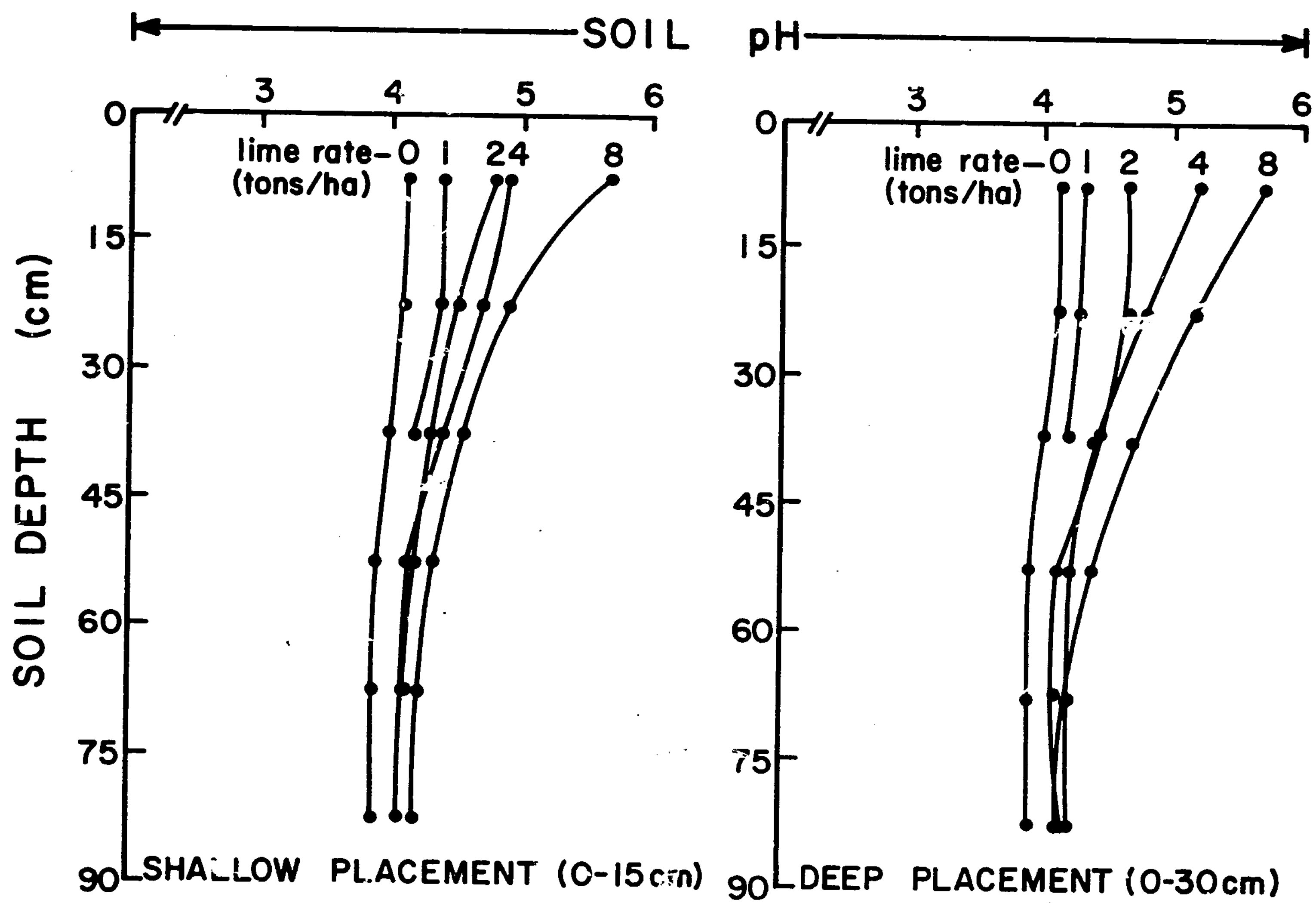



Figure 3.2:7. Residual effects of lime applications on soil pH after six crops; four corn and two sorghum crops. Brasilia, 1975-1976.

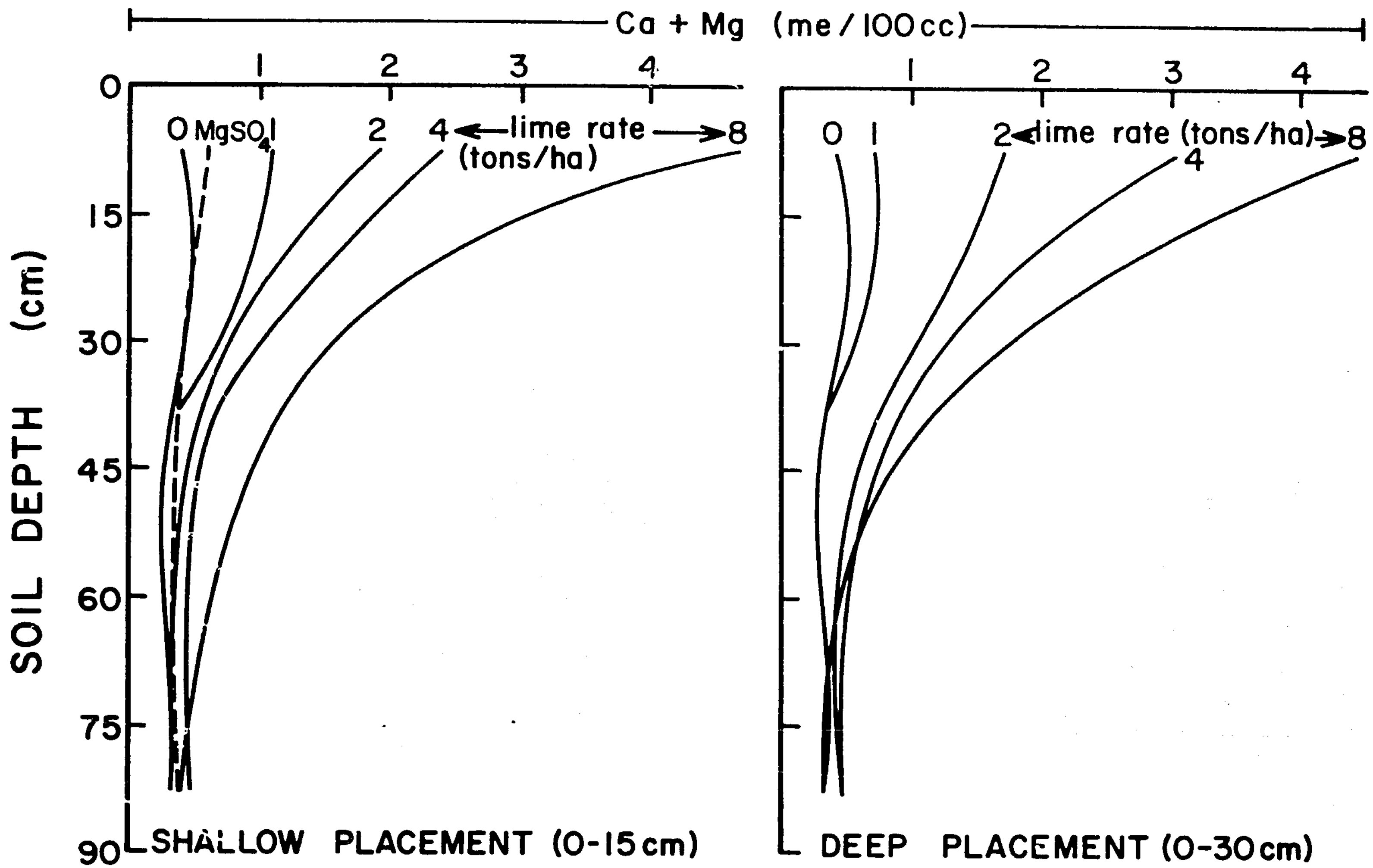



Figure 3.2:8. Residual effects of lime incorporations on exchangeable Ca and Mg; four corn and two sorghum crops. Brasilia, 1975-1976.

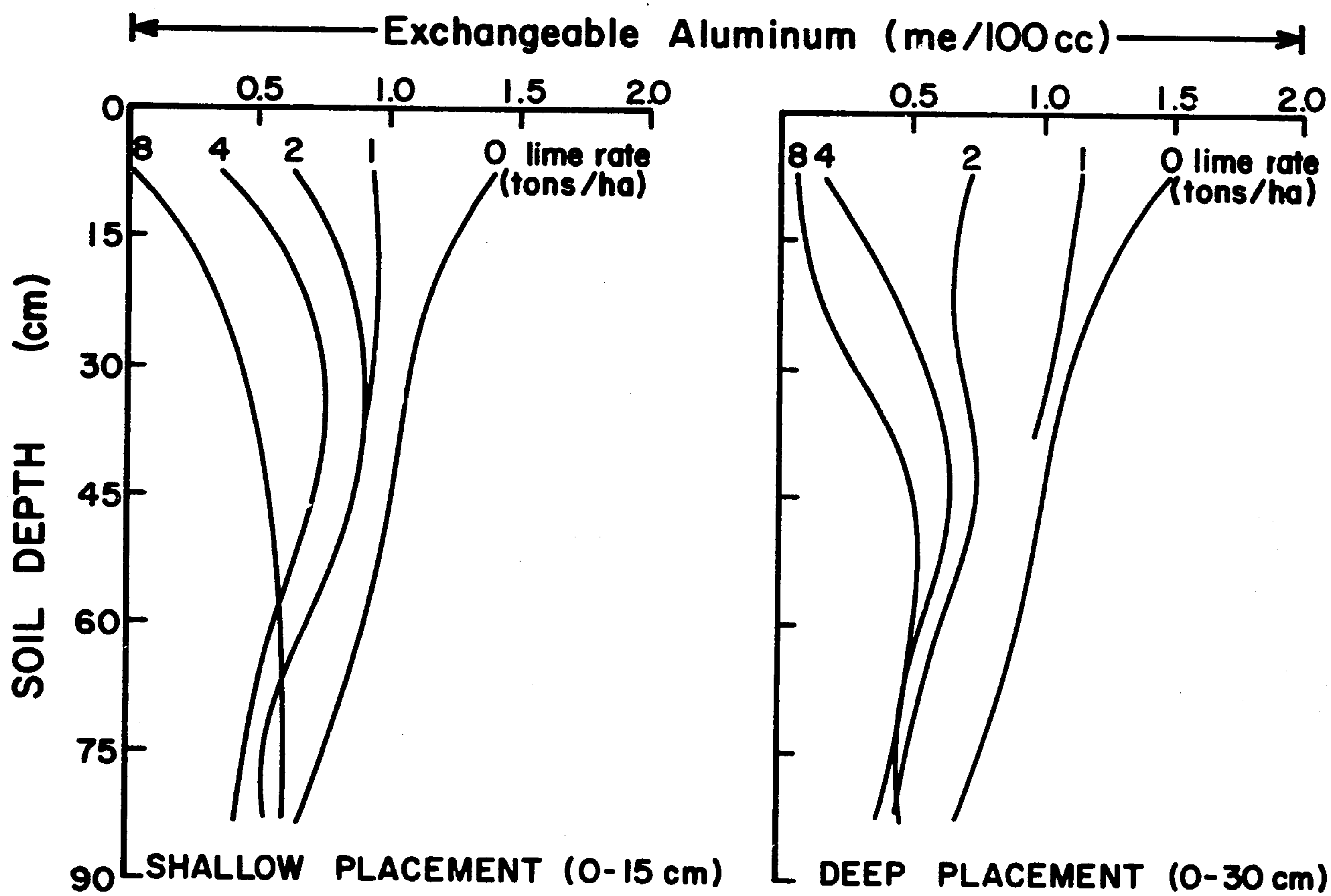



Figure 3.2:9. Residual effects of lime applications on exchangeable Al after six crops; four corn and two sorghum crops. Brasilia, 1975-1976.

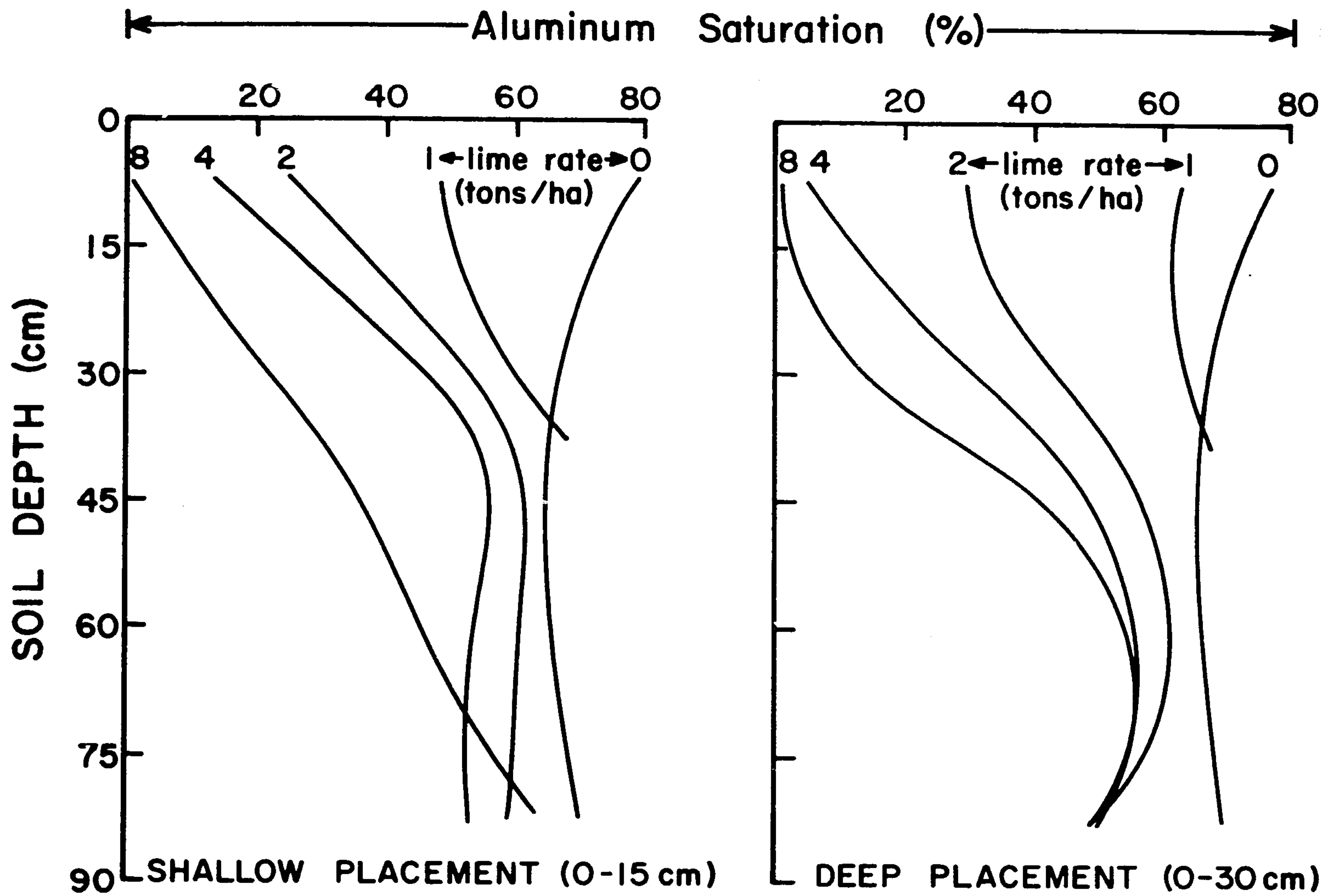



Figure 3.2:10. Residual effects of lime incorporations on percentage Al saturation after s:x crops; four corn and two sorghum crops. Brasilia, 1975-1976.

into the subsurface soil thereby reducing the degree of Al toxicity and establishing better conditions for deeper root growth.

### 3.3 MOVEMENT OF Ca AND Mg

K. D. Ritchey, O. Correa, D. Souza and E. Lobato

Because the roots of many agronomic crops are sensitive to Al, the presence of Al in toxic concentrations in the Dark Red Latosol (Typic Haplustox) presents a serious impediment to maximum crop production, particularly during dry spells when the plants quickly exhaust the soil water reserves in the limed surface layers.

The practice of deep incorporation of lime to 30 cm by rotovation or deep plowing has been shown in previous annual reports to have raised the pH and precipitated the Al to this depth, thus allowing the roots to grow and use the stored water reserves. During dry spells this additional water can provide several extra days of plant activity before wilting begins. Yield increases attributable to deep lime incorporation of 1000 to 1500 kg/ha grain have been observed in Cerrado soils.

The encouraging results obtained from mechanical incorporation of lime have given impetus to the search for other ways to promote deep rooting. One possibility for improving soil conditions deeper than is practical with mechanical lime incorporation is to take advantage of the relatively abundant summer rainfall and the low soil CEC to promote chemical movement of Ca and Mg down through the profile.

Research toward this goal has followed two lines. Field experiments already in existence were sampled at various depths to observe the effects of varying applications of soil amendments on improving subsoil rooting conditions. Laboratory experiments were initiated to study in more detail the nature of the movement observed in the field.

In the laboratory study two large columns 210 cm in length were set up, using plastic irrigation tubing of 9.7 cm inside diameter. The column was carefully filled with air-dried soil screened through a 2 mm mesh sieve which had been collected from the 30-45 cm layer of a virgin Dark Red Latosol profile. The top 0-15 cm section of the column was made up of soil collected from the surface of a nearby experiment that had been cropped for two years. A treatment consisting of 880 kg/ha P as ordinary superphosphate (which consists of monocalcium phosphate monohydrate and calcium sulfate) was mixed in the 0-15 cm section.

Each day for 15 days a quantity of distilled water equivalent to 100 mm rainfall was dripped slowly onto the surface of the column. This was equivalent to slightly more than the maximum daily rainfall observed in 1976. The total applied was 1500 mm, which is the average yearly rainfall for the Brasilia area. The solution which passed through the column was collected daily. Results shown in Fig. 3.3:1 show that very significant Ca and Mg movement occurred to a depth of 75-90 cm in the 15 days of the study.

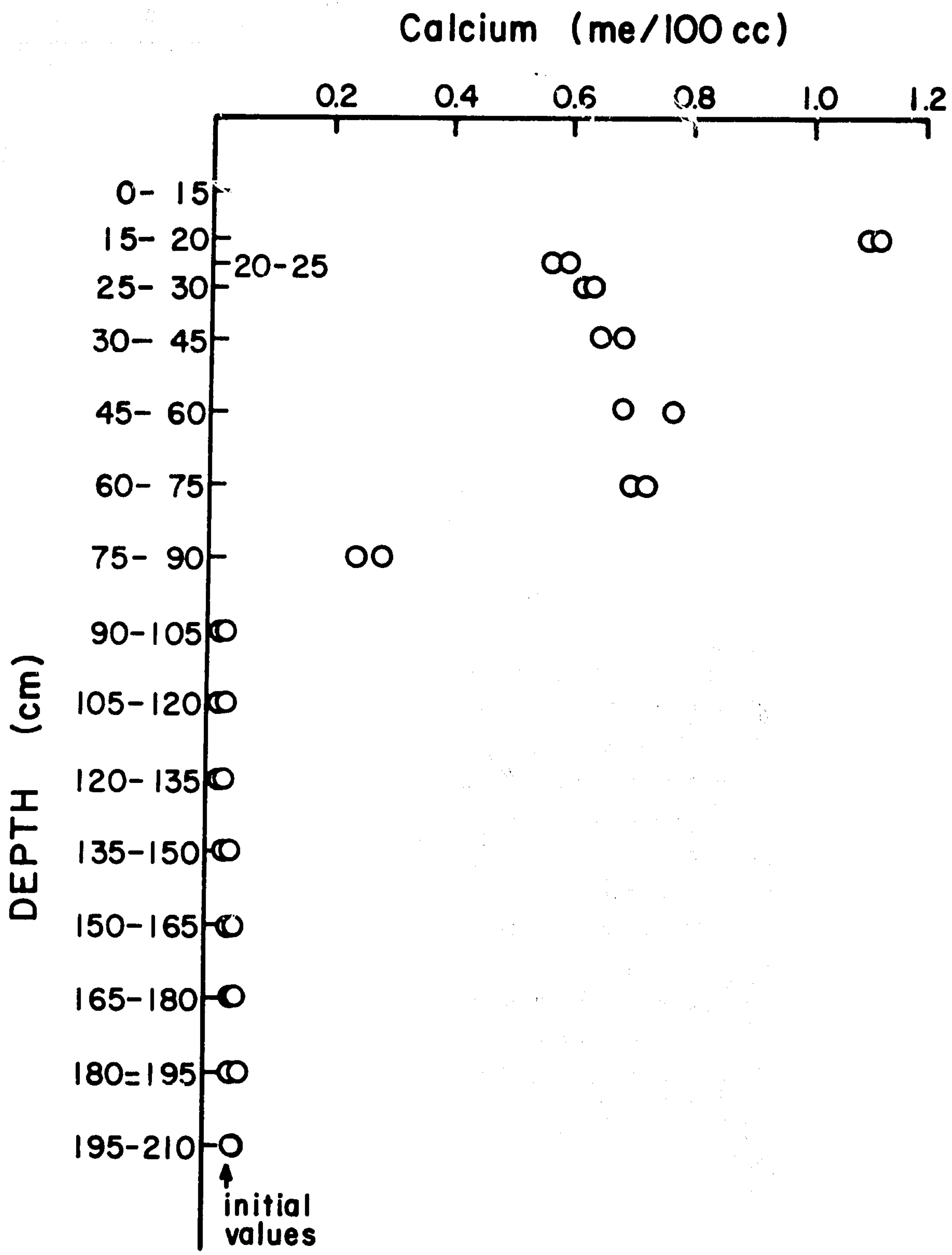



Figure 3.3:1. Vertical distribution of Ca in two 2.1 meter columns filled with soil taken from 30-45 cm of a virgin Dark Red Latosol profile after leaching for 15 days with the equivalent of one year's rainfall. The top 15 cm of the column consisted of a limed surface soil amended with approximately 880 kg P/ha as ordinary superphosphate.

In the experiment entitled "Residual Effect of Lime and Phosphorus Applications on the Loamy Red Yellow Latosol" two sources of P were used. The movement of Ca and Mg was much more pronounced in the treatment which received 352 kg P/ha as SSP than where 220 kg P/ha as triple superphosphate (TSP) plus 44 kg P/ha as SSP gave the best movement. The addition of 4 tons/ha calcitic lime had no effect on the Ca + Mg status below 30 cm (Fig. 3.3:2).

These results suggest that the $CaSO_4$ present in SSP and not in TSP may be responsible for some of the observed downward Ca movement.

An experimental area with three levels of lime applied in 1972 was used to observe the effect of heavy liming rates. This experiment, described in the 1973 Annual Report, received 7.5, 15 and 22.5 tons $CaCO_3$-equivalent/ha, in a factorial with three Zn rates. Applications of 187 kg P/ha and about 100 kg N/ha were also made. After one corn crop was harvested the area was planted to star grass. Occasional light fertilizer dressings were surface-applied to the grass, and it was irrigated during the dry seasons. The results of sampling done in 1976 are shown in Fig. 3.3:3. Similar effects on subsoil acidity by OSP applications are presented in Fig. 3.3:4.

The occurrence of a 40-day drought provided an opportunity to study the practical significance of deep rooting in relation to extraction of water stored in subsurface horizons. Plots from several experiments where the corn growth was approximately the same were sampled on the 32nd day of the drought. The absence or presence of roots was noted along with the water content of the soil.

As shown in Fig. 3.3:5, the water contents of the soil layers where roots were present were lower, indicating that this water had been taken up by the plants. The treatment with the shallowest roots shown in the graph was from the liming experiment, which received 4 tons of lime incorporated deep and about 440 kg P/ha as TSP. The deepest roots shown were observed in the residual effects of phosphorus experiment (607 kg P/ha as SSP). All the experiments received about the same amount of lime.

In another experiment where rooting continued to at least 120 cm depth, corn grain yields of 6 tons/ha were obtained in spite of the 40-day drought. The drought began 19 days after "black layer" formation. The water stored in the soil was therefore, sufficient to supply most of the plants' needs during the grain-filling period.

Additional studies are being carried out to determine what is the most economical way to promote deep calcium movement.

## 3.4 RESIDUAL P EFFECTS

### A. RESIDUAL EFFECTS OF LIME AND P ON THE LOAMY RED-YELLOW LATOSOL

E. Lobato, O. Correa, R. S. Yost and K. D. Ritchey

This extrapolation experiment, continued for the third year, has served to illustrate the impor-

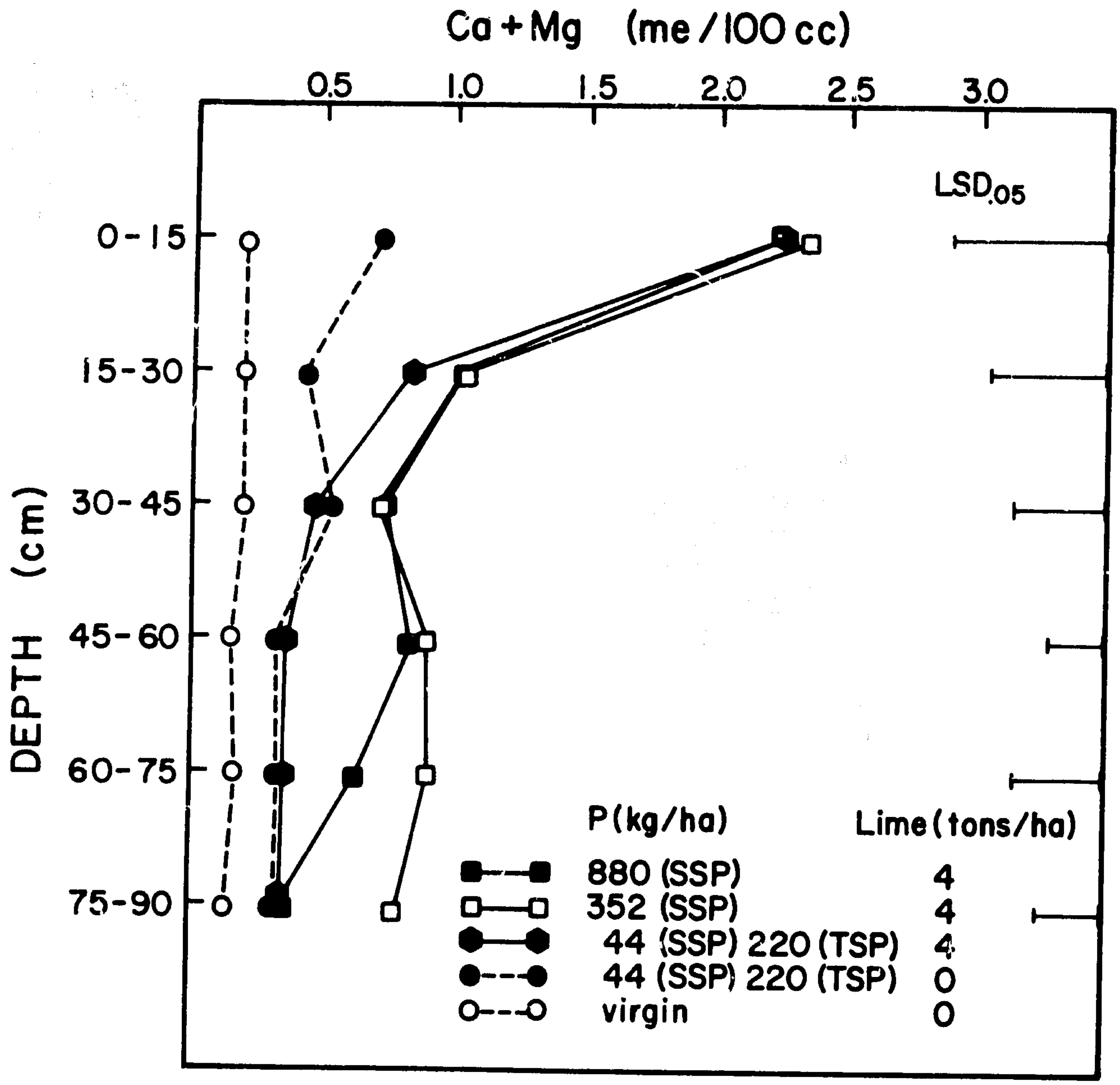



Figure 3.3:2. Effect of different phosphorus sources and rates and lime on distribution of Ca + Mg in the loamy Red-Yellow Latosol. CPAC. Values measured in the virgin area around the experiment were not included in the statistical analysis.

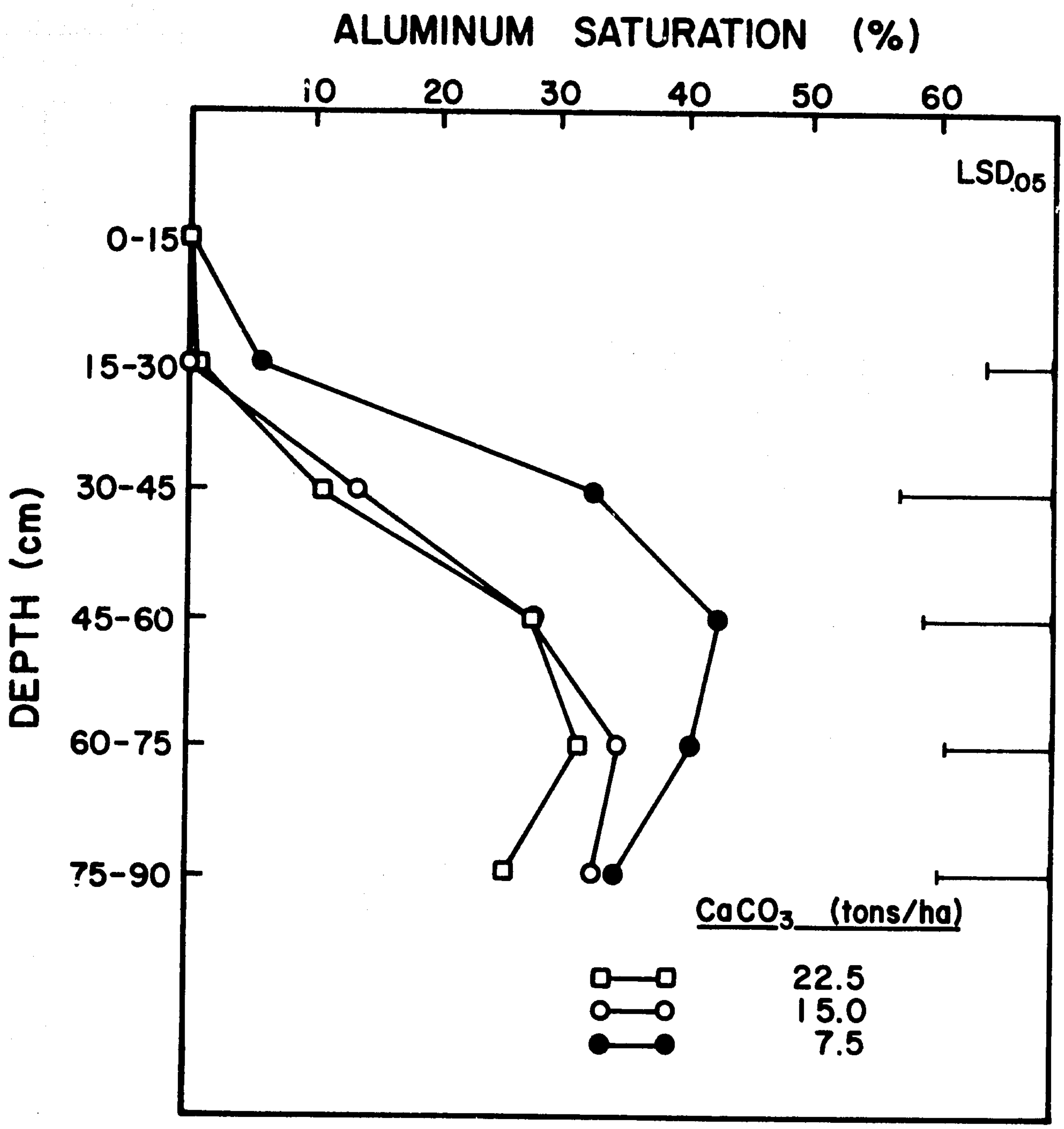



Figure 3.3:3. Aluminum saturation with depth measured in 1976 as a function of lime applied in 1972. Dark Red Latosol, Zinc II experiment.

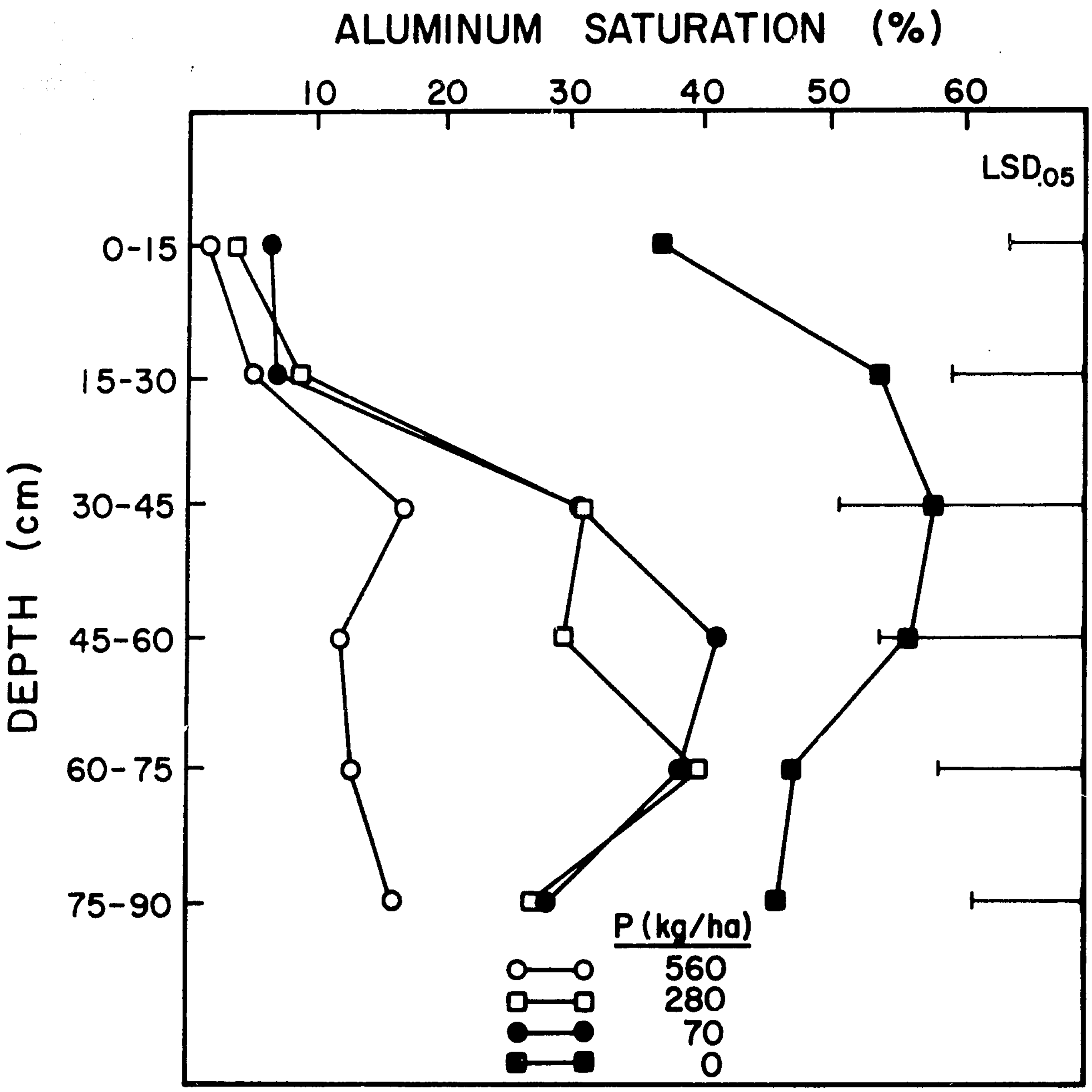



Figure 3.3:4. Effect of ordinary superphosphate applied in 1972 on Al saturation at six depths in Dark Red Latosol. Residual effects of phosphorus experiment, CPAC.

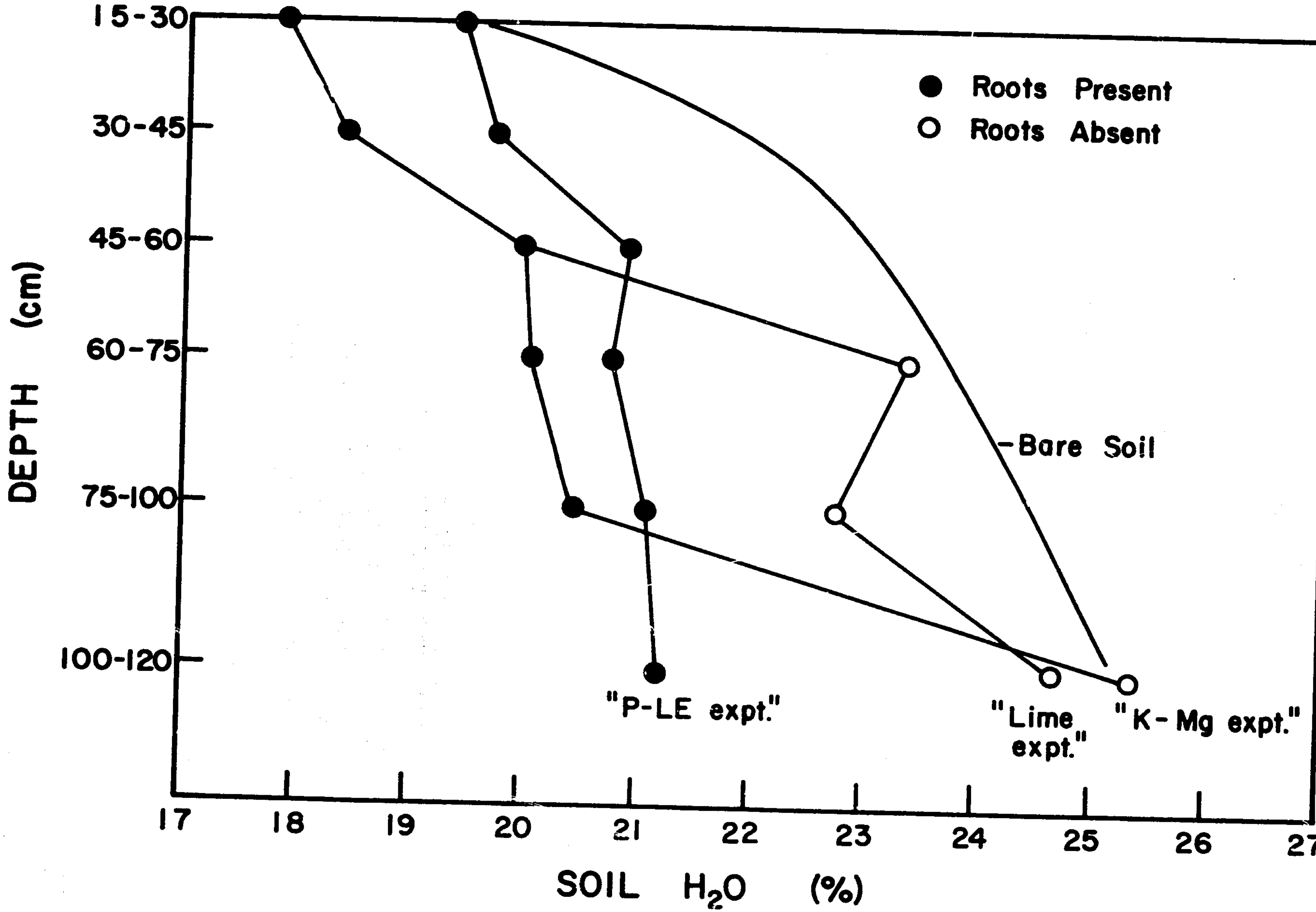



Figure 3.3:5. Soil water content versus depth and presence or absence of roots within selected treatments of three experiments on the 32nd rainless day during the grain filling period of corn.

tance of understanding the factors that limit the full utilization of the otherwise good physical properties of Oxisols and the economic advantages of first farming the areas where the limiting factors have minimal expression.

The loamy phase of the Red Yellow Latosol has continued to show superior yield potential, compared with clayey Dark Red Latosol, due to its higher available water-holding capacity, lower phosphorus fixation and lower aluminum content with depth.

The third rainy season crop was planted November 1, 1975. Cargill-111 hybrid maize was sown on one-half of the double-size plots and DeKalb E-57 grain sorghum on the other. Basic fertilizer applications of 125 kg K/ha as KCl, 30 kg Mg/ha as $MgSO_4$, and 200 kg N/ha as urea (20 kg in the furrow at planting and 90 kg at 20 and 60 days) were made on all the treatments. Phosphorus as simple superphosphate (SSP) was applied in the row at planting at rates varying from 0 to 66 kg P/ha.

As shown in Table 3.4:1, there was no significant difference in yield as a function of the residual effect of deep and shallow incorporation of lime applied in 1973. The absence of liming, however, decreased sorghum yields by 1406 kg/ha, which was nearly statistically significant at the 5% level. Sorghum is generally more sensitive than corn to Al toxicity.

Yearly maintenance band applications of 66 kg P/ha significantly increased yields of both sorghum and corn, compared to the absence of maintenance applications.

The total grain production during the three years of experimentation vs. the total P applied is shown in Fig. 3.4:1. In the range of 88-352 kg P/ha applied, the general trend was for yields to increase at about the same rate as the cost of P fertilizer applied. The cost of 176 kg P/ha was about 14% of the total grain produced at that rate.

Soil P as extracted by the NCSU soil test increased in proportion to the amount added as shown in Table 3.4:1.

In spite of the occurrence of four "veranicos" during the growing season, yields were very good, again confirming the high agricultural value of this medium-textured soil with lower P fixation, absence of Al toxicity below 30 cm, and greater available water-holding capacity.

The experiment will be planted again to corn and sorghum for the fourth consecutive rainy season by CPAC scientists.

## B. RESIDUAL EFFECTS OF P RATE, PLACEMENT AND TIME OF APPLICATION

E. Lobato, O. Correa and K. D. Ritchey

The sixth consecutive corn crop was grown during the 1975-1976 rainy season in order to continue to evaluate the residual and cumulative effects of ordinary superphosphate. Treatment 10 (35 kg P/ha broadcast in 1972 plus 35 banded for each crop) again received an application of 35 kg P/ha. Maintenance applications in the other treatments were suspended after the fourth crop, so that comparisons could be made between equal total amounts of P applied in dif-

Table 3.4:1. Residual effects of P and lime applications on loamy Red Yellow Latosol on Cargill-111 corn and DeKalb E-57 grain sorghum yields (third crop, 1975-1976).

| Treatment number | P Applied 1973 Bdc | P Applied 1973 Band | P Applied 1974 Band | P Applied 1975 Band | Lime applied in 1973 | Corn Yields | | Sorghum Yields | | Soil Prop. after 3rd harvest 0-20 cm P | Soil Prop. after 3rd harvest 0-20 cm pH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ------- kg/ha -------- | | | | ton/ha | kg/ha* | % max | kg/ha* | % max | ppm | |
| 4 | 176 | 44 | 66 | 66 | 4 deep | 8350a | 100 | 7956a | 100 | 32 | 5.65 |
| 7 | 176 | 44 | 44 | 44 | 4 shallow | 8298a | 99 | 7209abc | 91 | 19 | 5.82 |
| 6 | 880 | 0 | 0 | 0 | 4 deep | 8090a | 97 | 7679ab | 97 | 59 | 5.68 |
| 8 | 176 | 44 | 44 | 44 | 4 deep | 7956a | 95 | 6783abc | 85 | 20 | 5.64 |
| 1 | 176 | 44 | 22 | 22 | no lime | 7646ab | 92 | 5625 c | 71 | 15 | 4.66 |
| 3 | 176 | 44 | 22 | 22 | 4 shallow | 7403ab | 89 | 7031abc | 88 | 11 | 5.72 |
| 2 | 176 | 44 | 22 | 22 | 4 deep | 6953ab | 83 | 6560abc | 82 | 9 | 5.66 |
| 5 | 176 | 0 | 0 | 0 | 4 deep | 6337 b | 76 | 5954 bc | 75 | 5 | 5.52 |

* Means followed by the same letter are not significantly different at the 5 percent level by Duncan's Multiple Range Test.

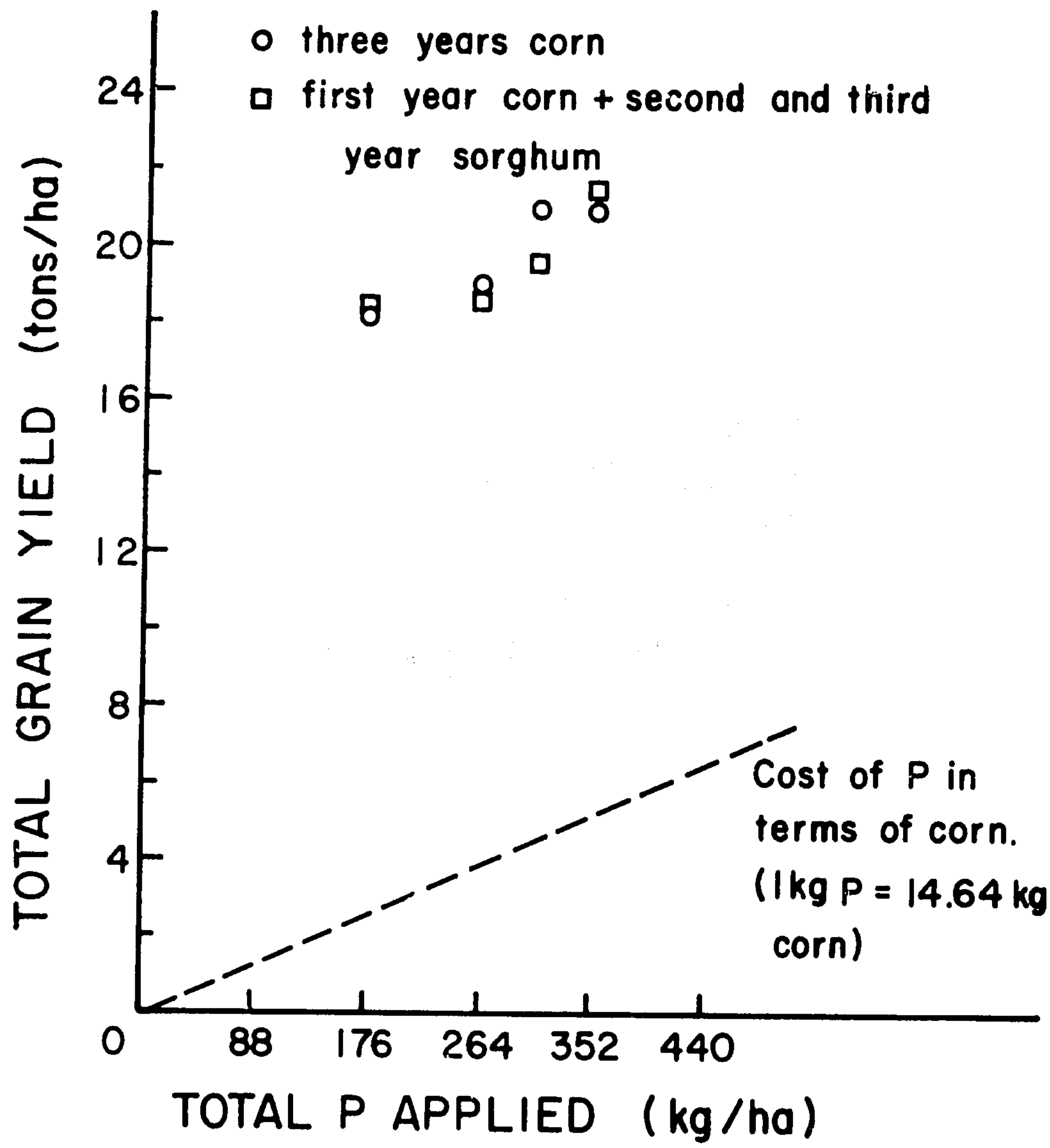



Figure 3.4:1. Cumulative grain yield as a function of total applied on medium-textured Red-Yellow Latosol at C!AC for two crop sequences (three consecutive years of corn, and one year corn followed by two years sorghum). The dotted line represents the relative cost of the total P applied in terms of corn grain at May 1976 prices (1 kg P = 14.64 kg corn grain).

ferent patterns. Liming and fertilization with N, K, Mg, Zn, B and Mo were equal over all treatments. Corn grain production for the six harvests are presented in Table 3.4:2. In terms of relative production (Fig. 3.4:2) one can see a residual effect of the initial broadcast phosphorus application, depending on the level applied. With an application of 282 kg P/ha, 85% of the maximum was produced the first year, falling to 63% in the latest harvest. The 141 kg P/ha level yielded 79% in the first harvest and 30% in the sixth. The rate of 70 kg P/ha started with 66% and fell to 11% in the most recent harvest. The level of 563 kg P/ha was used as a basis of comparison with the remaining levels and produced an average of 7.0 tons of grain per hectare for the six harvests. A comparison of treatments where the same levels of total P were applied, either broadcast or banded, showed that the total production after six years was equivalent, thus demonstrating two possible strategies for "reclaiming" the soil. The residual effect of applying 35 kg P/ha banded before each crop is sufficient to allow for increasing yields each year.

It can be seen in Fig. 3.4:2 that the first year's yields obtained with 70 and 141 kg P/ha applied broadcast the first year were superior to those obtained with the same levels banded, showing the necessity of "reclaiming" or correcting the soil rather than simply applying a maintenance level of fertilizer.

When 141 kg P/ha was broadcast initially and 35 kg P/ha were banded before each of the first four crops, yields remained about 80% of the maximum for the six harvests. The application of 35 kg P/ha broadcast followed by 35 kg P/ha banded before each crop resulted in a cumulative yield of about 72% of the maximum.

Where the total P applied was 282 kg/ha, the cumulative yields (about 78% of the maximum) were the same whether the entire 282 kg had been broadcast the first year or applied as 70 kg banded before the first four crops. The application of 141 broadcast followed by 35 kg P/ha before the first four crops resulted in a total production of about 80% of the maximum.

The application of part of the P broadcast and part banded appears to be a good practice for these soils with their relatively high P fixing capacities. If sufficient capital is available soil "correction" can be carried out the first year, or if funds are limited, the process can be spread out over several years.

Cumulative corn grain yields for the six harvests as a function of total phosphorus applied is shown in Fig. 3.4:3. The relative cost of the phosphorus fertilizer is presented in terms of kg of corn grain necessary to buy one kg of P. On-the-farm prices for October 1976 of approximately Cr.$1.00/kg corn grain and Cr.$22.73/kg P were used (in October 1976 U.S.$1.00 = Cr.$8.47). The slope of the P yield response curve equaled the slope of the P cost curve at about 440 kg/ha total P applied, indicating that

Table 3.4:2. Grain yields of six successive corn crops (Cargill-111 hybrid) as affected by rate, placement, timing, and residual effects of ordinary superphosphate applications.

| Treatment number | Initial broadcast application 1/ | Banded application per crop 2/ | Total applied in 6 crops | Consecutive Corn Yields: 1 Rainy 72-73 | 2 Dry 73 | 3 Rainy 73-74 | 4 Dry 74 | 5 Rainy 74-75 | 6 Rainy 75-76 | Total yields for six crops: Absolute yields | Relative yields |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ---------- kg P/ha | ---------- | ---------- | ---------- | ---------- | ---------- ton/ha | ---------- | ---------- | ---------- | ---------- | -- % -- |
| 1 | 70 | 0 | 70 | 5.23 | 3.27 | 0.87 | 1.78 | 1.65 | .66 | 13.46 | 32 |
| 2 | 141 | 0 | 141 | 6.27 | 5.68 | 2.20 | 3.42 | 3.00 | 1.89 | 21.43 | 51 |
| 3 | 282 | 0 | 282 | 6.79 | 7.48 | 2.97 | 6.43 | 4.82 | 3.89 | 32.38 | 77 |
| 4 | 563 | 0 | 563 | 7.96 | 8.53 | 3.86 | 9.09 | 6.25 | 6.19 | 41.88 | 100 |
| 5 | 880 | 0 | 880 | 2.26 | 9.54 | 4.56 | 9.02 | 6.60 | 6.97 | 38.95 | 93 |
| 6 | 0 | 35 | 141 | 2.42 | 5.08 | 3.08 | 6.03 | 4.49 | 2.27 | 23.37 | 56 |
| 7 | 0 | 70 | 282 | 3.85 | 6.57 | 3.41 | 8.07 | 5.86 | 4.73 | 32.49 | 78 |
| 8 | 0 | 141 | 563 | 4.79 | 8.42 | 4.19 | 9.03 | 6.89 | 6.91 | 40.14 | 96 |
| 9 | 141 | 35 | 282 | 6.65 | 7.32 | 3.33 | 7.22 | 5.40 | 3.72 | 33.64 | 80 |
| 10 | 35 | 35 | 246 | 4.56 | 6.00 | 2.56 | 6.48 | 5.79 | 4.98 | 30.28 | 72 |
| | | | $LSD_{.05}$ | 0.67 | 0.65 | 0.88 | 0.79 | 0.67 | 0.93 | | |

1/ All applied on November 1972 except for Treatment 5 which received 35 kg P/ha on November 1972 and 845 kg P/ha after the first crop on June 1973.

2/ All banded applications stopped after the fourth crop, except for Treatment 10 which continued on the fifth and sixth crops.

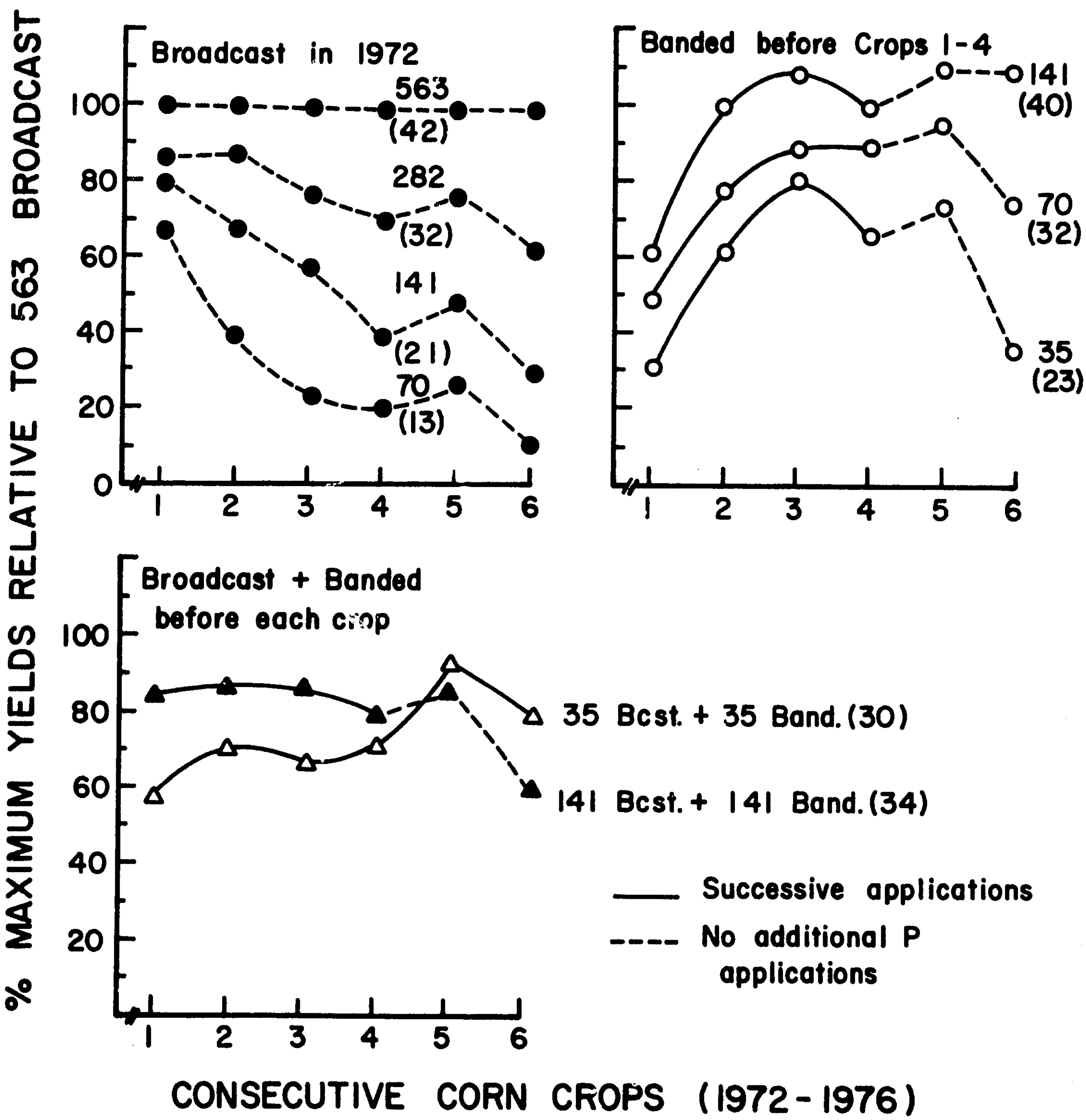



Figure 3.4:2. Effects of rate, placement and residual of P as SSP applications to six continuous corn crops. Grain yields are expressed as percent of the 563 broadcast treatments. Numbers in parentheses are the cumulative grain yields in tons/ha. Brasilia, 1972-1976.

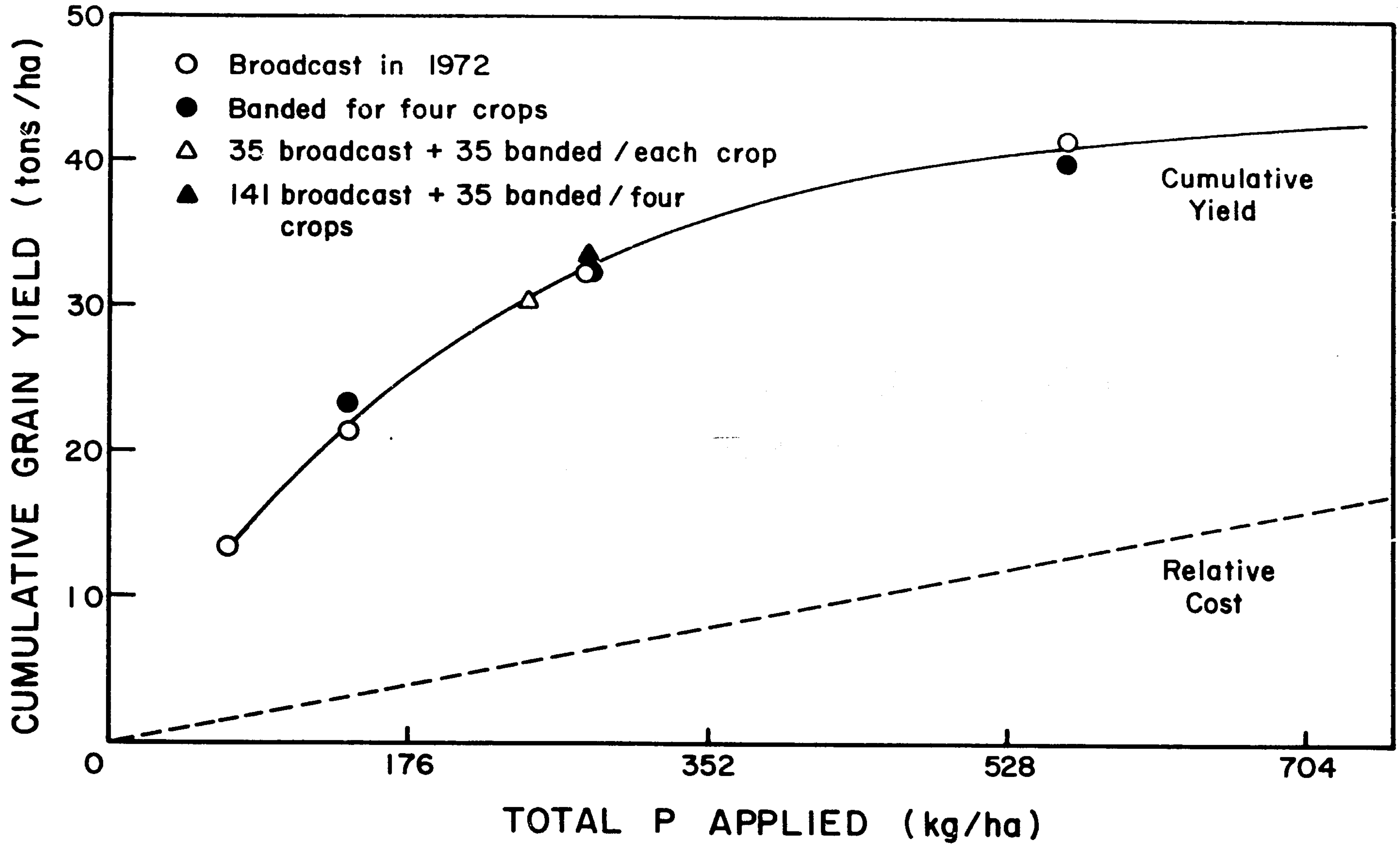



Figure 3.4:3. Cumulative Cargill-111 corn grain yields for six crops as a function of total P fertilizer added. The dotted line gives relative cost of P in terms of kg grain, based on October 1976 prices (corn grain = Cr.$1.00/kg; P = Cr.$22.73/kg; U.S.$ = Cr.$8.47).

Table 3.4:3. Soil test values for P (North Carolina dilute double acid method) after each corn harvest in the broadcast treatments.

| P applied broadcast in 1972 | 1 Rainy 72-73 | 2 Dry 73 | 3 Rainy 73-74 | 4 Dry 74 | 5 Rainy 74-75 | 6 Rainy 75-76 |
|---|---|---|---|---|---|---|
| kg/ha | | | Available P µg/cc | | | |
| 70 | 4.6 | 3.9 | 3.6 | 2.9 | 3.1 | 1.3 |
| 141 | 8.8 | 7.4 | 5.0 | 4.4 | 5.1 | 2.2 |
| 282 | 17.7 | 19.5 | 10.0 | 8.0 | 9.0 | 5.3 |
| 563 | 68.8 | 55.8 | 30.6 | 25.3 | 21.9 | 11.0 |
| 880 | -- | 103.5 | 65.6 | 50.2 | 42.9 | 28.0 |


Part of a CPAC lime and P fertilization study with Cerrado vegetation in the background.

up to this rate the extra yields obtained more than offset the cost of the P used.

These results emphasize the necessity of long-term experiments to show the important economic significance of high-residual value inputs such as P and lime. Fertilizer recommendations based on one or two years of data would have seriously underestimated the economically optimal application. The changes in available P after each harvest as measured by NCSU extractant are presented in Table 3.4:3. Critical soil test level by this method is set at 10 µg P/cc. The highest level of P is expected to continue to give good yields, and the experiment will again be carried out by personnel of CPAC.

### 3.5 RESIDUAL ZINC EFFECTS

K. D. Ritchey

The results of the first three years of cropping as reported in the previous Annual Reports (1972-1975) showed a very marked corn response to Zn, but a lesser response in sorghum. In the fourth year of the study Cargill-111 maize and soybeans were planted. No additional Zn, B or Mo were added but applications of 70 kg P/ha as SSP, 160 kg N/ha as urea and 125 kg K/ha 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 3.5:1, the residual effect of 3 kg Zn applied four years ago continued to be adequate for corn. The soybeans gave a greater response to Zn than did corn, showing a 140% yield increase with 9 kg Zn/ha as compared to the zero rate.

A supplementary experiment was installed on newly-cleared land to check Zn response at lower lime levels. The area received an application of dolomitic limestone equivalent to 3000 kg/ha $CaCO_3$ two weeks before planting corn on November 15. This 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 only 29%. Without added zinc 3840 kg/ha of corn grain was obtained. Thus, corn response to Zn was limited when other elements were more limiting.

### 3.6 K AND Mg FERTILIZATION

K. D. Ritchey

A new experiment was begun in the 1975-1976 growing season in a virgin clayey Dark Red Latosol to study the response to K and Mg. Five K and four Mg rates were applied. The desired Mg rates were obtained by varying the concentration of calcitic and dolomitic lime used to correct the soil acidity.

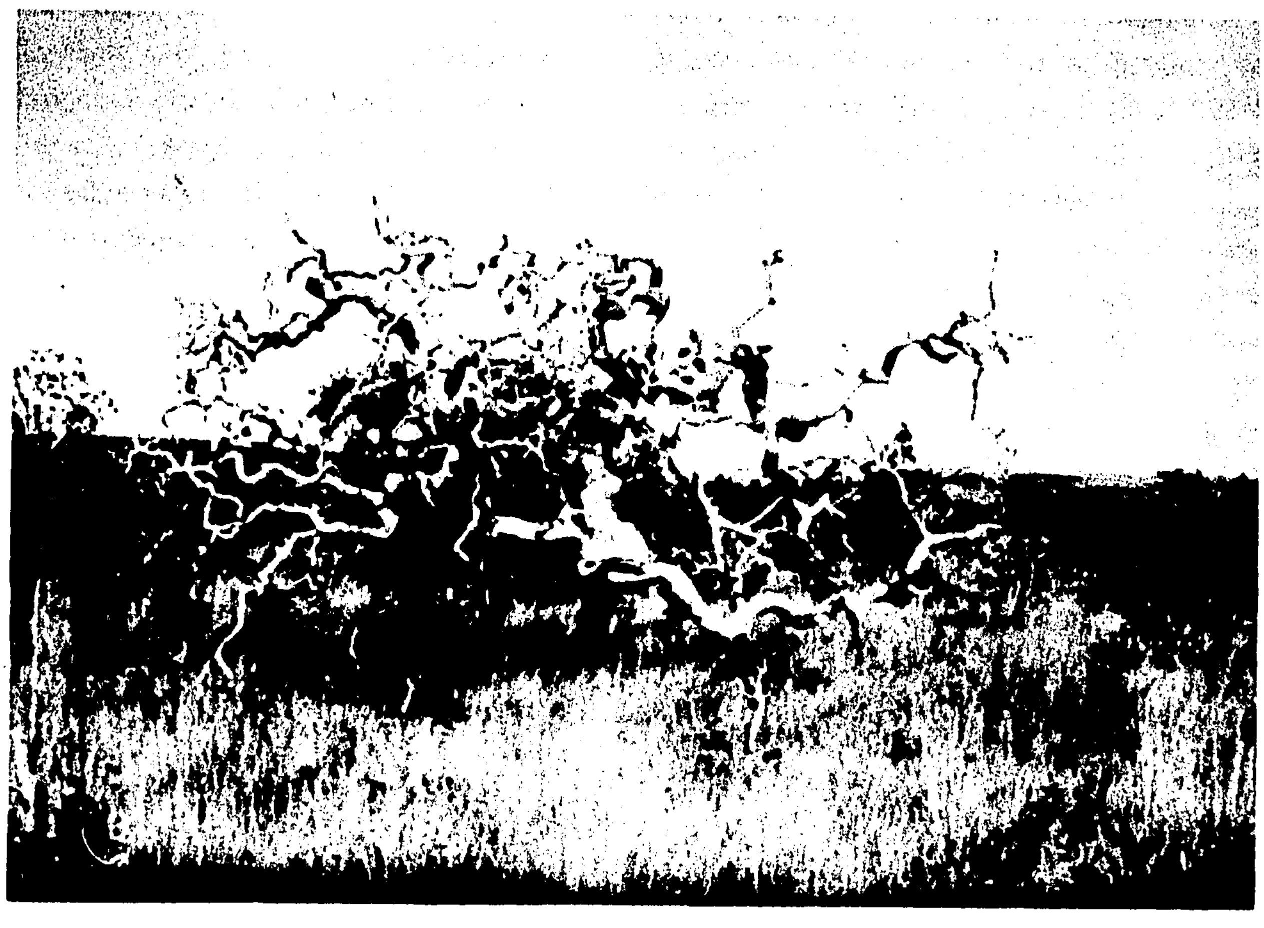
Initially the soil had a pH of 4.6 (1:2.5 soil: water) and contained 1.1, 0.34 and 0.064 me/100 cc exchangeable Al, Ca + Mg, and K, respectively.

Two weeks after the incorporation of ground limestone equivalent to 3000 kg/ha $CaCO_3$ and immediately preceding planting, the appropriate level of K as KCl, 141 kg P/ha as simple superphosphate (SSP), 9 kg Zn/ha as $ZnSO_4$,

Table 3.5:1. Cargill-111 maize grain production (15.5% moisture) and IAC-2 soybean grain production (13% moisture) for various levels of Zn applied in 1972 on clayey Dark Red Latosol. CPAC 1975-1976.

| Zn applied in 1972 | Grain Production | |
|---|---|---|
| | Corn* | 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).



Typical vegetation seen in the Cerrado of Brazil.

1.1 kg B/ha as borax and 0.2 kg Mo/ha as ammonium molybdate were broadcast and incorporated by rotovator to a depth of about 15 cm. Cargill-111 maize was planted November 15 at which time 20 kg N/ha as urea and 35 kg P/ha as SSP were applied in the furrow along with 125 kg K/ha for treatment 6. Sidedressings of urea sufficient to supply 60 kg N/ha each were applied at 24, 44 and 62 days.

There was a good response to K fertilization as shown in Table 3.6:1 and Fig. 3.6:1. Maximum production was obtained with 249 kg K/ha. The result of applying 62 kg K/ha was particularly impressive, increasing grain yields by 1748 kg/ha, worth 9.3 times as much as the cost of the K applied.

Soil test K levels prior to fertilization and at two subsequent dates as well as plant uptake and ear leaf contents are shown in Table 3.6:2. Similar data for magnesium are given in Table 3.6:3.

There was no deleterious effect from the application of KCl in the furrow at planting. Yield response to the calcitic and dolomitic limestone treatments was similar this first year although the plants showed some symptoms of Mg deficiency during dry periods.

## 3.7 NITROGEN FERTILIZATION

K. D. Ritchey

The fourth consecutive rainy season maize crop on the clayey Dark Red Latosol was planted November 22, 1975. This year ordinary urea was substituted for lime-coated $NH_4NO_3$ in treatment 8. Treatment 10 did not receive any N in order to evaluate the residual effect of three years of S-coated urea applications. Treatments 8 and 9 were modified to study the effect of the two versus three sidedressings for the 200 kg N rate.

Again, for the fourth year, grain production without added N was near the 4 ton/ha level. As shown in Table 3.7:1, maximum production of 6350 kg/ha maize grain was obtained with the application of 200 kg N. The application of 80 kg/ha N was sufficient to produce 86% 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 which had received S-coated urea for the previous three years and the treatment which never had received N.

## 3.8 TOLERANCE TO Al TOXICITY AND LOW AVAILABLE P

J. G. Salinas and P. A. Sanchez

The basic justification, general objectives and methodologies used for the series of experiments under greenhouse solution culture and field conditions in relation to the tolerance studies on Al toxicity and low available P have been reported in the previous Annual Reports.

Work during the year included both greenhouse and field research. Under greenhouse conditions sorghum and rice varieties were tested and under field conditions corn, rice and bean varieties.

Table 3.6:1. Cargill-111 maize grain production (15.5% moisture) for various levels of K and Mg applied on a virgin clayey Dark Red Latosol. CPAC, 1975-1976.

| Treatment Number | K applied* | Mg applied | Grain production** |
|---|---|---|---|
| | | kg/ha | |
| 1 | 0 | 345 | 2,328 a |
| 2 | 62 | 345 | 4,076 b |
| 3 | 125 | 345 | 4,372 bc |
| 4 | 249 | 345 | 4,890 c |
| 5 | 498 | 345 | 4,712 c |
| 6 | 125 | 345 | 4,453 bc |
| 8 | 125 | 7.5 | 4,362 bc |
| 9 | 125 | 27 | 4,301 bc |
| 10 | 125 | 97 | 4,017 b |

*Potassium chloride was applied in the furrow at planting.

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

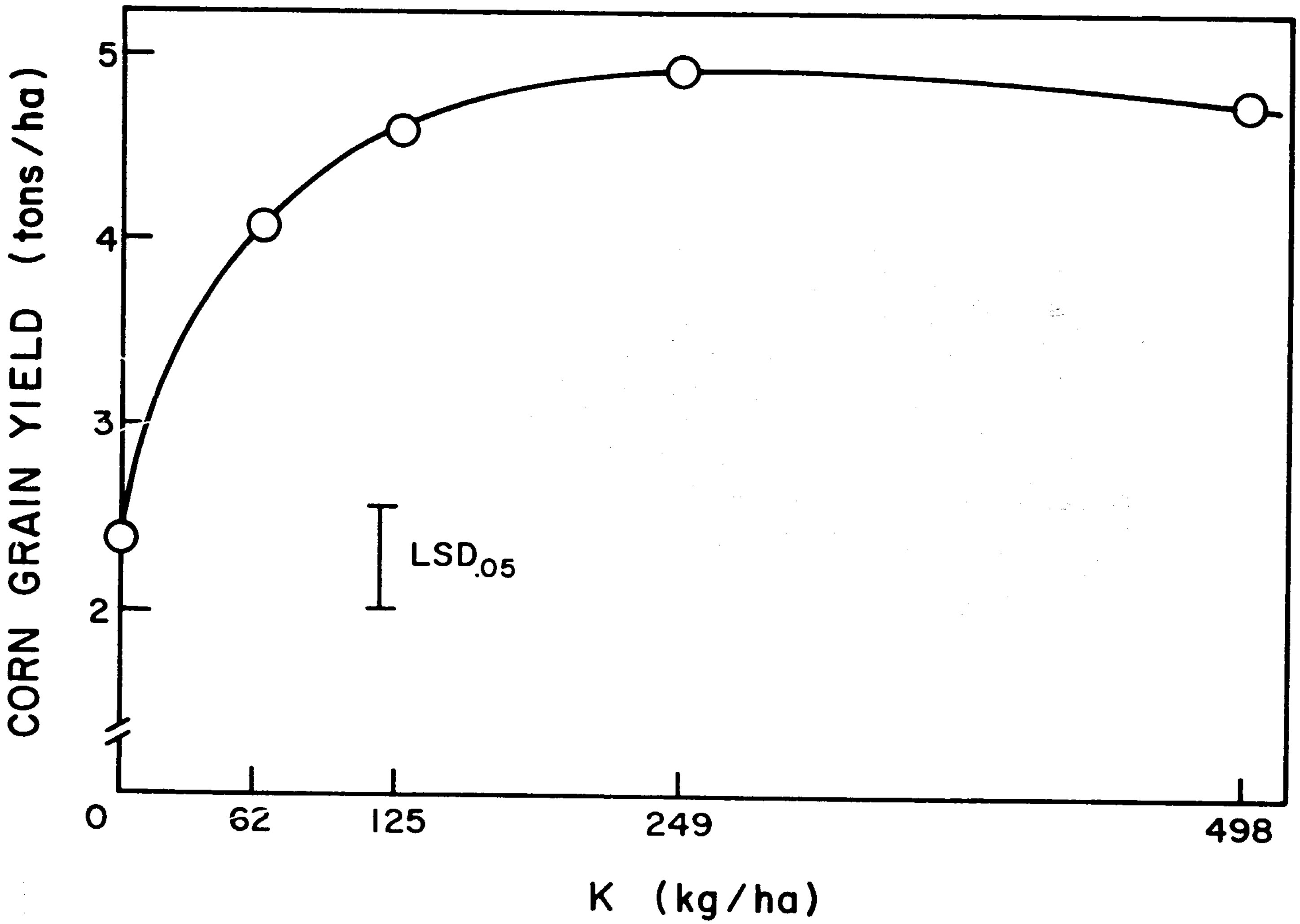



Figure 3.6:1. Cargill-111 maize grain production (15.5% moisture) as a function of K fertilizer added to a virgin clayey Dark Red Latosol. CPAC 1975-1976.

Table 3.6:2. Soil content of North Carolina State University double acid extractable K at three dates, K uptake by Cargill-111 maize, and ear-leaf K content as a function of K added to virgin clayey Dark Red Latosol. CPAC, 1975-1976.

| K applied | Extractable K in soil, (0-15 cm) 12 Nov | 14 Jan | 27 May | Total Plant K uptake | Ear Leaf K Content |
|---|---|---|---|---|---|
| --kg/ha-- | --------μg/cc--------- | | | --- kg/ha ---- | --- % --- |
| 0 | 23 | 20 | 17 | 18 | 0.48 |
| 62 | 21 | 26 | 23 | 35 | 1.06 |
| 125 | 22 | 32 | 29 | 56 | 1.56 |
| 249 | 21 | 58 | 52 | 90 | 2.38 |
| 498 | 21 | 137 | 80 | 102 | 2.46 |

Table 3.6:3. Soil content of Mg extractable by N KCl, 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 | Extractable Mg in soil 14 Jan., 0-15 cm | Total Mg uptake | Ear leaf Mg content |
|---|---|---|---|
| --kg/ha--- | ----- me/100cc ------ | --- kg/ha ----- | -------- % -------- |
| 7.5 | .14 | 7.3 | .09 |
| 27 | .13 | 7.8 | .10 |
| 97 | .20 | 8.2 | .14 |
| 345 | .52 | 11.3 | .32 |

Dr. Dale Ritchey views the effect of zero P fertilization (foreground plot) on corn at the CPAC Research Center, Brasilia, March 1977.

Table 3.7:1. Cargill-111 maize grain production (15.5% moisture) for various levels of nitrogen applied as urea on clayey Dark Red Latosol. CPAC, Fourth crop, 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 were not significantly different at the 5% level (Duncan).

## Greenhouse Studies with Sorghum and Rice Varieties

Emphasis was given to the interpretation of the data in terms of stress factor for varietal tolerance (Table 3.8:1). For each variety of both cereal crops, the effect of a given stress factor was evaluated by comparison with the control treatment which was assumed to result in adequate growth in both experiments. The magnitude of the stress effects is described by the percentage reduction in a given growth rate compared to the rates observed in the control treatment.

### Sorghum Cultivars

Table 3.8:2 presents the relative growth rates of roots and tops as well as relative root extension rates (as defined in Table 3.8:3) of five American sorghum hybrids introduced to Brazil by the National Corn and Sorghum Center at Sête Lagoas. When top $\overline{\text{RGR}}$ is used as the indicator of differential response, Taylor Evans Y-101 was clearly identified as being quite tolerant, while SC-334-9 and RS-610 were very sensitive to P stress. Top $\overline{\text{RGR}}$'s of those sorghum hybrids less tolerant to P stress (SC-334-9 and RS-610) were significantly reduced by the 0.05 ppm P treatment, whereas the top $\overline{\text{RGR}}$ of Taylor Evans Y-101 decreased little. The top $\overline{\text{RGR}}$'s of the hybrids SC-112 and TX-7078 also were affected adversely by the low P levels, but less than SC-334-9 and RS-610. Root growth rates and $\overline{\text{RER}}$ tended toward a response similar to top $\overline{\text{RGR}}$.

The sorghum hybrids RS-610, SC-334-9, and TX-7078 had a greater percent reduction (>60%) in root $\overline{\text{RGR}}$ than Taylor Evans Y-101 and SC-112 (54%) and were, thus, slightly more tolerant to Al stress. Under the combined Al and P stress, TX-7078 behaved more like Taylor Evans Y-101 and SC-112. Taylor Evans Y-101 showed significantly higher rates than the other sorghum hybrids under the combined stress. The extremes in root $\overline{\text{RGR}}$ under Al and P stress were 1.6%/day for Taylor Evans Y-101 and 0.4%/day for SC-334-9 and RS-610. The results generally indicate that under Al stress the external P level played an important role in the differential response of these sorghum hybrids and should be considered as a critical variable in studies of the tolerance of sorghum to Al stress.

Taylor Evans Y-101 was the most efficient variety under P stress, Al stress, and the combined Al + P stress. Its root and top $\overline{\text{RGR}}$'s under these conditions were among the best.

During growth under Al stress, hybrids RS-620 and SC-334-9 developed symptoms of chlorosis with purple pigmentation.

### Rice Cultivars

Of the five rice varieties used in this experiment, Pratão Precoce, IAC-47, IAC-1246, and Batatais are Brazilian while Flotante is a Colombian variety. Unlike the other crops, the growth changes evaluated in rice varieties showed the variety x Al x P interaction term to be nonsignificant. Therefore, only the data related to the significant two-factor interactions are dis-

Table 3.8:1. Al and P treatments in greenhouse study with sorghum and rice varieties.

| Treatment | | | |
| --- | --- | --- | --- |
| Number | Al | P | Stress Factor |
| | ---- ppm ---- | | |
| 1 | 0 | 0.20 | None |
| 2 | 0 | 0.05 | P |
| 3 | 8 | 0.20 | Al |
| 4 | 8 | 0.05 | Al and P |

Table 3.8:2. Effects of aluminum and phosphorus in culture solution on the relative growth rates (R$\bar{G}$R) of roots and tops and relative root extension rates (R$\bar{E}$R) of five sorghum hybrids (mean of three replications).

| Treatments | | Sorghum hybrids | | | | | | | | | | LSD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Al | P | RS-610 | | SC-112 | | SC-334-9 | | TX-7078 | | TE Y-101 | | % Red. |
| ---ppm---- | | R$\bar{G}$R roots[a] | % Red. | R$\bar{G}$R roots | % Red. | R$\bar{G}$R roots | % Red. | R$\bar{G}$R roots | % Red. | R$\bar{G}$R roots | % Red. | -- |
| 0 | 0.20 | 6.63 | 0 | 6.50 | 0 | 4.82 | 0 | 5.28 | 0 | 6.24 | 0 | |
| 0 | 0.05 | 4.68 | 29 | 3.90 | 40 | 2.80 | 42 | 3.78 | 28 | 4.91 | 21 | 15* |
| 8 | 0.20 | 2.57 | 61 | 3.02 | 54 | 1.56 | 68 | 1.93 | 63 | 2.86 | 54 | 10* |
| 8 | 0.05 | 0.42 | 94 | 1.36 | 79 | 0.41 | 91 | 1.38 | 74 | 1.64 | 74 | 11* |
| LSD = 0.96* | | | | | | | | | | | | |
| | | R$\bar{E}$R roots[a] | % Red. | R$\bar{E}$R roots | % Red. | R$\bar{E}$R roots | % Red. | R$\bar{E}$R roots | % Red. | R$\bar{E}$R roots | % Red. | |
| 0 | 0.20 | 7.63 | 0 | 4.05 | 0 | 5.20 | 0 | 4.53 | 0 | 6.84 | 0 | -- |
| 0 | 0.05 | 4.79 | 37 | 3.10 | 23 | 3.22 | 38 | 2.72 | 40 | 5.37 | 21 | 14* |
| 8 | 0.20 | 3.73 | 51 | 2.39 | 41 | 2.26 | 57 | 2.03 | 55 | 3.53 | 48 | NS |
| 8 | 0.05 | 1.51 | 80 | 2.07 | 49 | 1.18 | 77 | 0.72 | 84 | 2.66 | 61 | 13* |
| LSD = 0.77* | | | | | | | | | | | | |
| | | R$\bar{G}$R tops[a] | % Red. | R$\bar{G}$R tops | % Red. | R$\bar{G}$R tops | % Red. | R$\bar{G}$R tops | % Red. | R$\bar{G}$R tops | % Red. | |
| 0 | 0.20 | 10.01 | 0 | 8.05 | 0 | 7.15 | 0 | 8.03 | 0 | 6.72 | 0 | -- |
| 0 | 0.05 | 5.01 | 50 | 4.70 | 42 | 3.50 | 51 | 5.27 | 34 | 5.96 | 11 | 18* |
| 8 | 0.20 | 5.11 | 49 | 6.54 | 19 | 3.27 | 54 | 5.06 | 37 | 5.57 | 17 | 16* |
| 8 | 0.05 | 3.58 | 64 | 4.17 | 48 | 2.70 | 62 | 2.79 | 65 | 4.03 | 40 | 14* |
| LSD = 1.08* | | | | | | | | | | | | |

[a]R$\bar{G}$R roots and tops, and R$\bar{E}$R roots in %/day.

*P = 0.05.

Table 3.8:3. Formulae utilized to calculate relative growth rates ($\overline{RGR}$) of roots and tops and relative root extension rates ($\overline{RER}$) of the sorghum and rice cultivars evaluated.

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$$\overline{RGR}, \%/day = \frac{\ln W_2 - \ln W_1}{t_2 - t_1} \times 100$$

where $W_2$ and $W_1$ are the top or root weights at time $t_2$ and $t_1$, respectively

$$\overline{RER}, \%/day = \frac{\ln L_2 - \ln L_1}{t_2 - t_1} \times 100$$

where $L_2$ and $L_1$ are the root lengths at time $t_2$ and $t_1$, respectively

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cussed. Root growth and $\overline{RER}$ were affected differently among the varieties when Al was the limiting factor, while top $\overline{RGR}$ was not. When P was the stress factor, the top $\overline{RGR}$ was the only parameter differentially affected. These results suggest that the main effect of Al on rice varieties was the inhibition of root growth while the main effect of P deficiency was to decrease top growth relative to root growth.

Fig. 3.8:1 illustrates the differential response of the rice varieties to Al and P stresses. When Al and P were not limiting, all the rice varieties tended to grow at similar rates, although IAC-1246 tended to have a slightly greater $\overline{RER}$ than the others, and top $\overline{RGR}$ of Batatais was somewhat low. Adding 8 ppm Al to the nutrient solution caused the root $\overline{RGR}$ and $\overline{RER}$ to decrease in all rice varieties. However, the root $\overline{RGR}$'s of Batatais and Flotante were more severely affected than those of the other varieties. This difference among the varieties was not so evident in $\overline{RER}$ although Flotante clearly was most adversely affected.

The variety in which root growth was least affected by the presence of Al was Pratão Precoce. Root growth and $\overline{RER}$ in this rice variety were reduced only about 20% by Al stress. The rice varieties IAC-47 and IAC-1246 followed Pratão Precoce in the extent of reduction in root $\overline{RGR}$ under Al stress. In general, Batatais and Flotante appeared to be relatively sensitive to Al stress while Pratão Precoce was relatively tolerant.

Varietal differences were also noted among the rice varieties under P stress. As with other species, top growth was the most affected by low available P in the nutrient solution. Top $\overline{RGR}$'s were reduced about 60% in Batatais and Flotante while the corresponding reductions for Pratão Precoce, IAC-47 and IAC-1246 were about 48, 53, and 30%, respectively. These rice varieties therefore, are ranked as more tolerant to P stress while Batatais and Flotante are considered less tolerant. Pratão Precoce therefore, showed good tolerance to both Al and P stress, while Batatais and Flotante were Al-sensitive varieties, as well as being sensitive to P stress.

<u>Field Experiments</u>

The tolerance experiment whose design and methodology was reported in the 1975 Annual Report continued during the 1975-1976 rainy season. Varieties of corn and rice which had been tested earlier in the greenhouse were evaluated in the field. Also, four bean varieties from the initial screening under both greenhouse and field conditions were planted for a second evaluation.

Evaluated were the following corn varieties: three Brazilian hybrids: Cargill-111, Agroceres-152 and Agroceres-259, two Colombian lines: White and Yellow Carimagua and one American hybrid: DeKalb XL-45A. These were planted on November 17, 1975 in two 6 m rows and harvested on April 13, 1976, with the exception of the American hybrid, which was harvested on March 3, 1976. Plant population in corn was approximately 50,000 plants/ha. The following rice varieties were evaluated: four Brazilian varieties: Batatais, Pratão Precoce, IAC-47, and IAC-1246 and one Colombian rice

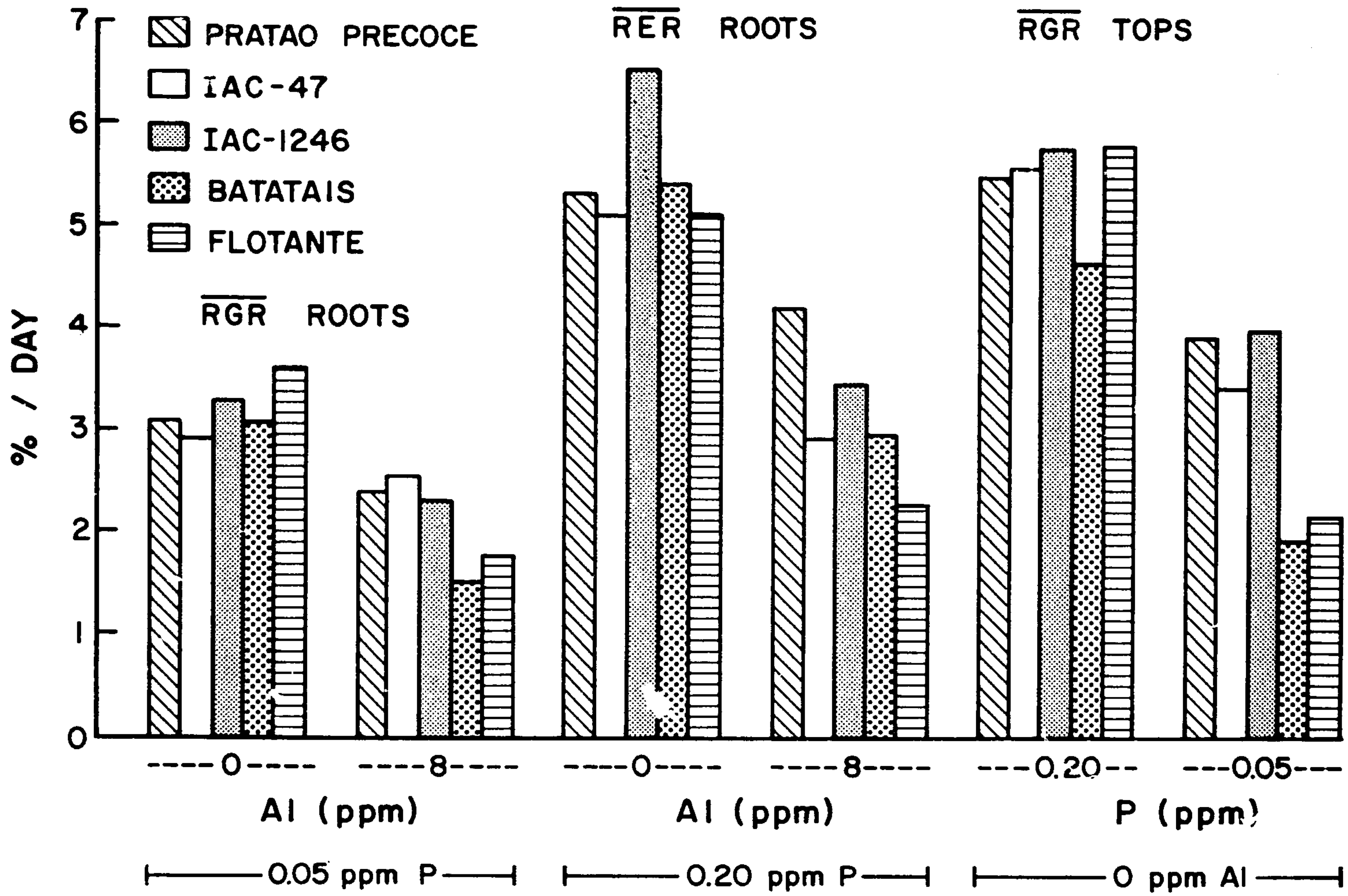


Figure 3.8:1. Effects of aluminum and phosphorus in culture solution on the relative growth rates ($\overline{RGR}$) of roots and tops and relative root extension rates ($\overline{RER}$) of five rice varieties.

variety, Flotante. These were planted on November 19, 1975 in four 6 m rows using a 45 cm row spacing at a planting rate of 50 kg seed/ha. Rice varieties were harvested on different dates; Pratão Precoce, on March 19, Batatais on April 15, 1976, IAC-47 and IAC-1246, on March 25, and Flotante, on April 24, 1976. The four bean varieties, Carioca-1030, Rico-pardo-896, Manteijão Fosco NI-11 and Caraota-260, were planted in four 6 m rows on January 27, 1976, and harvested on April 25, 1976. A row spacing of 60 cm was used giving an approximate population of 167,000 plants/ha.

A blanket application of 125 kg K/ha was applied to all crops before planting. As urea, N was applied to the various crops as follows: corn, 200 kg N/ha in two applications and beans, 60 kg N/ha also in two applications.

Soil Properties

Table 3.8:4 shows soil pH, exchangeable Al, percent Al saturation and available P after the harvest of the first (September, 1975) and second crops (May, 1976) of the tolerance experiment. No major changes in soil pH were noted at the lower levels of lime but a slight increase was observed at the highest level of lime. Exchangeable Al and percent Al saturation values in the 0-20 cm soil layer decreased from the first to the second harvest in the 1.5 and 4.0 ton lime/ha treatments and did not significantly differ at the lowest level of lime.

These results were quite similar to those from other experiments which were also established and limed during the dry season. In general, the results indicated that the dolomitic lime incorporated into moist soil which was irrigated every five days during the dry season had only partly dissolved after the first crop, resulting in incomplete Al neutralization. During the rainy season Al neutralization at the various lime rates approached that expected for a complete reaction. Reasons for this probably are: 1) that the lime mesh size was too large, which implied slow reaction rates, and 2) the soil never stayed moist long enough to dissolve the lime during the dry season. Levels of available P determined by the N. C. double acid extraction decreased in all treatments with time and slight influence on P availability was observed in the increment of lime rates. The levels of Al and P gave satisfactory ranges for the purposes of the experiment.

Crop Yields

Corn Cultivars. The corn field data are discussed on the basis of Al saturation and residual lime applications since this experiment was limed in early 1975. Consequently, the amount of Al neutralized was the result of lime applied a year before.

Corn hybrids exhibited significant reductions of their grain yields as Al saturation increased in the soil regardless of the available P levels (Table 3.8:5). The grain yields of the six corn hybrids and varieties were drastically reduced when corn was grown under Al + P stress (0.5 ton lime/ha and 70 kg P/ha). The reduction in grain yields was about 80% or more of the maximum attained by these corn lines at the highest com-

Table 3.8:4. Soil pH, exchangeable Al, percent Al saturation and available P after the first and second harvests of the tolerance experiment. Mean of nine replications. Brasilia. 1975-1976 wet season.

| Lime Rate | P applied broadcast in 1975 | Soil Depth | Soil pH | | Exch. Al | | Al Sat. | | Available P* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sept 1975 | May 1976 | Sept 1975 | May 1976 | Sept 1975 | May 1976 | Sept 1975 | May 1976 |
| ton/ha | kg/ha | cm | | | --mc/100cc- | | ---- % ---- | | --- ppm --- | |
| 0.5 | 70 | 0-20 | 4.4 | 4.3 | 1.20 | 1.17 | 65 | 65 | 5 | 4 |
| | | 20-40 | 4.3 | 4.2 | 1.13 | 1.13 | 69 | 72 | 12 | 2 |
| 0.5 | 340 | 0-20 | 4.6 | 4.6 | 1.21 | 1.15 | 61 | 65 | 28 | 20 |
| | | 20-40 | 4.4 | 4.3 | 1.11 | 1.01 | 65 | 71 | 4 | 3 |
| 0.5 | 600 | 0-20 | 4.6 | 4.6 | 1.12 | 1.00 | 57 | 58 | 48 | 37 |
| | | 20-40 | 4.5 | 4.3 | 1.06 | 1.02 | 58 | 68 | 5 | 4 |
| 1.5 | 70 | 0-20 | 4.7 | 4.7 | 1.03 | 0.89 | 46 | 45 | 6 | 7 |
| | | 20-40 | 4.4 | 4.4 | 1.10 | 1.00 | 57 | 65 | 2 | 2 |
| 1.5 | 340 | 0-20 | 4.7 | 4.9 | 1.00 | 0.68 | 44 | 32 | 25 | 23 |
| | | 20-40 | 4.5 | 4.6 | 1.07 | 0.89 | 56 | 58 | 4 | 5 |
| 1.5 | 600 | 0-20 | 4.7 | 4.7 | 1.00 | 0.72 | 46 | 35 | 46 | 38 |
| | | 20-40 | 4.5 | 4.5 | 1.05 | 0.96 | 52 | 60 | 5 | 5 |
| 4.0 | 70 | 0-20 | 4.9 | 5.3 | 0.75 | 0.20 | 27 | 9 | 5 | 5 |
| | | 20-40 | 4.6 | 4.6 | 0.91 | 0.74 | 48 | 44 | 2 | 2 |
| 4.0 | 340 | 0-20 | 5.0 | 5.3 | 0.70 | 0.26 | 23 | 18 | 22 | 19 |
| | | 20-40 | 4.7 | 4.7 | 0.90 | 0.71 | 45 | 39 | 4 | 4 |
| 4.0 | 600 | 0-20 | 5.0 | 5.4 | 0.65 | 0.13 | 23 | 8 | 46 | 40 |
| | | 20-40 | 4.7 | 4.7 | 0.85 | 0.72 | 44 | 38 | 6 | 6 |

*N. C. double acid extraction.

Table 3.8:5. Corn grain yields as affected by different percent aluminum saturation and soil available phosphorus in the Dark Red Latosol, Brasilia (mean of three replications).

| Lime rate | P rate | Al saturation | Available P* | Grain yields, 15.5% moisture | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | AG-259 | White Carimagua | Yellow Carimagua | AG-152 | Cargill-111 | DeKalb XL-111 |
| ton/ha | kg P/ha | % | ppm | kg/ha | | | | | |
| 0.5 | 70 | 66 | 4 | 1292 | 617 | 528 | 545 | 863 | 33 |
| 0.5 | 340 | 64 | 22 | 4216 | 1919 | 3664 | 2900 | 3329 | 181 |
| 0.5 | 600 | 60 | 33 | 4583 | 4043 | 4863 | 5550 | 4973 | 1402 |
| 1.5 | 70 | 43 | 7 | 3370 | 2828 | 2956 | 2236 | 3264 | 761 |
| 1.5 | 340 | 36 | 24 | 5683 | 5344 | 5716 | 4811 | 4619 | 965 |
| 1.5 | 600 | 34 | 37 | 5801 | 6322 | 5478 | 5386 | 6376 | 2052 |
| 4.0 | 70 | 5 | 6 | 3967 | 3294 | 3253 | 4276 | 2641 | 928 |
| 4.0 | 340 | 6 | 27 | 5472 | 6488 | 4886 | 6403 | 5483 | 1626 |
| 4.0 | 600 | 4 | 40 | 6264 | 6542 | 6234 | 6178 | 6842 | 2830 |

LSD .01: Lime (L) = 315; Phosphorus (P) = 315; L x P = NS; Variety (V) = 397; V x L = 561; V x P = 561; V x L x P = 750; CV (%) = 18

*N. C. double acid extraction.

bination of the lime and P rates. These results indicate that in general the six corn lines were quite sensitive to 66% Al saturation. Corn grain yields significantly increased as Al toxicity was eliminated even under P stress.

It is interesting to note that similar corn grain yields were achieved at different lime-P treatment combinations. The agronomic significance of these data is the important role that the lime plays in the economy of P fertilization. The results showed that P requirements of the soil were reduced significantly as lime rates were increased. This suggests that liming this acid soil enabled the corn plants to more efficiently utilize the native and fertilizer P since less of this P was complexed as soil Al compounds.

In spite of the general reduction in grain yields a differential response among corn hybrids and varieties under Al and P stress was observed (Fig. 3.8:2). This was the case of Agroceres-259, followed by Cargill-111, with lesser reductions in relative grain yields than most of the other corn lines. The grain yield of Agroceres-259 was significantly superior to those of Yellow Carimagua, Agroceres-152, and DeKalb XL-45A, while the grain yield of Cargill-111 was superior only to that of DeKalb XL-45A under Al and P stress (Table 3.8:5).

Under P stress alone (6 ppm available P and 5% Al saturation), Agroceres-259, Cargill-111, Agroceres-152, and Yellow Carimagua showed a grain yield reduction about 60% of their maximum yields while White Carimagua and DeKalb XL-45A were most susceptible to P stress, showing a production of 30 and 40% of their maximum yields, respectively.

Even when P stress was eliminated, Al saturation greater than 38% appeared to control the response of these corn hybrids and varieties and negatively affected their grain yields. For most crops the value of 60% Al saturation is considered harmful for adequate growth; however, at 63% Al saturation and no P stress the corn hybrid Agroceres-259 showed only 30% grain yield reduction. Yellow Carimagua and Cargill-111 had grain yield reductions equivalent to about 40%. White Carimagua and DeKalb XL-45A were the corn lines with the highest reduction under Al stress with 72 and 94% grain yield reductions, respectively. These results, consequently, show the wide differential tolerance of these corn lines to Al stress.

The results also indicated that the Colombian line is drastically reduced. In addition, the Brazilian corn hybrid Agroceres-152 under conditions of high P supply (37 ppm P) did not show significant changes in its grain yields as the percent Al saturation increased. However, when the available P was reduced to 24 and 6 ppm, respectively, this hybrid corn variety also exhibited large reductions in grain yield as percent Al saturation was increased.

These results indicate that the Al tolerance of these corn lines was controlled by the presence of a certain level of available P. This, in turn, suggested that the selection of varieties for Al tolerance should involve levels of P as an important variable.

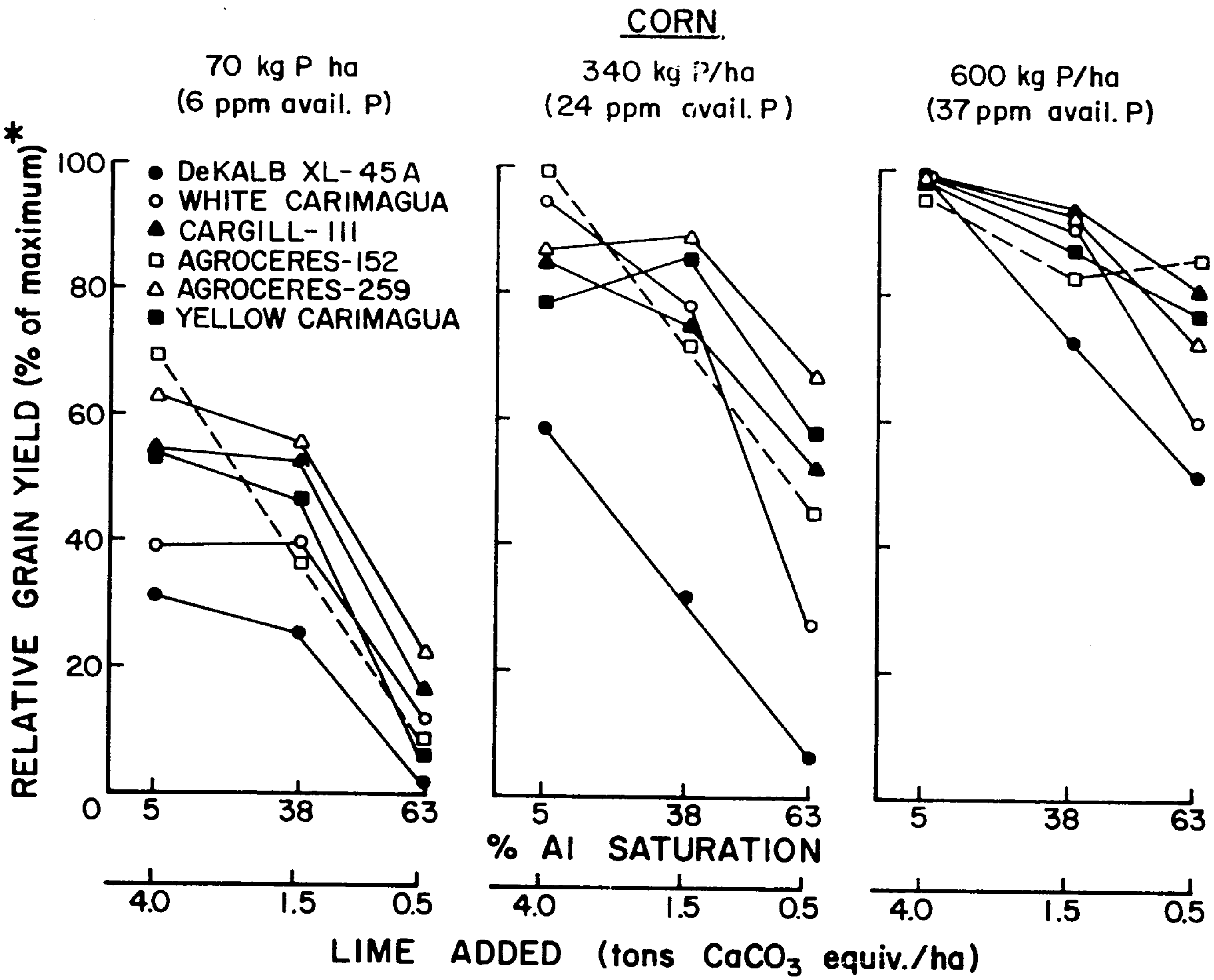


Figure 3.8:2. Differential performance of corn hybrids and varieties at various levels of aluminum saturation as a function of phosphorus under field conditions (Brasilia, Brazil; 1975-1976 rainy season).
*Based on maximum for each variety.

The elimination of Al and P stress by the highest lime and P rates resulted in maximum yield production by all the corn hybrids and varieties. This maximum yield of five varieties and hybrids was equivalent to about 6 tons/ha. The lower grain yield of 3 tons/ha of DeKalb XL-45A was attributed to climate and geographical factors rather than soil fertility factors, since this hybrid had been developed in the American corn belt.

These results showed yield potential of all corn hybrids and varieties and especially Al-sensitive corn lines were attained under the high lime and P treatments. This may be associated with the fact that there was no Al toxicity to adversely affect the root systems in the 20-40 cm zone since previous lime applications had largely neutralized the Al. Therefore, although root length measurements were not made in this experiment, it is logical to expect that with levels of 5% Al saturation in the 0-20 cm depth and 35% Al saturation in the 20-40 cm soil layer, the root growth was adequate.

The differential performance of the corn hybrids and varieties under Al stress may be related to critical concentrations of Al in the soil which affected differentially the root growth of the various varieties. It is speculated that the higher grain yields of Agroceres-152, Agroceres-259, Cargill-111, and Yellow Carimagua than White Carimagua and DeKalb Xl-45A under P stress alone (6 ppm P and 5% Al saturation) were also due to a better root growth which, in turn, might have improved the efficiency of use of low available soil P.

Rice Cultivars

Table 3.8:6 presents the grain yields of the rice varieties as affected by the lime-P treatments. The grain yields of the rice varieties showed that the highest grain yields were with the broadcast P rates of 340 and 600 kg P/ha at any level of lime rate. Fig. 3.8:3 illustrates the performance of these rice varieties in terms of relative grain yields obtained on the basis of the maximum grain yield of each rice variety.

Most of the maximum yields of the rice varieties occurred at the medium available soil P level of 26 ppm, but a different Al saturation level, e.g., maximum yields came for Batatais and IAC-1246 at no Al stress (4% Al saturation), IAC-47 at 40% Al saturation, and Pratão Precoce at 63% Al saturation. The maximum yield of the Colombian rice variety Flotante occurred under no Al and P stress (35 ppm P and 4% Al saturation). These results clearly show differential varietal tolerance of toxic Al levels under no P stress. On the other hand, the varieties Pratão Precoce, IAC-47 and IAC-1246 showed slighter reduction in their maximum yield (about 20%) than Batatais and Flotante under P stress. This indicates that the first group of rice varieties also showed tolerance to low available P. The second group formed by Batatais and Flotante showed a reduction in their grain yields under Al and P stress which was equivalent to 60 and 80%, respectively.

Under P stress alone (6 ppm P and 4% Al saturation), all rice varieties showed a reduction in grain yields which was statistically significant to 1% level but with a marked varietal difference. It was possible to distinguish two

Table 3.8:6. Field performance of five rice varieties at different levels of aluminum saturation and phosphorus (Brasilia 1975-1976 wet season; mean of three replications).

| Lime applied (March 1975) | Broadcast P applied (May 1975) | Al saturation | Available P* | Grain yields, 14% moisture: Batatais | IAC-1246 | IAC-47 | Pratão Precoce | Flotante |
|---|---|---|---|---|---|---|---|---|
| ton/ha | kg P/ha | % | ppm | kg/ha | | | | |
| 0.5 | 70 | 63 | 5 | 393 | 1188 | 1654 | 2442 | 148 |
| 0.5 | 340 | 64 | 24 | 610 | 1471 | 2435 | 3466 | 358 |
| 0.5 | 600 | 60 | 32 | 413 | 1850 | 2819 | 3489 | 518 |
| 1.5 | 70 | 40 | 6 | 682 | 2138 | 2199 | 3071 | 151 |
| 1.5 | 340 | 35 | 27 | 706 | 2737 | 2984 | 2962 | 441 |
| 1.5 | 600 | 40 | 35 | 715 | 2534 | 2721 | 3087 | 687 |
| 4.0 | 70 | 4 | 7 | 482 | 2172 | 2122 | 2724 | 227 |
| 4.0 | 340 | 5 | 26 | 1303 | 2771 | 2618 | 3116 | 514 |
| 4.0 | 600 | 3 | 39 | 741 | 1806 | 1622 | 2764 | 753 |

LSD .01: Lime (L) = 140; Phosphorus (P) = 140; L x P = 243; Variety (V) = 166

V x L = 289; V x P = 289; V x L x P = 495

CV (%) = 14

*N. C. double acid extraction.

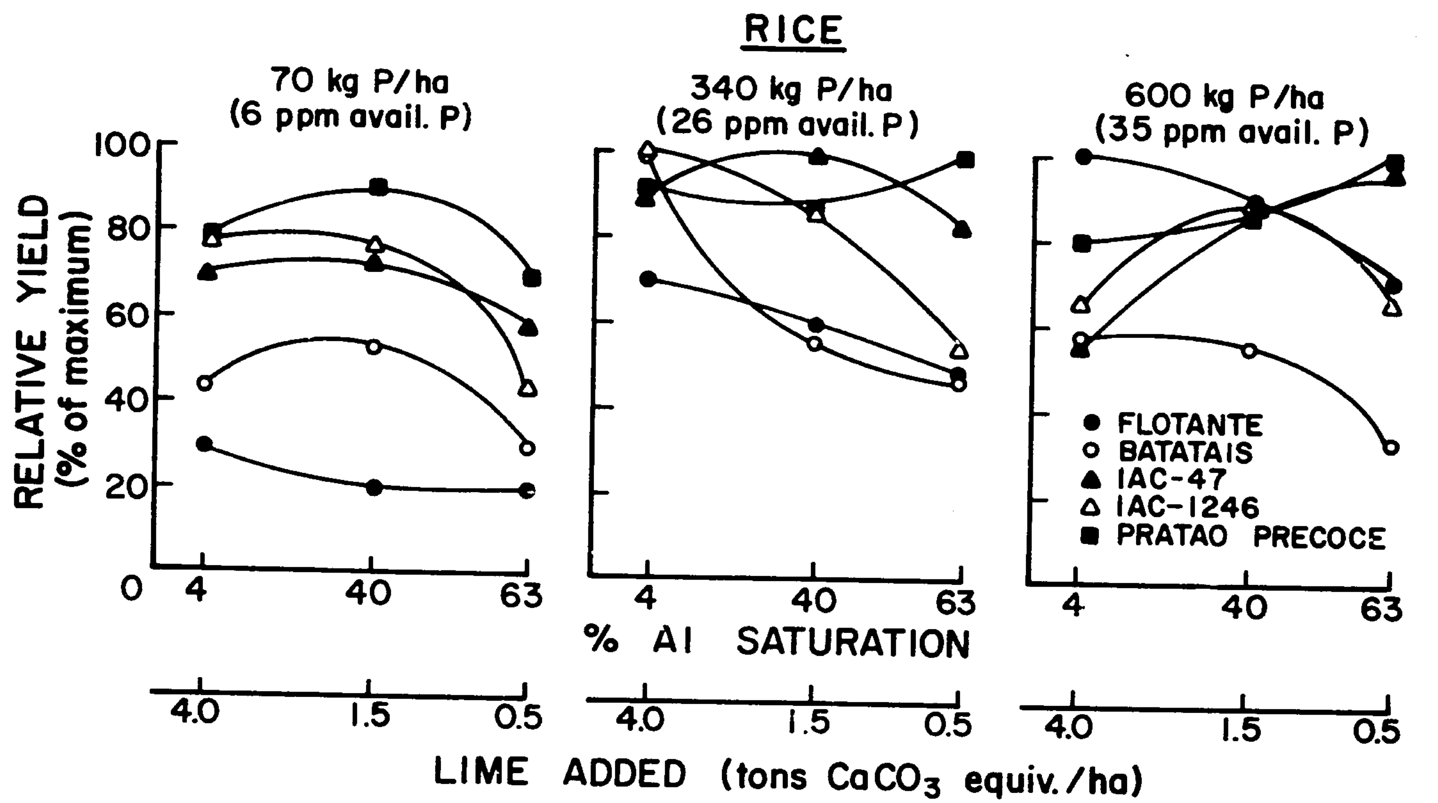


Figure 3.8:3. Differential performance of rice varieties at various levels of aluminum saturation as a function of phosphorus under field conditions (Brasilia, Brazil; 1975-1976 rainy season).

groups relative to varietal response: the first was formed by Pratão Precoce, IAC-47, and IAC-1246 with no significant differences among them and a yield reduction of about 20% of their maximum yield; the second group was formed by Batatais and Flotante also with no significant difference between both rice varieties but with about 60% reduction in their maximum yield. The first group of rice varieties also showed a better stand in the field without symptoms of P deficiency as compared with the second group of rice varieties.

Maintaining P stress and increasing the Al toxicity by reducing the amount of lime from 4 tons/ha to 1.5 tons/ha to 0.5 tons/ha, none of the rice varieties showed grain yield reductions until subjected to 40% Al saturation. These results indicate that the varieties used in this experiment are quite tolerant to Al even under P stress. Under both conditions of P and Al stress (6 ppm P and 63% Al saturation), Pratão Precoce, IAC-47, and IAC-1246 had significantly higher yields than Batatais and Flotante rice varieties (Table 3.8:6). Among the most tolerant rice varieties, Pratão Precoce was the variety with less reduction in grain yield under Al and P stress, showing about 33% maximum reduction of its yield. The IAC-1246 and IAC-47 exhibited 48 and 53% reductions, respectively, under the same conditions. The susceptible rice varieties, Batatais and Flotante, showed 70 and 82% grain yield reduction, respectively. Both susceptible rice varieties showed a yellowing and necrosis in the leaves under P and Al stress.

Grain yields of all varieties increased with the increase in available soil P from 6 to 26 ppm. Most attained maximum yields at 26 ppm P with no further yield increase when available P was increased to 35 ppm. Under P stress (6 ppm P), all the rice varieties showed minimal changes in grain yields and relative grain yields (Table 3.8:6 and Fig. 3.8:3) as percent Al saturation increased from 4 to 40. In addition, the rice variety Pratão Precoce, identified as the most tolerant to Al and P, did not show significant reduction at any level of Al saturation.

Under no P stress (35 ppm P), three kinds of varietal responses were found. First, the most Al-P tolerant variety, Pratão Precoce, did not show significant change in grain yield as Al toxicity increased, thus, confirming the high tolerance to Al of this variety. Second, IAC-47 showed an increase in its grain yield only until 40% Al saturation was reached. Third, the varieties Batatais and Flotante showed a gradual reduction in their grain yield as Al saturation increased from 4 to 63%.

Of those stated, Pratão Precoce is the rice variety most tolerant to both Al and P stress. IAC-47 and IAC-1246 followed Pratão Precoce in tolerance to Al and P stress although IAC-47 was more tolerant to Al toxicity than IAC-1246. Finally, the most sensitive varieties under both adverse soil conditions were Batatais and Flotante.

Bean Cultivars

Four bean varieties were used for a second evaluation under field conditions after an initial screening of several bean varieties under both greenhouse and field conditions. The main objective for this evaluation was to confirm or deny the results of the previous screening experiments under both conditions. For this purpose, two bean varieties, Ricopardo-896 and Carioca-1030, characterized as tolerant to Al toxicity and low available P were evaluated with two other bean varieties, Manteijão Fosco and Caraota-260, characterized as being sensitive to such adverse soil conditions.

The results of the bean field data are shown in Table 3.8:7. The four bean varieties responded positively and significantly to both lime and P applications. A similar response had been observed in the previous experiment (1975 Annual Report). These results confirmed that there are varietal differences among these bean varieties under Al and P stress conditions and also that these differences were minimized when the adverse soil conditions disappeared.

In general, maximum grain yields of all bean varieties were lower than those obtained in the first experiment during the 1975 dry season. The main reason for this yield difference was attributed to the fact that the 1975 dry season experiment was irrigated regularly without water stress periods while the 1976 wet season experiment, which was planted on January 27, 1976, was affected by an early cessation of the rains at the end of March and continuing through April with just 12 mm precipitation. The first days of this water stress period coincided with the grain formation stage, thus affecting the grain yield of these four bean varieties. Under Al and P stress (66% Al saturation and 4 ppm available P) Ricopardo-896 and Carioca-1030 had significantly higher yields than Manteijão Fosco and Caraota-260. Under this adverse soil condition, these last two varieties showed a yellowing and necrosis in the leaf tip, considered to be symptomatic of Al toxicity.

Under P stress, Carioca-1030, Ricopardo-869 and Manteijão Fosco had higher grain yields than Caraota-260. However, when these yields were expressed as a percent of their maximum yields, only Carioca-1030 showed a significant difference over the other three varieties.

Under Al stress, yields of the four bean varieties were reduced only by 30%. Finally, when Al was neutralized and available P was increased, no significant differences between these bean varieties were found. These results confirmed the preliminary results in which Carioca-1030 and Ricopardo-869 were characterized as tolerant varieties and Manteijão Fosco and Caraota-260 as sensitive varieties under Al and P stress conditions. Carioca-1030 was the most tolerant bean variety under P stress.

## Conclusion

From the experiments carried out during the 22 months and from the results emanated from them, it is evident that a potential for utilizing tolerant cultivars exists as an important component of managing Oxisols. One of the most satisfactory methods of avoiding Al injury in these types of soils is the use of tolerant varieties in combination with low rates of surface liming. The final result of this and similar studies in the Cerrado of Brazil as well as in similar areas would be the identification and use of tolerant varieties which make economically feasible the opening of new acid savanna areas for intensive crop production.

Table 3.8:7. Bean grain yields at different levels of available soil phosphorus and aluminum saturation in the field (Brasilia, 1975-1976 wet season; mean of three replications).

| Lime applied March 1975 | Broadcast P applied May 1975 | Al saturation | Available P* | Grain Yields, 13% moisture: Ricopardo 896 | Carioca 1030 | Caraota 260 | Manteigao Fosco |
|---|---|---|---|---|---|---|---|
| ton/ha | kg P/ha | % | ppm | kg/ha | | | |
| 0.5 | 70 | 66 | 4 | 530 | 235 | 94 | 32 |
| 0.5 | 340 | 64 | 20 | 506 | 378 | 219 | 470 |
| 0.5 | 600 | 62 | 30 | 949 | 766 | 519 | 835 |
| 1.5 | 70 | 44 | 6 | 397 | 426 | 218 | 448 |
| 1.5 | 340 | 40 | 25 | 822 | 590 | 474 | 790 |
| 1.5 | 600 | 35 | 33 | 1043 | 967 | 698 | 1070 |
| 4.0 | 70 | 6 | 6 | 675 | 826 | 378 | 694 |
| 4.0 | 340 | 5 | 29 | 869 | 960 | 621 | 842 |
| 4.0 | 600 | 4 | 37 | 1509 | 1105 | 802 | 1235 |

LSD: Lime (L) = 277; Phosphorus (P) = 94; L x P = NS; Variety (V) = 92; V x L = 120; V x P = 120; V x L x P = 180; CV (%) = 20

* N. C. double acid extraction.

## 3.9 EFFECTS OF P, LIME, AND Si APPLICATIONS ON SORPTION, ION EXCHANGE AND RICE GROWTH

T. J. Smyth and P. A. Sanchez

### Objectives and Design

Previous research conducted in the Central Plateau of Brazil has delineated the extreme deficiency and relatively large sorption capacity for P as one of the principal limitations for agricultural development of Oxisols in the area. The susceptibility to leaching of plant nutrients in these soils can also be large, as evidenced by their naturally low CEC's. However, the predominance of constant surface potential minerals in Cerrado Oxisols suggests that their negative charge may be increased with applications of lime, silicate, and P. Studies in other regions of the world have indicated that Si applications may be more effective than the conventional lime applications in improving the availability of P on Oxisols.

Rice yields also have often been increased with Si applications on soils low in this element. Considering the relatively high cost of P fertilizers and the large areas of the Cerrado currently cropped with upland rice, the effects of Si applications should be considered as a possible soil management concept for Cerrado agriculture.

Greenhouse and laboratory studies were conducted with the specific objectives of comparing the effects of lime and Si applications on: 1) The P sorption and ion exchange of a Cerrado Oxisol treated with different levels of P, and 2) the growth, yield and P uptake of upland rice grown in pots.

The soil used in this study was collected from a uniform area of a Dark Red Latosol adjacent to the depth of the liming experiment at CPAC. A topsoil sample was collected from the 0 to 20 cm depth, and a subsoil sample was collected from the 20 to 40 cm depth. Soil properties are summarized in Table 3.9:1.

Greenhouse experiment 1 was performed with the topsoil sample and consisted of a factorial distribution of three sources of liming materials, two lime rates, and four P levels. The liming treatments consisted of equal amounts of Ca supplied individually or as a mixture of $CaCO_3$ or TVA $CaSiO_3$ slag. The P treatments corresponded to the amounts required to obtain 0, 0.05, 0.1 and 0.2 ppm P in solution, according to the P sorption isotherm for this soil. Lime and P treatments are presented in Tables 3.9:2 and 3.9:3, respectively. A blanket application of N, K, Mg, Zn, and Mo was also made in all treatments. Two rice plants, variety CICA-4, were grown to maturity in each 2 kg pot.

Greenhouse experiment 2 was performed with the subsoil sample. The methodology of this experiment was the same as experiment 1, but the treatments involved only two lime rates with a broader range of P treatments. Experimental treatments are described in Table 3.9:4. Rice plants in this experiment were harvested at 100 days after planting.

### Results

After harvest, P sorption isotherms were obtained on the soil from all treatments in experiment 1 to determine the residual effects of the P and liming treatments on additional P sorption. Results are presented in Fig. 3.9:1.

Table 3.9:1. Properties of the Brasilian Cerrado Oxisol used in the P, Lime, and Si studies.

| Soil properties | Topsoil (0-20 cm) | Subsoil (20-40 cm) |
|---|---|---|
| Clay (%) | 45.4 | 50.8 |
| Silt (%) | 19.9 | 16.9 |
| Sand (%) | 34.7 | 32.3 |
| pH ($H_2O$) | 4.5 | 4.6 |
| pH (KCl) | 4.4 | 4.5 |
| Exch. Ca (me/100g) | 0.20 | 0.17 |
| Exch. Mg (me/100g) | 0.09 | 0.03 |
| Exch. K (me/100g) | 0.08 | 0.06 |
| Exch. Al (me/100g) | 1.45 | 0.71 |
| Effective CEC (me/100g) | 1.82 | 0.97 |
| Al Saturation (%) | 80 | 73 |
| Organic C (%) | 1.45 | 0.83 |
| Available P (N.C. method, ppm) | trace | trace |

Mechanical analysis courtesy of Dr. J. M. Bigham.

Table 3.9:2. Rates, sources, and amounts of lime added per pot.

| Liming treatment | Liming Rate | | Amount Added | |
|---|---|---|---|---|
| | $CaCO_3$ | $CaSiO_3$ | $CaCO_3$ | $CaSiO_3$ |
| | me Ca/me exch Al | | -- g/2kg soil -- | |
| Lime 1 | 1 | 0 | 1.45 | 0 |
| Lime 2 | 2 | 0 | 2.90 | 0 |
| Silicate 1 | 0 | 1 | 0 | 1.85 |
| Silicate 2 | 0 | 2 | 0 | 3.70 |
| Combined 1 | 0.5 | 0.5 | 0.72 | 0.92 |
| Combined 2 | 1 | 1 | 1.45 | 1.85 |

Table 3.9:3. Phosphorus rates and sources used in Experiment 1.

| P levels | P Sources | | | |
|---|---|---|---|---|
| | $Ca(H_2PO_4)_2 \cdot H_2O$ | $NH_4H_2PO_4$ | $KH_2PO_4$ | $NaH_2PO_4 \cdot H_2O$ |
| ppm | ppm P | | | |
| 0 | 0 | 0 | 0 | 0 |
| 380 | 250 | 130 | 0 | 0 |
| 460 | 250 | 130 | 80 | 0 |
| 540 | 250 | 130 | 80 | 80 |

Table 3.9:4. Rates and sources of lime and P used in the greenhouse experiment with the subsoil sample.

| Liming Treatment | Lime Rate | Phosphorus Level |
|---|---|---|
| | me Ca/me exch Al | ppm |
| Control | 0 | 0 |
| | | 65 |
| | | 130 |
| | | 260 |
| | | 350 |
| | | 420 |
| $CaCO_3$ | 1 | 0 |
| | | 65 |
| | | 130 |
| | | 260 |
| | | 350 |
| | | 420 |
| $CaSiO_3$ | 1 | 0 |
| | | 65 |
| | | 130 |
| | | 260 |
| | | 350 |
| | | 420 |

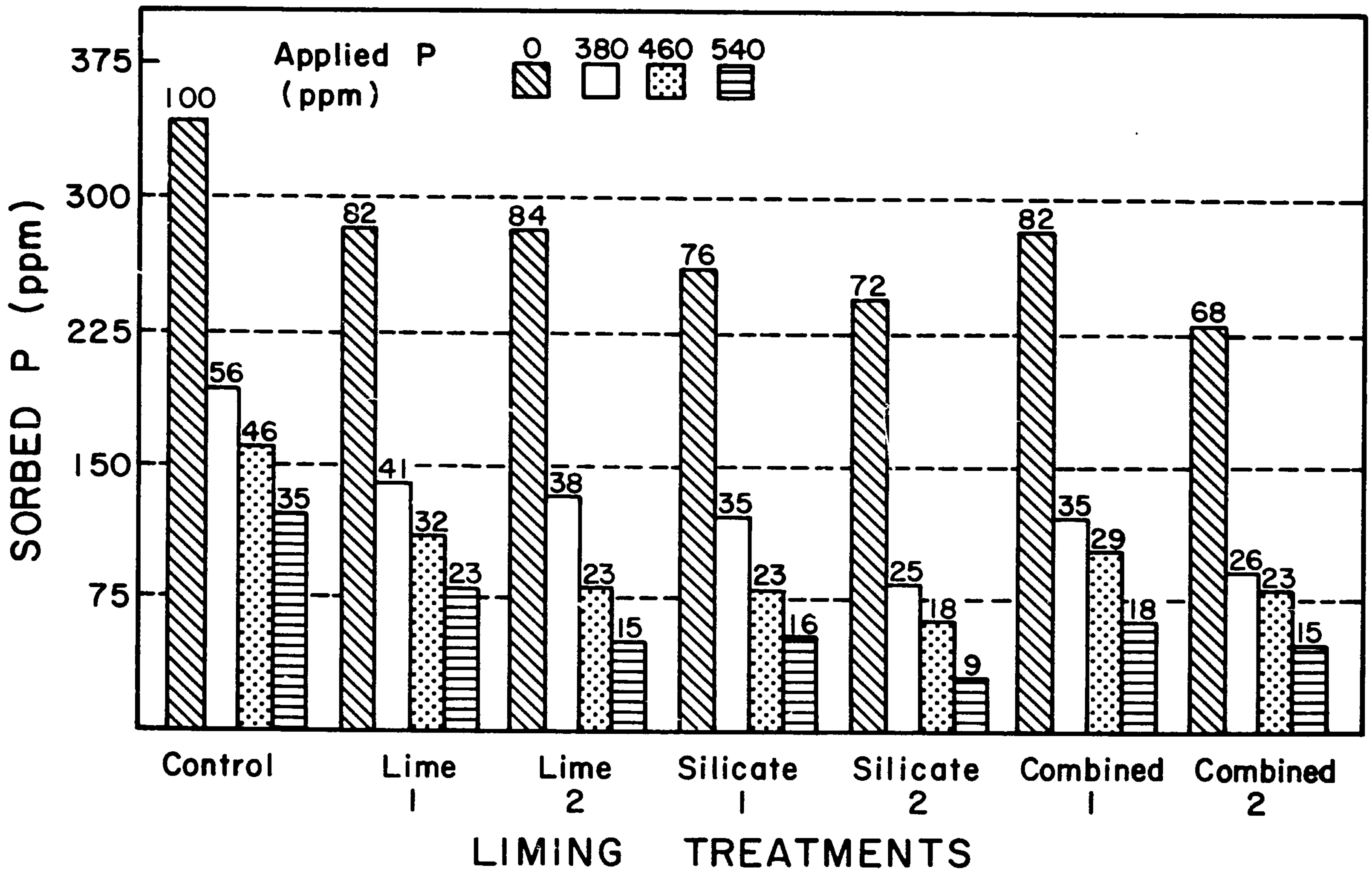


Figure 3.9:1. Effects of liming and P treatments on the amount of sorbed P required to obtain 0.1 ppm P in the equilibrating solution. Numbers on top of the columns are the % of the maximum sorbed P (340 ppm P) of the Control (0 P) treatment.

Previous P applications were more effective than the liming treatments in reducing additional P requirements. Application of 380 ppm P decreased P sorption by 44%, while maximum reduction in P sorption among the liming treatments was 32% in the Combined 2 treatment. Among the P treatments the application of $CaSiO_3$ at the level of one times the exchangeable acidity was just as effective as the application of $CaCO_3$ at the level of two times the exchangeable acidity.

Data presented in Fig. 3.9:1 shows the advantages of combining the liming and P treatments. The P requirement may be reduced by 65% with the application of 540 ppm P, whereas treating the soil with liming materials reduced P requirement by 32%. However, by liming the soil with the Silicate 2 treatment and applying 540 ppm P, P requirement was decreased by 91%. These results also implied that future determinations of the amounts of P required to obtain a given solution concentration should be performed after the liming material has been applied and allowed sufficient time to react with the soil.

Effects of the liming and P treatments on net soil charge are presented in Fig. 3.9:2. The lime treatments without P increased the initial net soil charge by 34 and 47%, respectively, for the levels of one and two times the exchangeable acidity. Combined effects of P and liming treatments on net charge were superior to the sum of their individual effects. Application of 540 ppm P provided a 34% increase in net soil charge, whereas the combination of this phosphorus treatment with lime increased the initial net charge by 62 and 138% at the respective lime rates of one and two times the exchangeable acidity.

Values for the negative and positive soil charges are presented in Tables 3.9:5 and 3.9:6, respectively. The principal effect of the liming treatments on the individual charge components appeared to be an increase in negative charge, whereas the principal effect of the P applications appears to be a decrease in positive charge.

Although these results suggested that the leaching of cations could be decreased by lime and P applications, movement of anions such as $NO_3$ and $SO_4$ may be increased due to decreases in positive soil charge.

Data for dry matter yields of rice plants grown in experiment 1 are shown in Table 3.9:7. Extremely poor yields were obtained in all treatments which did not receive P. Plants in these treatments never produced tillers and essentially ceased growth after the first six weeks. No additional response in growth was observed beyond the level of 380 ppm P. This may be explained by the large amounts of available P present. With the application of 380 ppm P in the Control treatment, the soil contained 47 ppm P, which was approximately five times greater than the suggested critical level for rice on Cerrado soils (Table 3.9:8). The level of 0.05 ppm solution P, equivalent to 380 ppm P, was above the critical level of soil P for rice. This soil solution P level was considerably lower than the level recommended for crops in other regions. The soil used in this study had a greater sorption

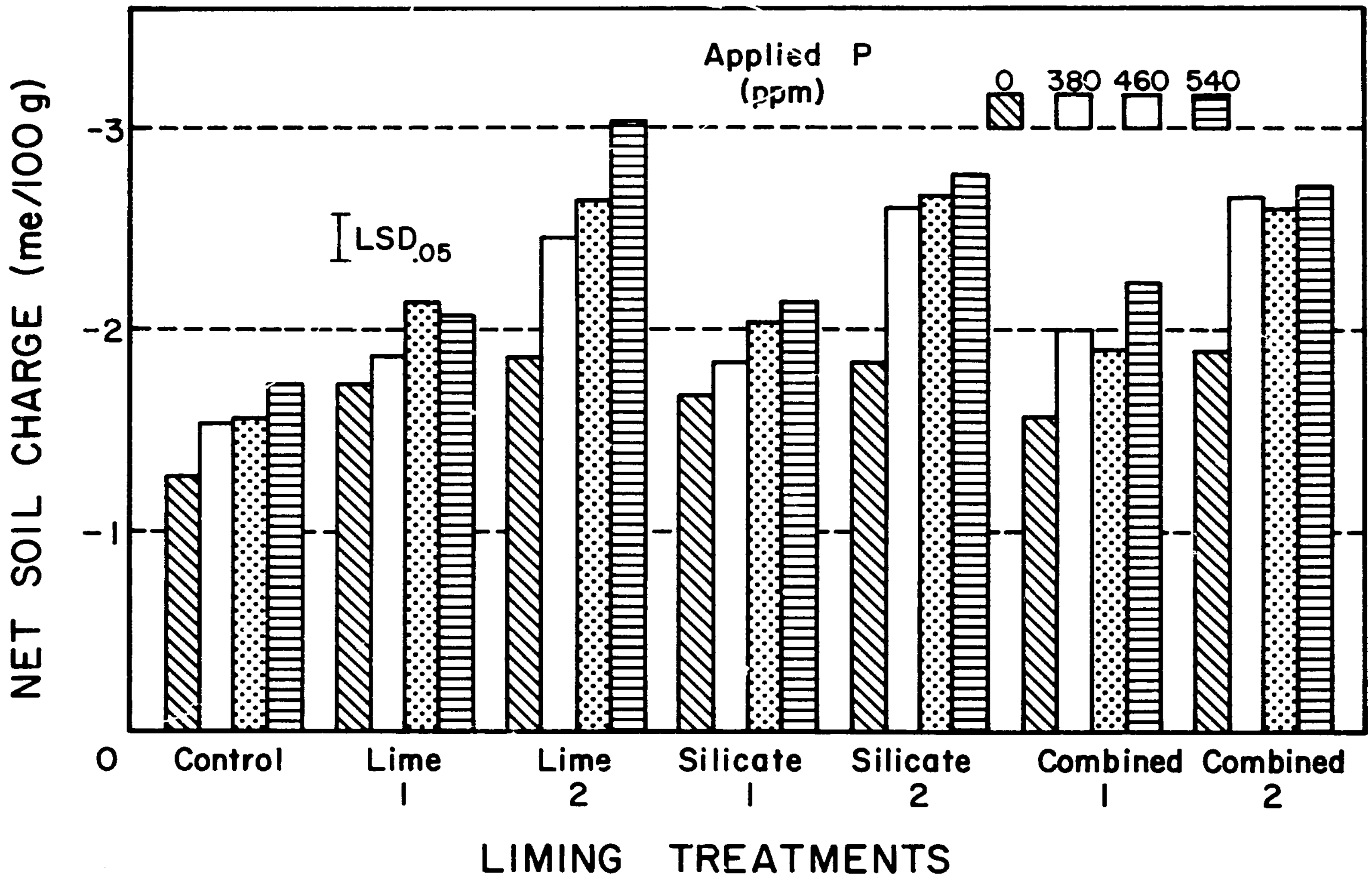


Figure 3.9:2. Effects of liming and P treatments on net soil charge.

Table 3.9:5. Effects of the lime and P treatments on negative soil charge.

| Liming Treatment | Applied P (ppm) 0 | 380 | 460 | 540 |
|---|---|---|---|---|
| | Negative soil charge (me/100cc) | | | |
| Control | 1.61 | 1.76 | 1.74 | 1.78 |
| Lime 1 | 1.97 | 2.01 | 2.18 | 2.16 |
| Lime 2 | 2.14 | 2.38 | 2.42 | 2.86 |
| Silicate 1 | 1.97 | 1.83 | 2.04 | 2.11 |
| Silicate 2 | 2.12 | 2.56 | 2.53 | 2.62 |
| Combined 1 | 1.85 | 2.02 | 1.97 | 2.19 |
| Combined 2 | 2.14 | 2.51 | 2.50 | 2.54 |

$LSD_{.05} = 0.19$

CV = 4.2%

Table 3.9:6. Effects of the lime and P treatments on positive soil charge.

| Liming Treatment | Applied P (ppm) | | | |
|---|---|---|---|---|
| | 0 | 380 | 460 | 540 |
| | Positive soil charge (me/100cc) | | | |
| Control | 0.33 | 0.24 | 0.18 | 0.06 |
| Lime 1 | 0.25 | 0.15 | 0.01 | 0.08 |
| Lime 2 | 0.26 | -0.04 | -0.22 | -0.19 |
| Silicate 1 | 0.30 | -0.01 | 0.01 | -0.03 |
| Silicate 2 | 0.30 | -0.04 | -0.15 | -0.14 |
| Combined 1 | 0.28 | 0.03 | 0.06 | -0.04 |
| Combined 2 | 0.24 | -0.16 | -0.15 | -0.18 |

$LSD_{.05} = 0.14$

CV = 6.7%

Table 3.9:7. Effects of the lime and P treatments on dry matter yield of rice tops grown in the topsoil sample.

| Liming Treatment | Applied P (ppm) | | | |
|---|---|---|---|---|
| | 0 | 380 | 460 | 540 |
| | ---- Rice Dry Matter (g/pot) ---- | | | |
| Control | 0.30 | 19.44 | 20.32 | 20.78 |
| Lime 1 | 0.34 | 21.87 | 22.52 | 22.13 |
| Lime 2 | 0.31 | 19.83 | 19.81 | 23.07 |
| Silicate 1 | 0.46 | 20.79 | 21.23 | 19.96 |
| Silicate 2 | 0.88 | 20.79 | 20.96 | 20.28 |
| Combined 1 | 0.52 | 18.03 | 21.41 | 18.31 |
| Combined 2 | 0.48 | 22.33 | 22.30 | 23.62 |

$LSD_{.05} = 2.51$

CV = 9.7%

Table 3.9:8. Effects of the lime and P treatments on available P in the topsoil sample following plant growth.

| Liming Treatment | Applied P (ppm) | | | |
|---|---|---|---|---|
| | 0 | 380 | 460 | 540 |
| | Available P (ppm) | | | |
| Control | 0.6 | 47 | 64 | 76 |
| Lime 1 | 0.5 | 43 | 66 | 85 |
| Lime 2 | 0.5 | 46 | 67 | 87 |
| Silicate 1 | 0.7 | 48 | 66 | 85 |
| Silicate 2 | 0.9 | 48 | 67 | 88 |
| Combined 1 | 0.6 | 46 | 66 | 78 |
| Combined 2 | 0.7 | 48 | 66 | 76 |

$LSD_{.05} = 5$

CV = 5.5%

capacity and apparently was able to supply adequate amounts of P to rice plants at a considerably lower solution concentration than soils in other regions.

A second greenhouse experiment was performed in order to obtain further information on the P requirement of upland rice in Cerrado Oxisols. Dry matter yields at 100 days after planting are presented in Fig.3.9:3. No signficiant increases in yields were observed above the level of 65 ppm P, which was approximately one-sixth of the amount of P required to obtain 0.05 ppm P in solution. Lime treatments did not provide significant responses in plant growth at any of the P levels. Analysis of the soil after plant growth indicated no effect of lime or Si on the levels of available soil P (Table 3.9:9).

Comparison of relative yields with available P by a Cate-Nelson diagram (Fig. 3.9:4) revealed a critical soil test level of approximately 3 ppm P, which is considerably lower than the level of 13 ppm P previously observed for corn on the same soil at the Centro de Pesquisa Agropecuaria dos Cerrados.

The Si concentration of the rice straw in experiment 1 is presented in Table 3.9:10. Due to the small amounts of dry matter produced, the plants in the treatments without applied P contained large percentages of Si. Plants in all treatments receiving P had silicon concentration below the suggested critical level. However, rice plants treated with $CaSiO_3$ maintained an erect leaf habit during growth, while less turgid leaves were observed in all other treatments. The Si concentration of the rice straw and the water-soluble Si level in the soil were highly correlated ($r = 0.82$).

The low Si concentration for the rice plants in this study may have been caused by the restricted volume of soil used in the experiment. Possibly under field conditions, where rice roots could have explored larger soil volumes, Si concentration of the straw would have been higher. However, these results merit further investigation, since the straw Si concentration in the silicate treatments also were below the suggested critical level.

## 3.10 OUTREACH STUDY OF PROPERTIES OF "CERRADO" SOILS

A. S. Lopes and F. R. Cox

This study is a continuation of one conducted by Alfredo Scheid Lopes[1] and presented in the 1974 Annual Report, pages 148 to 153. Forty-four composite topsoil samples were collected under "Cerrado" vegetation in Central Brazil, the sites being selected from the previous study.[2] Fourteen samples were in the hue range 10R to 2.5YR, 15 were 5YR, and 15 were from 7.5 to 10YR and thereafter referred to as dark-red, red and red-yellow

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[1] Lopes, A. S. 1977. Available water, phosphorus fixation, and zinc levels in Brazilian Cerrado Soils in relation to their physical, chemical, and mineralogical properties. Unpublished Ph.D. Thesis, Department of Soil Science, North Carolina State University, 189 pp.

[2] Lopes, A. S. 1975. A survey of the fertility status of soil under Cerrado vegetation in Brazil. M.S. Thesis, Department of Soil Science, North Carolina State University, 138 pp.

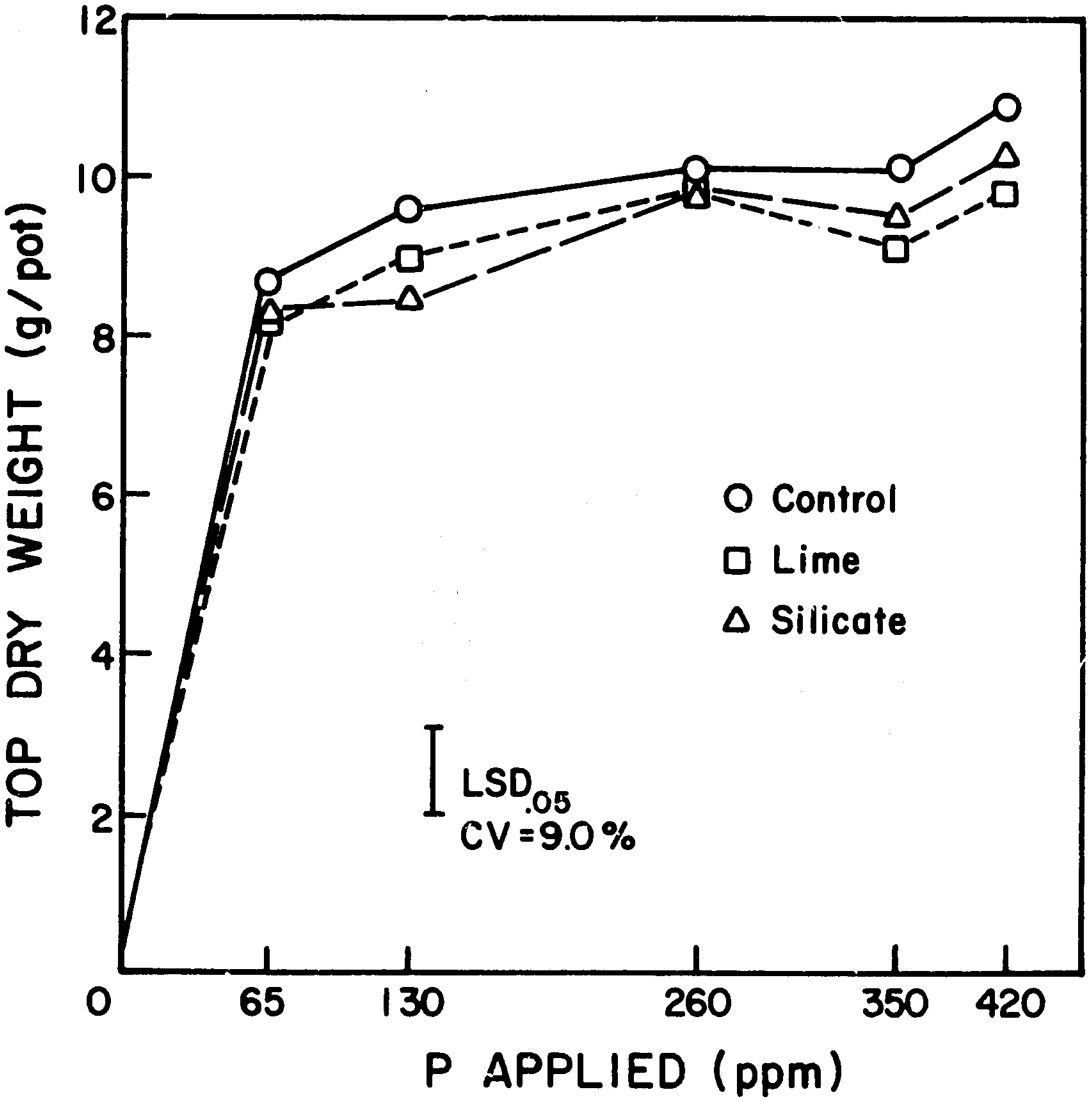


Figure 3.9:3. Effects of P applications on dry matter production of rice plants as a function of lime treatments. Subsoil sample.

Table 3.9:9. Effects of the lime and P treatments on available P in the subsoil sample after plant growth.

| P Applications | Lime Treatments | | |
|---|---|---|---|
| | Control | Lime | Silicate |
| ppm | ---------- ppm P ------------- | | |
| 0 | 0 | 0 | 0.2 |
| 65 | 1.6 | 1.6 | 1.7 |
| 130 | 5.1 | 5.0 | 5.2 |
| 260 | 18.9 | 19.1 | 19.8 |
| 350 | 35.4 | 34.5 | 35.9 |
| 420 | 48.2 | 47.0 | 47.8 |

$LSD_{.05} = 1.8$

CV = 6.1%

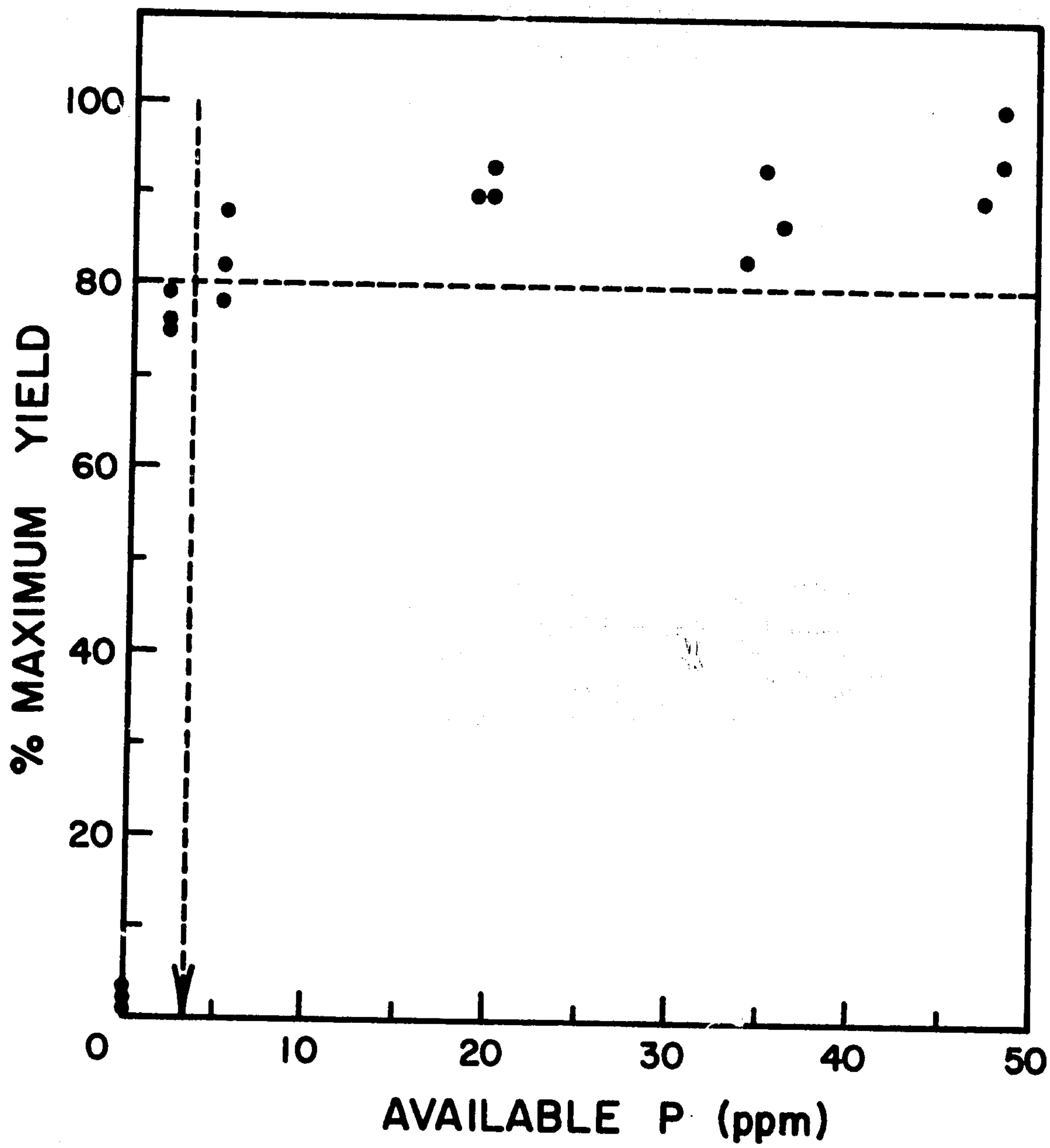


Figure 3.9:4. Distribution of relative yield versus available P extracted with the dilute double acid. Subsoil sample.

Table 3.9:10. Effects of lime and P treatments on the Si concentrations in the rice straw. Experiment with the topsoil sample.

| Liming Treatment | Applied P (ppm) | | | |
|---|---|---|---|---|
| | 0 | 380 | 460 | 540 |
| | % Si | | | |
| Control | 4.18 | 0.50 | 0.43 | 0.43 |
| Lime 1 | 3.52 | 0.42 | 0.42 | 0.40 |
| Lime 2 | 3.27 | 0.36 | 0.37 | 0.35 |
| Silicate 1 | 5.80 | 0.95 | 0.90 | 0.97 |
| Silicate 2 | 6.51 | 1.24 | 1.19 | 1.34 |
| Combined 1 | 5.24 | 0.69 | 0.73 | 0.70 |
| Combined 2 | 5.39 | 0.88 | 0.85 | 0.83 |

$LSD_{.05}$ = 0.09

CV = 7.6%

NOTE: LSD values cannot be used to compare the treatments not receiving P applications since replicate samples were not analyzed in these treatments.

Cerrado topsoils. In each of these topsoil color groups there was a wide range in texture (including sand, loam and clay soils) and types of Cerrado vegetation. The soil sampling sites are shown in Fig. 3.10:1. Detailed locations of the sampling sites are available upon request at:

1) Centro de Pesquisa Agropecuaria dos Cerrados
Km. 18 Rodovia BR-020
Caixa Postal 07-0084
70.000 Brasilia, Distrito Federal, Brazil

2) Departamento de Ciencias do Solo
Escola Superior de Agricultura de Lavras
Caixa Postal 37
37.200 Lavras, Minas Gerais, Brazil

This report will be divided into three parts: 1) selected characteristics of Cerrado topsoils; 2) prediction models for available water, P characteristics and Zn levels; 3) soil factors limiting agricultural development of the Cerrado area.

Selected Characteristics of Cerrado Topsoils

To be discussed are selected characteristics of Cerrado topsoils not considered in the 1974 Annual Report.

Texture is one important characteristic of these soils and will be referred to frequently throughout this study. The mean and range for each textural component is shown for each color group in Table 3.10:1. These data show that regardless of topsoil color there is a wide range in textural components, especially sand and clay.

Charge characteristics (positive, negative, and net) of these samples are presented in Table 3.10:2. Over all samples, the ranges for positive, negative and net-negative charges were 0.00 to 1.25, 0.31 to 4.48, and 0.31 to 4.01 me/100 g, and the means were 0.46, 1.58 and 1.11 me/100 g, respectively. Even though these topsoils had an average of 42% clay and 2.6% organic matter, the means for both negative charge and net negative charge were quite low, suggesting that the CEC also was quite low.

The relationship between effective CEC (Ca + Mg + K + Al in me/100 g) and negative charge and net-negative charge is presented in Figs. 3.10:2 and 3.10:3. A higher coefficient of determination was observed for the second relationship ($R^2 = 0.96$) than for the first one ($R^2 = 0.88$). This indicated a better explanation of effective CEC by net negative charge than by negative charge. The slope for effective CEC versus net negative charge was almost equal to unity (0.99). The slope for effective CEC versus negative charge was 0.79. These results indicated that some of the negative charges of the colloidal complex must have off-set positive charges of iron and aluminum oxides and hydroxides associated with the clay fraction, thus leaving only the remaining negative charges available for cation exchange. The almost perfect linear relationship (slope = 0.99) between effective CEC and net negative charge was also evidence that exchangeable Al existed in these topsoils and that 1N KCl was an effective extractant to remove it from exchange sites. None of the topsoil samples studied had a net positive charge

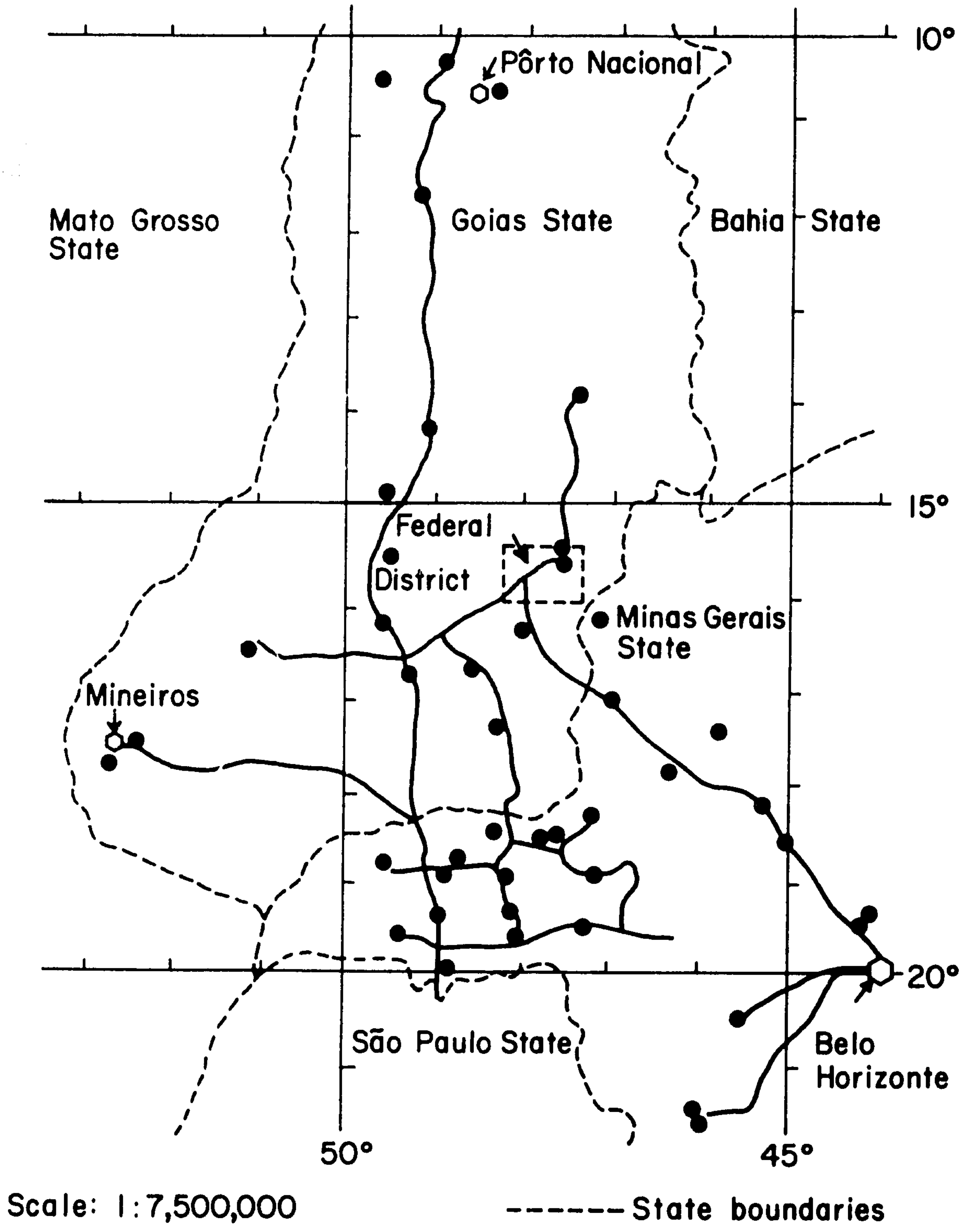


Figure 3.10:1. Route map and sample sites of outreach study.

Table 3.10:1. Sand, silt, and clay ranges and means for red-yellow, red, and dark-red cerrado topsoils.

| Topsoil color | Textural component | Range | Mean |
|---|---|---|---|
| | | ------- % ------- | |
| Red-yellow | Sand | 1.4-90.0 | 48.4 |
| | Silt | 1.4-22.7 | 9.5 |
| | Clay | 7.7-82.2 | 42.1 |
| Red | Sand | 7.6-92.3 | 49.1 |
| | Silt | 1.5-18.6 | 8.2 |
| | Clay | 6.2-83.1 | 42.7 |
| Dark-red | Sand | 4.3-80.7 | 50.2 |
| | Silt | 3.4-15.4 | 7.9 |
| | Clay | 15.0-82.6 | 41.9 |
| Overall | Sand | 1.4-92.3 | 49.2 |
| | Silt | 1.4-22.7 | 8.5 |
| | Clay | 6.2-83.1 | 42.3 |

Table 3.10:2. Charge characteristics of various textures and colors of cerrado topsoils.

| Texture | Color: Red-Yellow Pos | Neg | Net (-) | Red Pos | Neg | Net (-) | Dark-red Pos | Neg | Net (-) | Average by topsoil texture Pos | Neg | Net (-) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % clay | me/100 g | | | | | | | | | | | |
| <18 | 0.07 | 0.61 | 0.54 | 0.12 | 1.19 | 1.07 | 0.19 | 0.91 | 0.72 | 0.12 | 0.90 | 0.78 |
| 18-35 | 0.32 | 1.32 | 1.00 | 0.28 | 0.99 | 0.71 | 0.33 | 1.01 | 0.68 | 0.31 | 1.11 | 0.80 |
| 35-60 | 0.60 | 2.07 | 1.47 | 0.43 | 1.38 | 0.94 | 0.56 | 1.69 | 1.13 | 0.53 | 1.71 | 1.18 |
| >60 | 0.79 | 1.88 | 1.09 | 0.86 | 2.79 | 1.93 | 0.84 | 2.58 | 1.74 | 0.83 | 2.45 | 1.62 |
| Avg by color | 0.43 | 1.43 | 1.00 | 0.46 | 1.72 | 1.26 | 0.50 | 1.58 | 1.08 | | | |

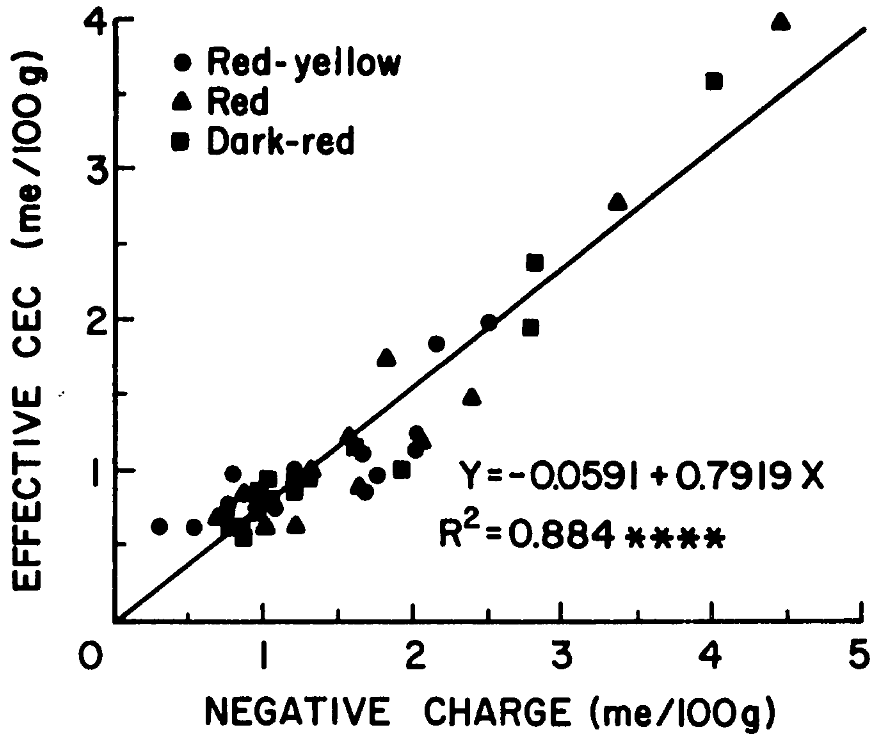


Figure 3.10:2. Relationship between effective CEC and negative charge in red-yellow, red, and dark-red Cerrado topsoils.

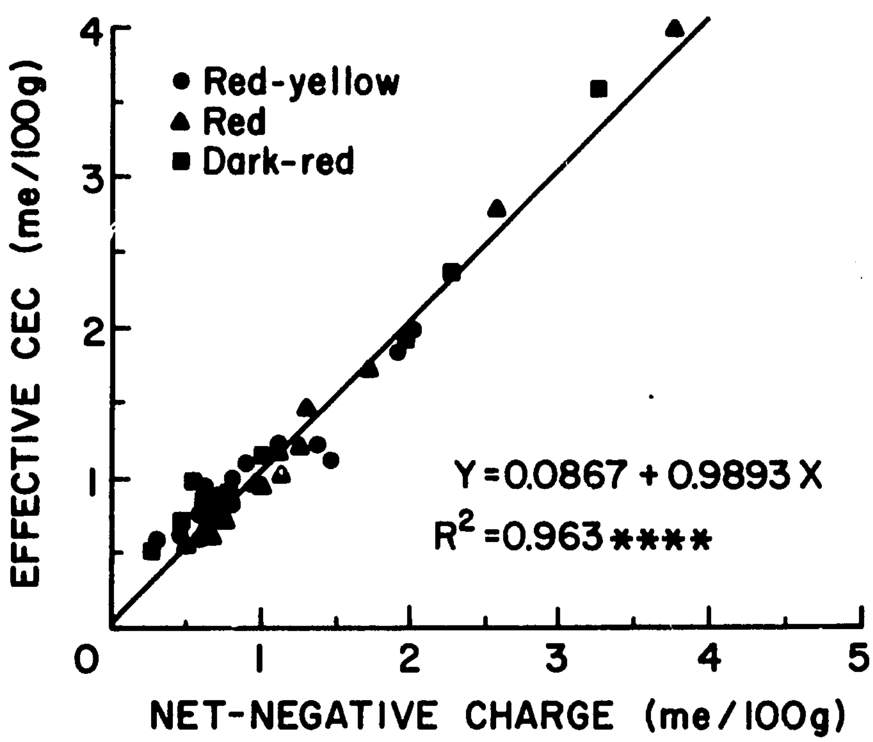


Figure 3.10:3. Relationship between effective CEC and net-negative charge in red-yellow, red, and dark-red Cerrado topsoils.

but there was a considerable range in the level of this factor (Table 3.10:2).

The mean values of positive, negative, or net negative charge did not differ among red-yellow, red and dark-red Cerrado topsoils. Also, there was no difference in the rate of increase for any of these charge characteristics with an increase in clay for the three different topsoil color groups. However, the slope of the positive charge in relation to free $Fe_2O_3$, a clay constituent, was greater for the red-yellow than for the red and dark-red topsoils (Fig. 3.10:4). At the same level of free $Fe_2O_3$ in the clay (calculated on a total soil basis) there was more positive charge in the red-yellow than in the red and dark-red topsoils. This likely was due to there being a smaller particle size of clay in red-yellow topsoils than in the others. This resulted in more hydration, more surface area and, thus greater reactivity in relation to formation of positive charge.[3] Most of the relationships involving Fe compounds in these soils showed a similar behavior; a different slope for the red-yellow when compared to red and dark-red topsoils (Figs. 3.10:4, 3.10:11, 3.10:12, 3.10:13, 3.10:14).

The mineralogical composition of the clay fraction for the red-yellow, red, and dark-red topsoils is presented in Table 3.10:3. Kaolinite was the main constituent of the clay fraction (33.8%) followed by gibbsite (23.4%), free $Fe_2O_3$ (9.1%), amorphous $Al_2O_3$ (4.0%) and amorphous $SiO_2$ (2.1%). Amorphous $Al_2O_3$ and amorphous $SiO_2$ were determined without removal of Fe. A difference in free $Fe_2O_3$ of the clay was observed for the red-yellow, red, and dark-red topsoils (5.3, 9.6 and 12.4%, respectively). This was the major difference in relation to clay components among these three color groups. A total of 39% of the 44 samples had gibbsite as a predominant component of the clay fraction.

The level of free $Fe_2O_3$ determined in the total soil tended to be slightly greater than that obtained as free $Fe_2O_3$ in the total soil estimated from the clay fraction. The relationship between these two parameters is shown in Fig. 3.10:5. These data indicated that other soil fractions, probably silt, also could be contributing $Fe_2O_3$ to some degree.

Two methods are often used to determine the composition of the clay fraction. In the first, the clay is completely fused using $Na_2CO_3$. In the second, the soil sample is boiled with 1.47 density $H_2SO_4$.[4] This procedure is often used to determine molecular ratios in soil surveys in Brazil. Analyzed are Fe, Si, Ti, Mn, and P levels. The amounts are generally expressed in terms of their respective "total" oxides ($Al_2O_3$, $Fe_2O_3$, $SiO_2$, $TiO_2$, $MnO_2$, and $P_2O_5$). The results of the chemical composition and molecular ratios by the 1.47 density $H_2SO_4$ method on a topsoil color and clay content basis are presented in Tables 3.10:4 and 3.10:5. As would be expected, there was much more variation in the

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[3] Personal communication. J. Bigham, Ohio State University, Columbus, Ohio.

[4] Vettori, L. 1969. Metodos de analise de solo. E. P. F. Ministerio da Agricultura. Boletim tecnico No. 7, Rio de Janeiro, Brasil.

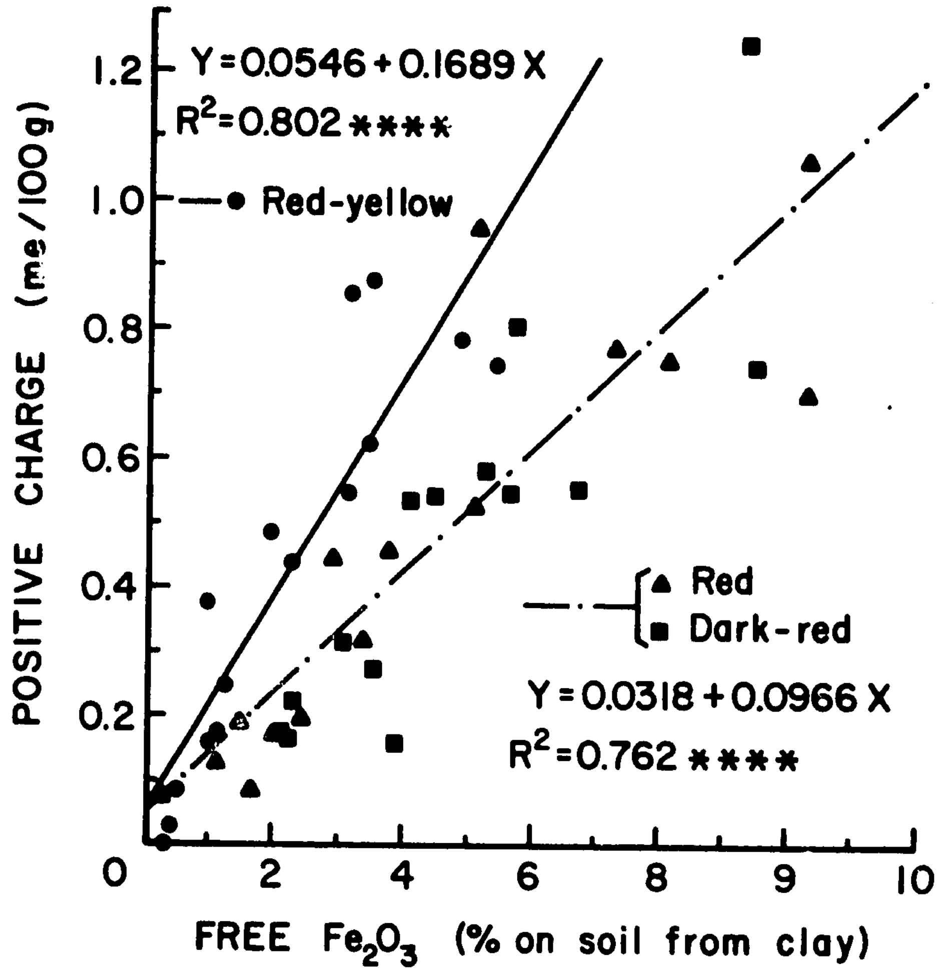



Figure 3.10:4. Relationship between positive charge and free $Fe_2O_3$ in red-yellow, red, and dark-red Cerrado topsoils.

Table 3.10:3. Mineralogical composition of clay (<0.002 mm) in various colors of cerrado topsoils.

| Clay component | Red-yellow | | Red | | Dark-red | | Overall | |
|---|---|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean | Range | Mean |
| | % | | | | | | | |
| Free $Fe_2O_3$ | 2.9-10.0 | 5.3 | 6.0-15.9 | 9.6 | 9.4-16.1 | 12.4 | 2.9-16.1 | 9.1 |
| Gibbsite | 12.7-40.2 | 27.9 | 0.3-38.6 | 18.4 | 6.6-50.0 | 23.9 | 0.3-50.0 | 23.4 |
| Kaolinite | 5.1-71.7 | 32.6 | 12.7-55.0 | 35.9 | 9.0-62.1 | 32.8 | 5.1-71.7 | 33.8 |
| Amorphous $Al_2O_3$ | 1.1- 5.8 | 3.6 | 1.7- 7.2 | 4.7 | 1.9- 6.2 | 3.6 | 1.1- 7.2 | 4.0 |
| Amorphous $SiO_2$ | 0.3- 3.2 | 1.3 | 0.8- 5.0 | 2.6 | 0.9- 5.5 | 2.3 | 0.3- 5.5 | 2.1 |

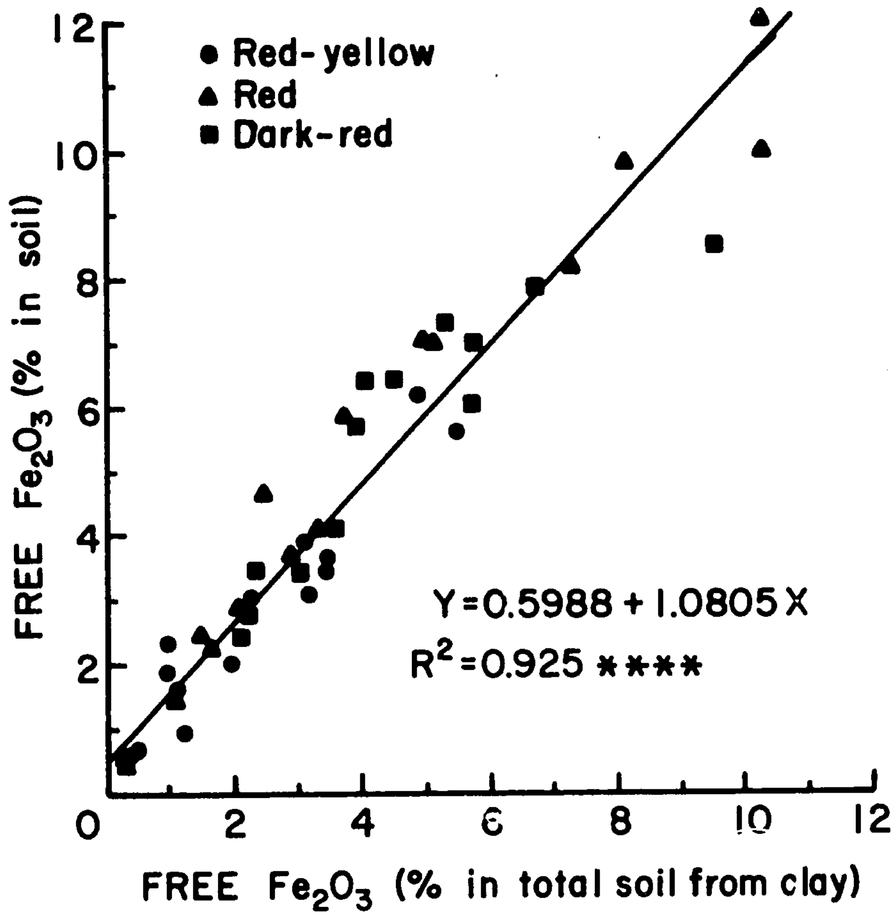



Figure 3.10:5. Relationship between free $Fe_2O_3$ (% in soil calculated from % in clay) and free $Fe_2O_3$ (% in soil) in red-yellow, red, and dark-red Cerrado topsoils.

Table 3.10:4. Chemical composition and molecular ratios of red-yellow, red, and dark-red cerrado topsoils*.

| Soil property** | Topsoil color | | | Overall | |
|---|---|---|---|---|---|
| | Red-yellow | Red | Dark-red | Range | Mean |
| $SiO_2$ (%) | 7.55 | 8.72 | 6.34 | 1.00 -20.32 | 7.54 |
| $Al_2O_3$ (%) | 18.88 | 15.67 | 16.51 | 1.97 -41.57 | 17.02 |
| $Fe_2O_3$ (%) | 5.00 | 8.37 | 9.54 | 0.74 -18.76 | 7.59 |
| $P_2O_5$ (%) | 0.034 | 0.082 | 0.064 | 0.006-0.303 | 0.060 |
| $TiO_2$ (%) | 0.67 | 1.04 | 1.03 | 0.08 -2.84 | 0.91 |
| Ki | 0.72 | 1.07 | 0.79 | 0.30 -1.78 | 0.85 |
| Kr | 0.62 | 0.78 | 0.54 | 0.21 -1.46 | 0.65 |
| b | 6.13 | 2.96 | 2.54 | 1.31 -10.20 | 3.91 |
| Sf | 4.51 | 3.16 | 1.87 | 0.53 -9.63 | 3.21 |
| b2 | 23.27 | 16.95 | 17.38 | 2.71 -57.24 | 19.24 |

* Extracted by 1.47 density $H_2SO_4$.

** Molecular ratios Ki = $SiO_2/Al_2O_3$; Kr = $SiO_2/Al_2O_3 + Fe_2O_3$; b = $Al_2O_3/Fe_2O_3$; Sf = $SiO_2/Fe_2O_3$; b2 = $Al_2O_3/TiO_2$.

Table 3.10:5. Chemical composition and molecular ratios of various textures of cerrado topsoils*.

| Soil property** | % Clay | | | |
|---|---|---|---|---|
| | <18 | 18-35 | 35-60 | >60 |
| $SiO_2$ (%) | 3.00 | 4.82 | 8.21 | 13.30 |
| $Al_2O_3$ (%) | 4.66 | 11.36 | 19.50 | 30.59 |
| $Fe_2O_3$ (%) | 3.10 | 6.45 | 8.76 | 11.55 |
| $P_2O_5$ (%) | 0.020 | 0.035 | 0.051 | 0.121 |
| $TiO_2$ (%) | 0.67 | 0.74 | 1.15 | 1.09 |
| Ki | 1.12 | 0.80 | 0.75 | 0.78 |
| Kr | 0.78 | 0.58 | 0.60 | 0.62 |
| b | 3.43 | 3.42 | 3.89 | 4.74 |
| Sf | 3.42 | 2.71 | 3.24 | 3.44 |
| b2 | 14.08 | 16.02 | 14.28 | 29.77 |

* Extracted by 1.47 density $H_2SO_4$.

** Molecular ratios: Ki = $SiO_2/Al_2O_3$; Kr = $SiO_2/Al_2O_3 + Fe_2O_3$; b = $Al_2O_3/Fe_2O_3$; Sf = $SiO_2/Fe_2O_3$; b2 = $Al_2O_3/TiO_2$.

level of these soil characteristics when grouped by texture than when grouped by topsoil color. However, some differences for the three color groups in relation to these parameters were: 1) there was a considerable increase in "total" $Fe_2O_3$ going from red-yellow to red, and finally to dark-red topsoils. The average values were 5.00, 8.37 and 9.54% "total" $Fe_2O_3$, respectively. This was shown also by a considerable decrease in the molecular ratios b($Al_2O_3/Fe_2O_3$) and Sf($SiO_2/Fe_2O_3$) going from red-yellow to dark-red topsoils; 2) red-yellow topsoils had about one-third the "total" $P_2O_5$ content of the red topsoils and about one-half that of the dark-red topsoils, suggesting that a close association existed between "total" $Fe_2O_3$ and "total" $P_2O_5$ in these topsoils; 3) both red and dark-red topsoils had considerably more "total" $TiO_2$ than the red-yellow topsoils; 4) all samples had Ki ratios ($SiO_2/Al_2O_3$) of less than 2.0. This suggested that the Ki ratio obtained from the total soil by extraction with 1.47 density $H_2SO_4$ would be close to values of the Ki ratio obtained from total analysis of the clay fraction. In other words, this indicated that the mineralogy of the clay fraction of most of these soils was very similar qualitatively; however, the quantity of individual components may differ.

Data from 1.47 density $H_2SO_4$ extraction are used for soil classification purposes in Brazil. Some useful soil characteristics, such as gibbsite (% in clay), free $Fe_2O_3$ (% in clay) and free $Fe_2O_3$ (% in soil) could be reasonably well explained by the following regression models:

$$\text{Gibbsite (\% in clay)} = 48.0217 - 27.6682\ SiO_2/Al_2O_3 \quad (R^2 = 0.785^{****})$$

$$\text{Free } Fe_2O_3 \text{ (\% in clay)} = 17.2530 - 2.8637\ Al_2O_3/Fe_2O_3 + 0.1495\ (Al_2O_3/Fe_2O_3)^2 \quad (R^2 = 0.721^{****})$$

$$\text{Free } Fe_2O_3 \text{ (\% in soil)} = 0.2484 + 0.6529\ \text{"total" } Fe_2O_3 \text{ (\%)} \quad (R^2 = 0.922^{***})$$

## Levels and Prediction Models for Available Water, P Characteristics and Zn

Available water. Water retention curves for soil water content at tensions of 1/10, 1/3, 1/2, 1, 5, and 15 bars were obtained for each of the 44 samples in this study. Selected water retention curves for various topsoil textures and color groups are presented in Figs. 3.10:6, 3.10:7 and 3.10:8. About two-thirds or more of the available water in these soils was released between 1/10 and 1 bar, irrespective of soil texture or topsoil color. In other words, the soils behaved like sands, even though some may have contained as much as 83% clay.

The relations between available water and color (red-yellow, red, and dark-red) and texture (< 18, 18 to 35, 35 to 60, and >60% clay) are presented in Table 3.10:6. Percent available water was calculated as the difference between the amount of water retained under

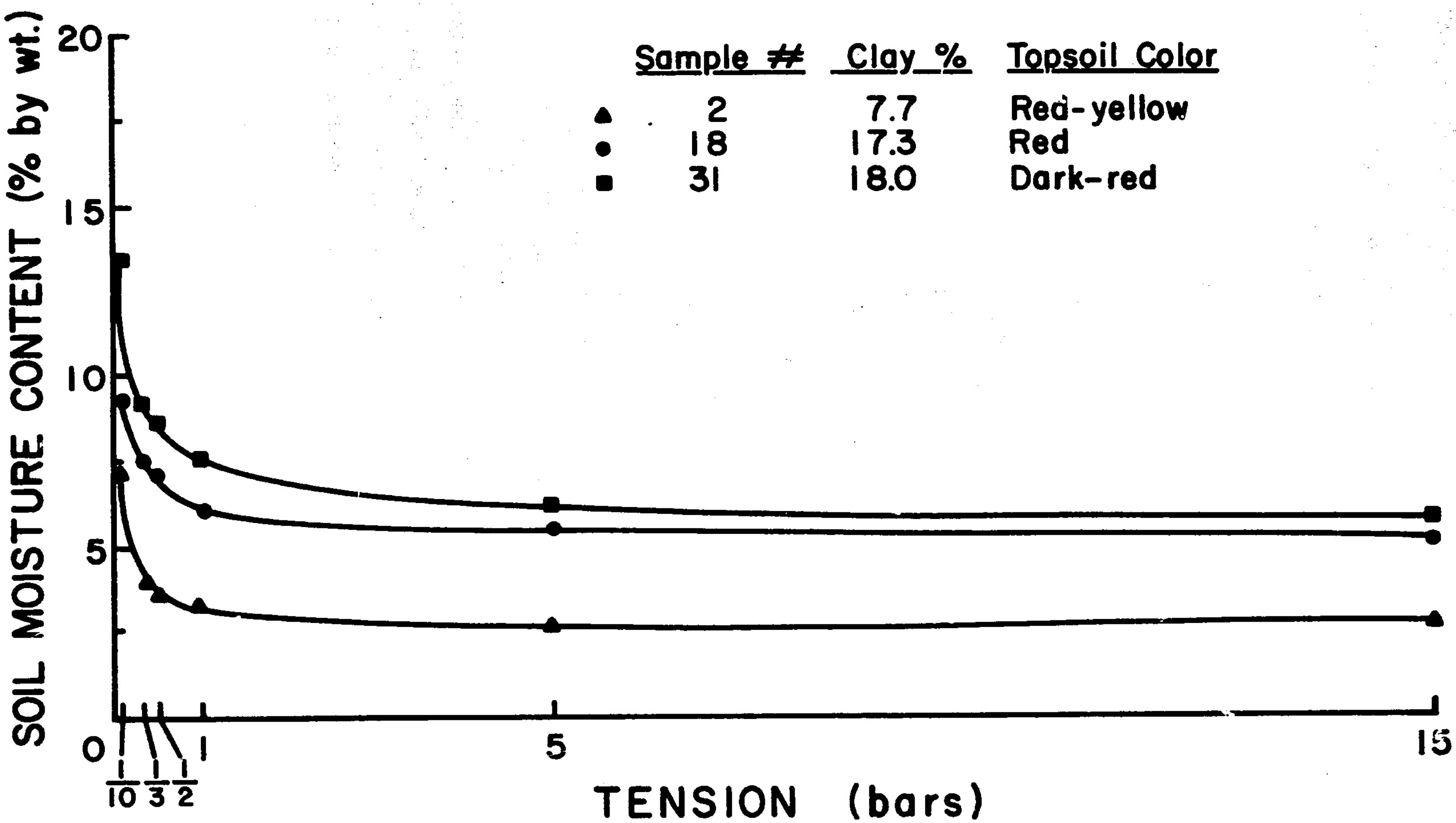



Figure 3.10:6. Water retention curves for three sandy Cerrado topsoils.

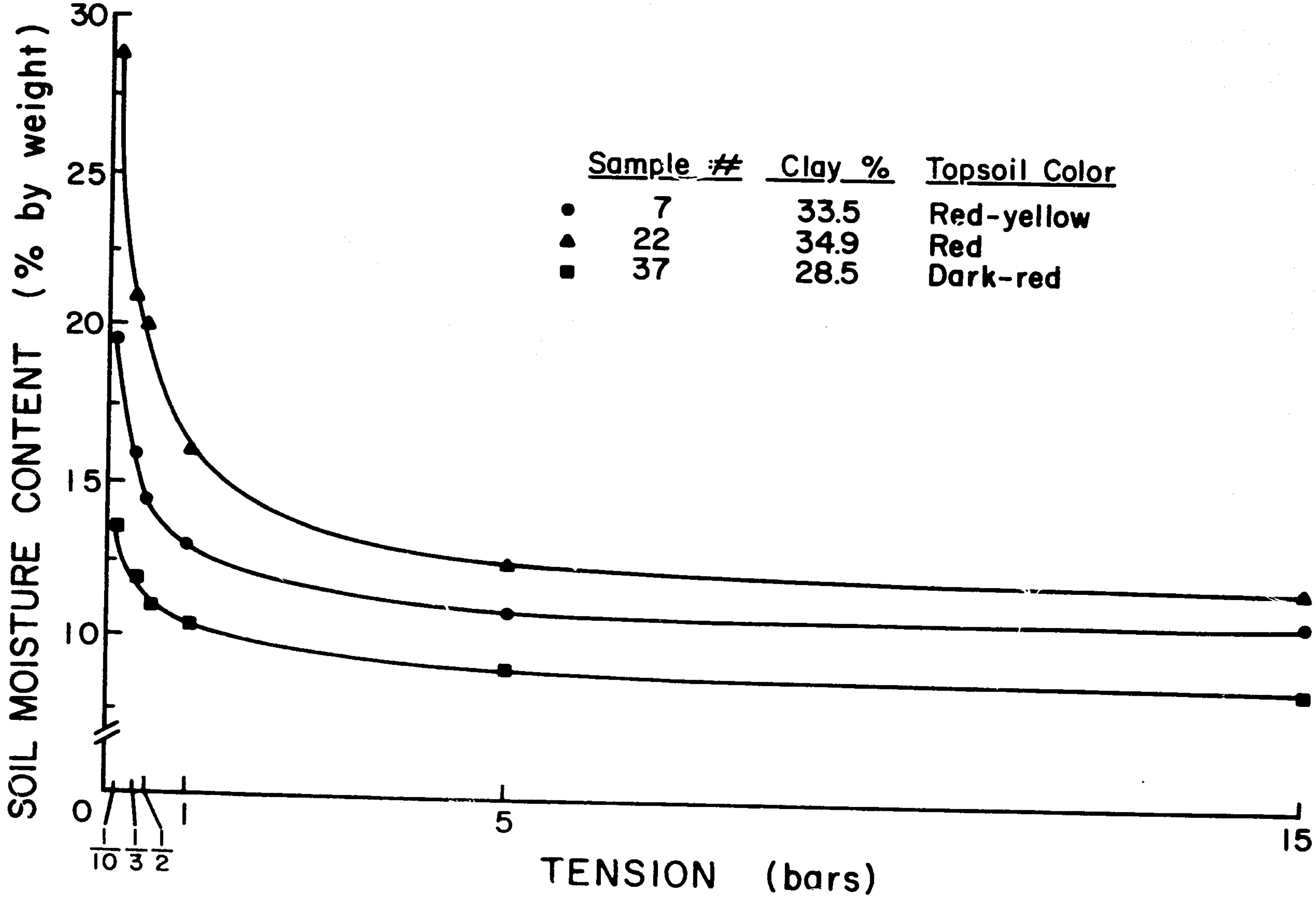



Figure 3.10:7. Water retention curves for three loamy Cerrado topsoils.

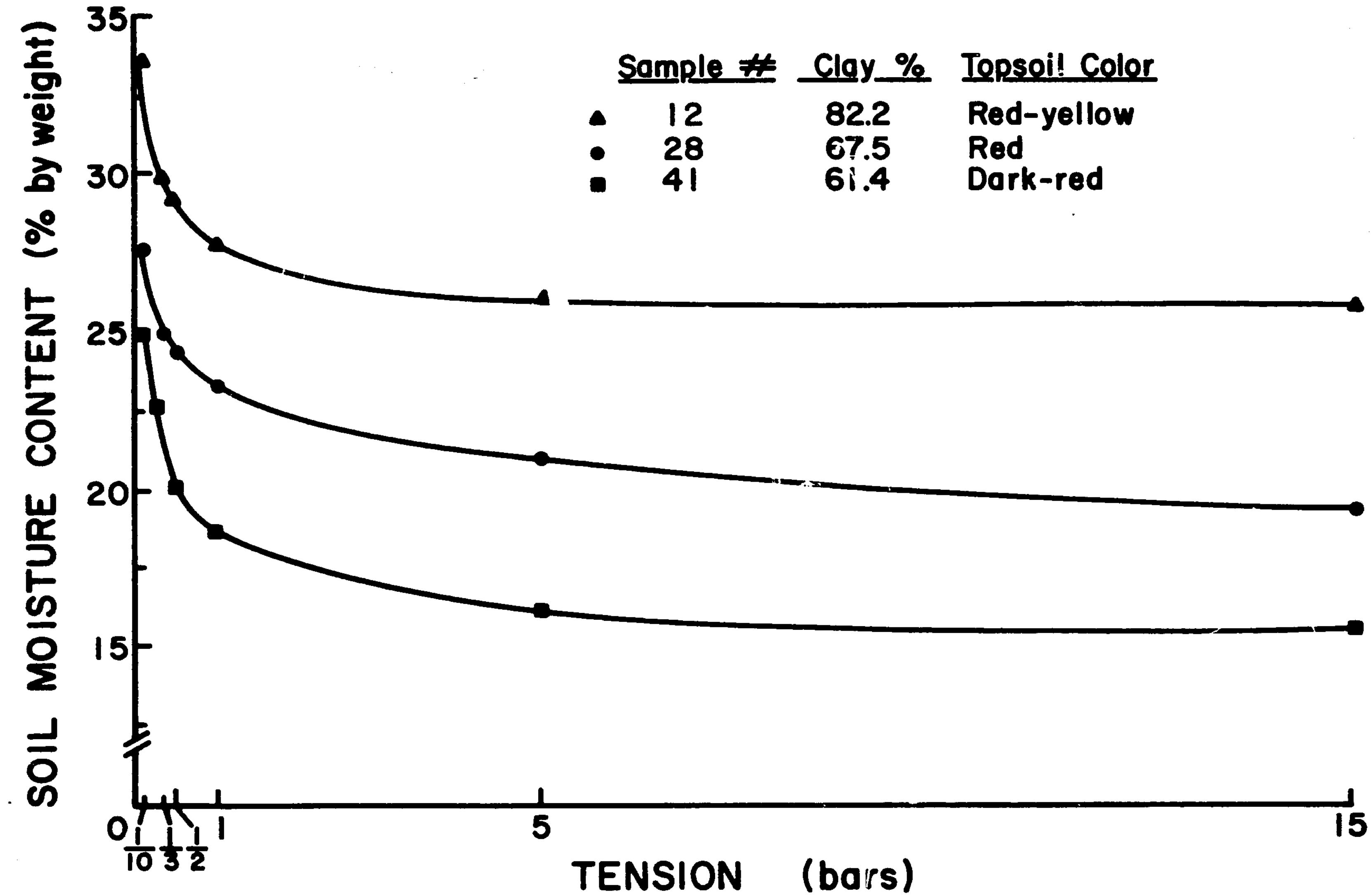



Figure 3.10:8. Water retention curves for three clayey Cerrado topsoils.

Table 3.10:6. Available water of various textures and colors of cerrado topsoils.

| | Color | | | |
|---|---|---|---|---|
| Texture | Red-yellow | Red | Dark-red | Avg by texture |
| % clay | ---------------- | % by weight | ---------------- | |
| <18 | 4.9 | 5.0 | 4.7 | 4.9 |
| 18-35 | 7.9 | 10.7 | 6.9 | 8.5 |
| 35-60 | 10.7 | 9.7 | 9.0 | 9.8 |
| >60 | 8.7 | 9.2 | 9.3 | 9.1 |
| Avg by color | 7.9 | 8.6 | 7.5 | |

Texture $LSD_{.10}$ = 1.7

Color NS.

1/10 bar minus that under 15 bars tension. These data indicated that sandy soils had much less available water than the other textural groups. Soils with a 35 to 60% clay tended to have the maximum values in available water, however, there was not a significant difference among soils with 18-35, 35-60, and > 60% clay in relation to the level of available water.

Prediction models for the levels of available water (% by weight) and other soil properties indicated that percentage of silt was the best single variable to explain the variation. The observed data points and the simple regression line for this equation is in Fig 3.10:9. The regression equation with a $R^2$ = 0.598****, was of the following form:

Available water (% by wt.) = 4.0538 + 0.4602 silt (%)

Prediction models for the levels of available water (% by weight) as a function of clay content were not as good as those based on a function of the silt content. The following regression equation had a coefficient of determination ($R^2$) of 0.391**** indicating that percent clay in these soils was not as good a predictive variable for estimating available water.

Available water (% by wt.) = 2.0563 + 0.2692 clay (%) – 0.0023 [clay (%)]$^2$

These observations suggested that even though it was not the ideal predictive variable, in terms of water management loams and clay soils would have a higher probability of less water stress during short term droughts during the rainy season than sands. Sandy soils definitely have the lowest available water holding capacity of the Cerrado soils.

P characteristics. Three P characteristics were studied in these samples: P adsorption maxima, P sorbed at 0.2 ppm P in soil solution, and P buffering capacity between 0.05 and 0.2 ppm P in soil solution. The results of these P characteristics by topsoil color and texture are presented in Tables 3.10:7, 3.10:8, and 3.10:9.

The P adsorption maxima varied from 0.396 to 2.419 mg P adsorbed per g of soil with an overall mean of 1.421 mg P adsorbed per g of soil. These results indicated a considerable range in the P fixation capacity of Cerrado soils, and a mean value that is quite high. The range for P sorbed at 0.2 ppm P in soil solution was from 70.5 to 738.2 ppm P with an overall mean of 291.6 ppm P. Values for the P buffering capacity between 0.05 and 0.2 ppm ranged from 7.5 to 259.1 ppm with an overall mean of 91.7 ppm P.

For all three P characteristics studied there was no effect due to differences in topsoil color, but they increased markedly with an increase in the clay content of the soil (Tables 3.10:7, 3.10:8, and 3.10:9). This observation indicated that topsoil texture was one of the main characteristics to be considered in the management of P fertilizers in the Cerrado soils.

Prediction models for P adsorption maxima, P sorbed at 0.2 ppm P in soil solution

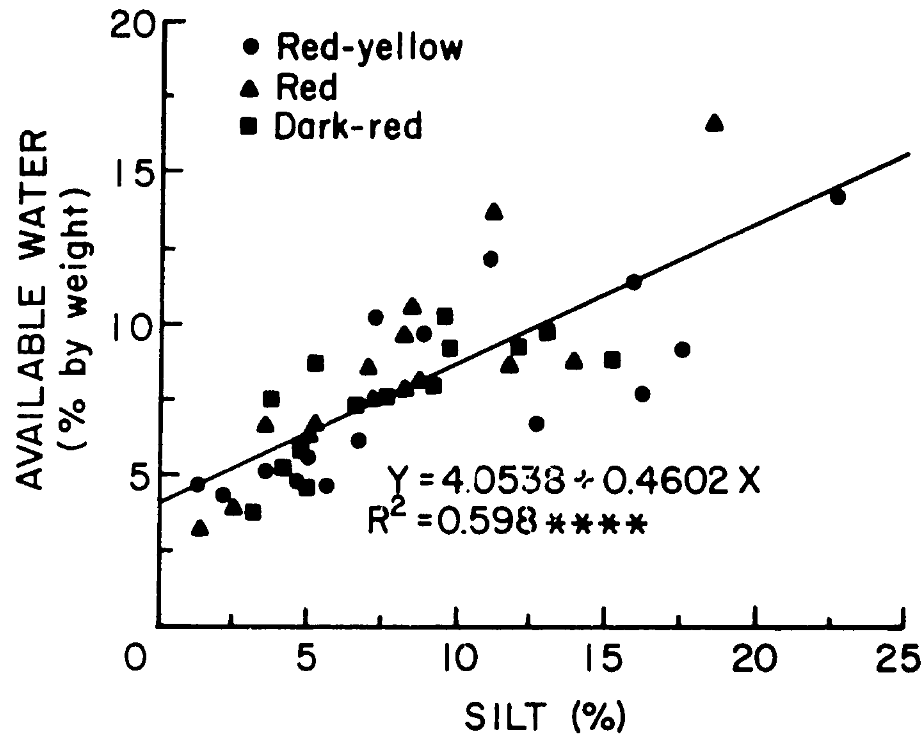



Figure 3.10:9. Relationship between available water and silt in red-yellow, red, and dark-red Cerrado topsoils.

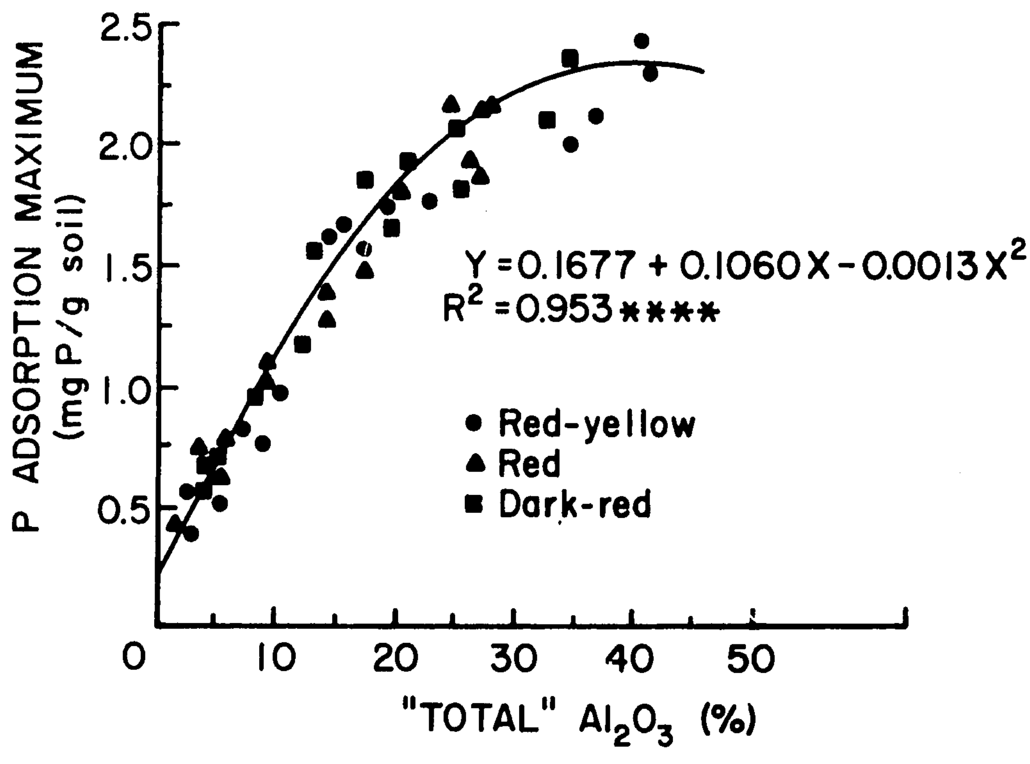



Figure 3.10:10. Relationship between P adsorption maximum and "total" $Al_2O_3$ in red-yellow, red, and dark-red Cerrado topsoils.

Table 3.10:7. Phosphorus adsorption maxima (mg P/g soil) in cerrado topsoils - by texture and by color.

| Texture | Color | | | Avg by texture |
|---|---|---|---|---|
| | Red-yellow | Red | Dark-red | |
| % clay | ---------- mg P/g soil ---------- | | | |
| 18 | 0.572 | 0.642 | 0.671 | 0.629 |
| 18-35 | 1.248 | 1.139 | 1.110 | 1.166 |
| 35-60 | 1.717 | 1.696 | 1.847 | 1.752 |
| 60 | 2.206 | 1.988 | 2.058 | 2.084 |
| Avg by color | 1.435 | 1.366 | 1.422 | |

Table 3.10:8. Phosphorus sorbed (ppm) at 0.2 ppm P in soil solution in cerrado topsoils - by texture and by color.

| Texture | Color | | | Avg by texture |
|---|---|---|---|---|
| | Red-yellow | Red | Dark-red | |
| % clay | ---------- ppm ---------- | | | |
| 18 | 94.7 | 117.2 | 118.9 | 110.2 |
| 18-35 | 239.5 | 211.7 | 204.6 | 218.6 |
| 35-60 | 346.5 | 382.4 | 401.7 | 376.8 |
| 60 | 503.6 | 394.8 | 459.5 | 452.6 |
| Avg by color | 296.0 | 276.5 | 296.2 | |

Table 3.10:9. Phosphorus buffering capacity between 0.05 - 0.2 ppm P in soil solution (ppm) in Cerrado topsoils - by texture and by color.

| Texture | Color | | | Avg by texture |
|---|---|---|---|---|
| | Red-yellow | Red | Dark-red | |
| % clay | ppm | | | |
| 18 | 28.0 | 29.3 | 34.9 | 30.7 |
| 18-35 | 72.9 | 62.9 | 60.9 | 65.6 |
| 35-60 | 106.7 | 113.2 | 120.1 | 113.3 |
| 60 | 175.9 | 131.0 | 149.5 | 152.1 |
| Avg by color | 95.9 | 84.1 | 91.3 | |

and P buffering capacity were developed by using stepwise multiple regression analysis that included selected charge, mineralogical and textural characteristics and also, properties determined with a 1.47 density $H_2SO_4$ extraction. In all cases, soil characteristics determined after extraction with 1.47 density $H_2SO_4$ explained more of the variation in the P parameters than other soil properties studied. The following are some of these prediction models:

P adsorption maximum (mg P/g soil) = 0.5348 + 0.8981 positive charge (me/100 g) + 0.1532 amorphous $Al_2O_3$ (%) + 0.0184 gibbsite (%)
$R^2$ = 0.899****

P adsorption maximum (mg P/g soil) = 0.1732 + 0.0913 "total" $Al_2O_3$ (%) + 0.0192 ["total" $Al_2O_3$ (%)]$^2$
$R^2$ = 0.962****

P sorbed at 0.2 ppm P in solution (mg P/g soil) = 0.0802 + 0.0090 gibbsite (%) + 0.2468 positive charge (me/100 g)
$R^2$ = 0.830****

P sorbed at 0.2 ppm P in solution (mg P/g soil) = 0.0451 + 0.0128 "total" $Al_2O_3$ (%) + 0.0118 "total" $Fe_2O_3$ (%) + 0.0080 "total" $SiO_2$ (%)
$R^2$ = 0.867****

P buffering capacity between 0.05 and 0.2 ppm (ppm) = 115.8855 – 1.0520 sand (%) + 2.5508 gibbsite (%)
$R^2$ = 0.871****

P buffering capacity between 0.05 and 0.2 ppm (ppm) = 2.9016 + 3.8665 "total" $Al_2O_3$ (%) + 3.0213 "total" $Fe_2O_3$ (%)
$R^2$ = 0.898****

These prediction models indicated that data from the 1.47 density $H_2SO_4$ extraction could be used for purposes other than soil classification. They are available in all soil profile descriptions in Brazilian Soil Surveys.

From the practical agronomic point of view, the clay content is certainly the best single predictor for the P fixation capacity in the Cerrado soils. By using the linear and quadratic terms for clay the $R^2$ was 0.915.**** This regression model was as follows:

P adsorption maximum (mg P/g soil) = -0.0009 + 0.0507 clay (%) – 0.0003 [clay (%)]$^2$

When considering variables pairwise "total" $Al_2O_3$ (%), "total" $Fe_2O_3$ (%) and free $Fe_2O_3$ (%) versus some of the P characteristics studied, the observed values for the red-yellow topsoils showed a different slope in the regression equation when compared with red and dark-red topsoils (Figs. 3.10:10, 3.10:11 and 3;10:12). This suggested that red-yellow topsoils fixed more P than the other two groups at the same level of "total" $Fe_2O_3$ and free $Fe_2O_3$ in the soil. This did not mean however, that red-yellow topsoils actually fix more P than red or dark-red topsoils. There is not a significant difference in the mean P adsorption maxima and/or mean P sorbed at 0.2 ppm P in solution among these three topsoil color groups (Tables 3.10:7 and 3.10:8). The reason for this could be the lower mean levels of "total" $Fe_2O_3$ and free $Fe_2O_3$ for the red-yellow topsoils as compared with that for red and dark-red topsoils.

Zinc

The levels of "total" 1.47 density $H_2SO_4$ extraction and extractable Zn (0.05 N HCl + 0.025 N $H_2SO_4$, 0.1 N HCl, 1% $Na_2$ EDTA, or DTPA – TEA) were more related to differences in topsoil texture than to those in topsoil color. "Total" Zn ranged from 1.25 to 66.25 ppm with a mean of 16.92 ppm. The range for extractable Zn over all four soil extractants was much more narrow (0.08 to 1.12 ppm Zn) than for the range in "total" Zn. Irrespective of extractant solution, the overall mean value of Zn was below 0.5 ppm. Only two out of 44 samples had more than 1 ppm Zn by one or more extractants. This suggested a high probability of response to Zn fertilizers in most of these soils.

Prediction model for "total" Zn as extracted by 1.47 density $H_2SO_4$ by using soil characteristics was as follows:

"Total" zinc (%) = –1.1929 + 7.4186 "total" $TiO_2$ (%) + 87.0696 "total" $P_2O_5$ (%) + 0.8131 "total" $SiO_2$ (%)
$R^2 = 0.698^{****}$

Prediction models for levels of extractable Zn were not as precise as those for P parameters. The best prediction model considering the four extracting solutions was:

N. C. double acid extr. Zn (ppm) = 0.4386 + 0.1150 extr. P (ppm) + 0.2224 exch. Ca (me/100 g) – 0.0983 eff. CEC (me/100 g) – 0.0021 sand (%)
$R^2 = 0.694^{****}$

The lack of adequate ability to predict soils and areas most likely to be deficient in Zn, the variability in levels of extractable Zn, and the almost complete lack of calibration studies indicate an urgent need for work toward inclusion of extractable Zn in soil testing programs in Brazil.

Soil Factors Limiting Agricultural Development of Cerrado Area

This section of this report is an attempt to integrate the knowledge about limiting factors for advanced agriculture in Cerrado soils. These limiting factors have been identified as: Seasonality of rainfall, poor rainfall distribution in the rainy season, low levels of P and most other nutrients, relatively high P fixation capacity, high Al saturation, and low available water-holding capacity.

Data previously presented indicate that soils with less than 18% clay, even though low in P fixation, have rather severe restrictions due to low available water-holding capacity. Loams and clays have rather similar available water. Soils with more than 35% clay can become restrictive by their relatively high P fixation capacities.

Loamy soils (18 to 35% clay) should have the least limitation for non-irrigated crop production. Soils with 35 to 60% clay will require rather high initial rates of P fertilizers and should be considered second in priority. Soils with more than 60% clay would probably be third and those with less than 18% clay would definitely be lowest in priority.

Adequate lime rates and depth of lime incorporation, reducing Al saturation below the topsoil, selection of species and varieties tolerant to low available water and to high Al saturation and low P, and time of planting and crop sequence are also essential points to be considered to increase the probability of success for non-irrigated crop production in the Cerrado area.

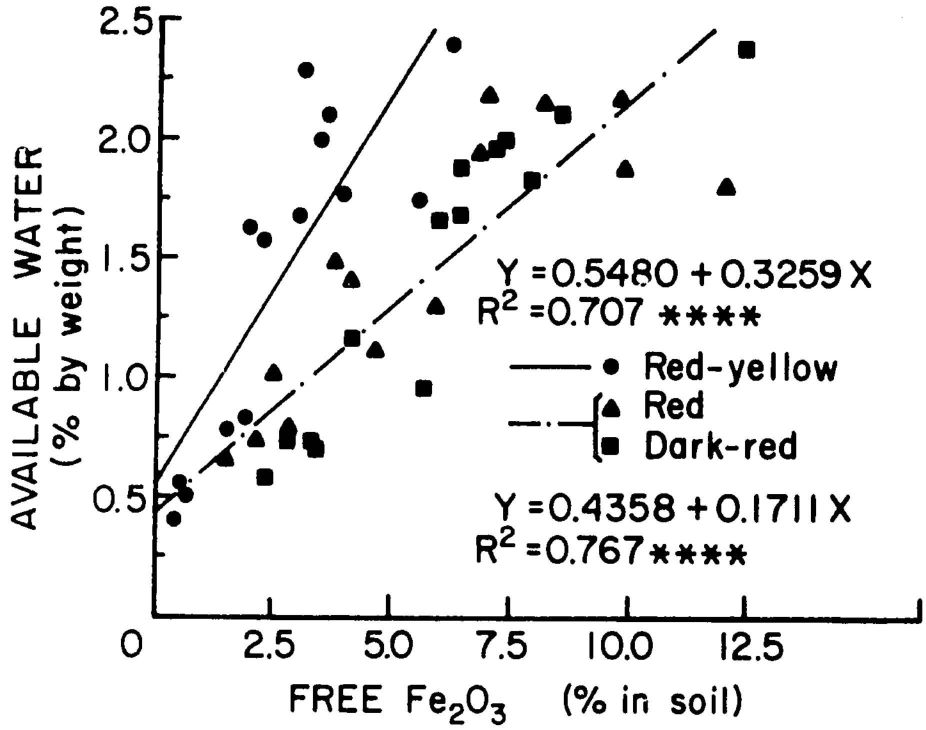



Figure 3.10:11. Relationship between P adsorption maximum and free $Fe_2O_3$ in red-yellow, red. and dark-red Cerrado topsoils.

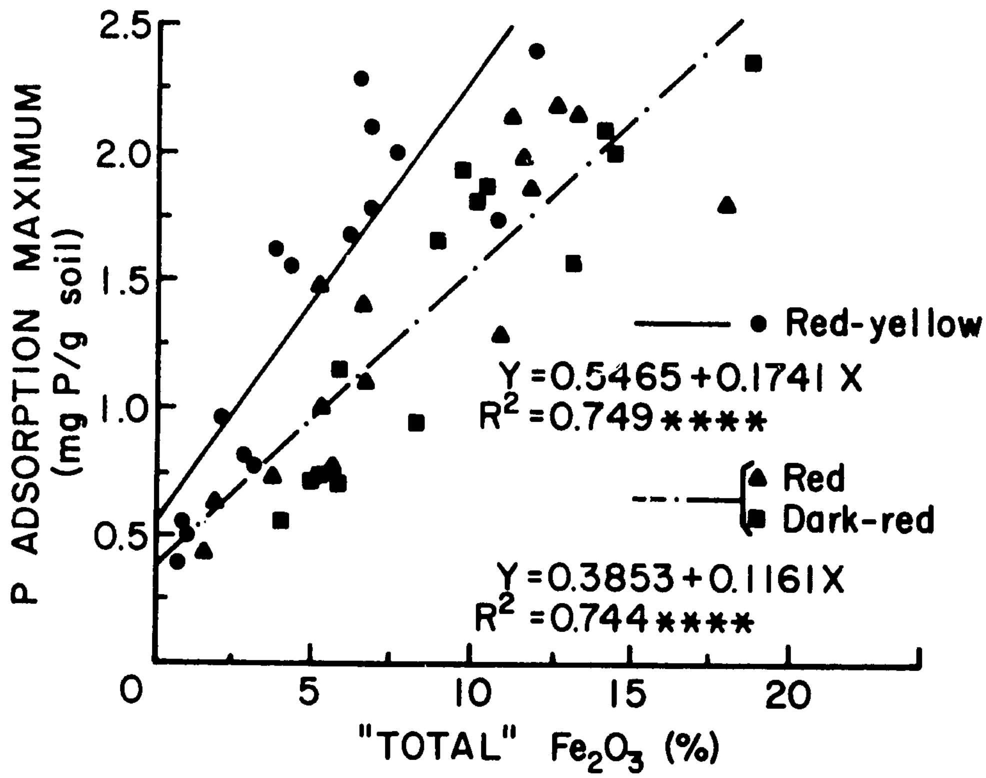



Figure 3.10:12. Relationship between P adsorption maximum and "total" $Fe_2O_3$ in red-yellow, red, and dark-red Cerrado topsoils.

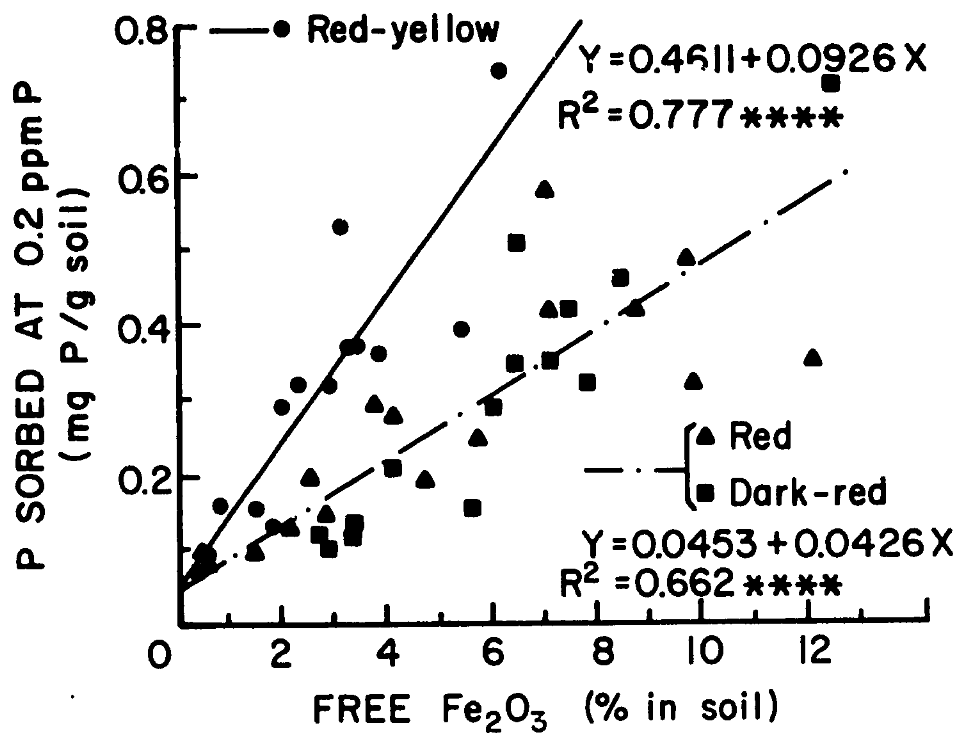



Figure 3.10:13. Relationship between P sorbed at 0.2 ppm P in soil solution and free $Fe_2O_3$ in red-yellow, red, and dark-red Cerrado soils.

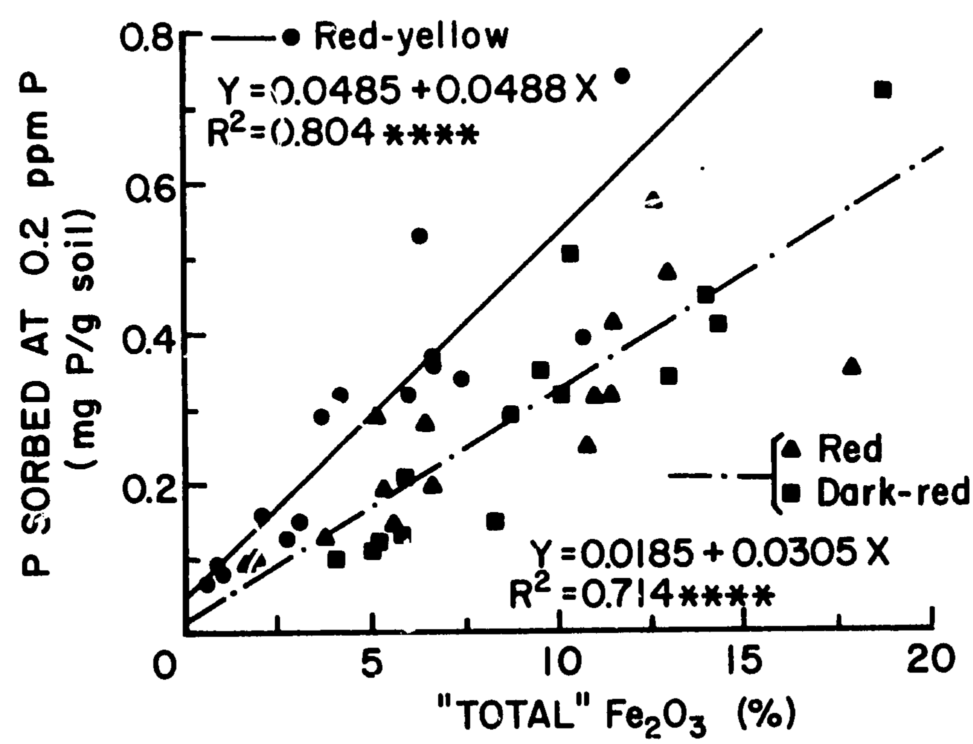



Figure 3.10:14. Relationship between P sorbed at 0.2 ppm P in solution and "total" $Fe_2O_3$ in red-yellow, red, and dark-red Cerrado topsoils.

# INTERCROPPING

Corn and soybeans intercropped at Plymouth, North Carolina.

For the last two years (1975 and 1976), research on intercropping annual field crops has been conducted at NCSU and at North Carolina agriculture experiment stations. This intercrop research has had two main objectives, which were to investigate the following questions:

1. How does the productivity and response to nitrogen of the following intercrops, corn—soybeans, corn—snapbeans, and corn—sweet potatoes, compare to the same crops in monoculture?

2. How can the productivity of intercrops and monocultures be compared?

These issues are discussed in the following two articles.

## 4.1 INTERCROPPING RESEARCH IN NORTH CAROLINA

A. Cordero and R. E. McCollum

Field experiments involving interplanted annual food crops were conducted at two locations each year during 1975 and 1976. Although the local research evolved from the Tropical Soils Research Program, significant financial support has been provided through ARS—USDA.[1]

Procedures in Brief

Imposed treatments included intercrop systems in factorial combination with N rates. In all instances, corn was the "base" crop; and soybeans, snapbeans (*Phaseolus vulgaris*), or sweet potatoes (*Ipomoea batata*) was the interplanted "understory" species. For most interplanting treatments, the normal (97 cm) row pattern was altered to provide for increased light penetration into the corn leaf canopy (Figs. 4.1:1 and 4.1:2). In 1975, however, one treatment consisted of normal-row corn (97 cm) with soybeans planted between the rows ("CSBNR," Table 4.1:1, Fig. 4.1:3). Planting patterns employed and approximate time-sequences are shown in Fig. 4.1:3. At all but one site, four N rates were used; these varied from 0 to 252 or 270 kg/ha in 84- or 90-kg increments. Plant populations differed among sites, but there was no imposed population variable within a given experiment. All operations except the final harvest were performed with conventional farm machinery. One supplemental irrigation was applied at each site in 1975. No supplemental water was applied in 1976, but a prolonged moisture stress during ear formation at one site (Clinton) reduced potential corn yields substantially.

Results

Plymouth, 1975. Mean yields (four replications) of grain and total biomass for the full treatment array are shown in Table 4.1:1. Corn yields were maximal with about 170 kg N/ha, regardless of cropping system (Fig. 4.1:4). In the paired-row system, monoculture corn yields were about 86% of the normal-row monoculture check; another 5-6% reduction resulted when soybeans were planted between row pairs. Soybean yields in the paired-row interplanting system were 55%

[1]The continued support by ARS, through Dr. G. R. Burns, is gratefully acknowledged.

# SEED BED PREPARATION AND ROW ARRANGEMENT OF PLOTS USED FOR INTERCROPPING STUDY. PLYMOUTH, N.C. 1975-76.

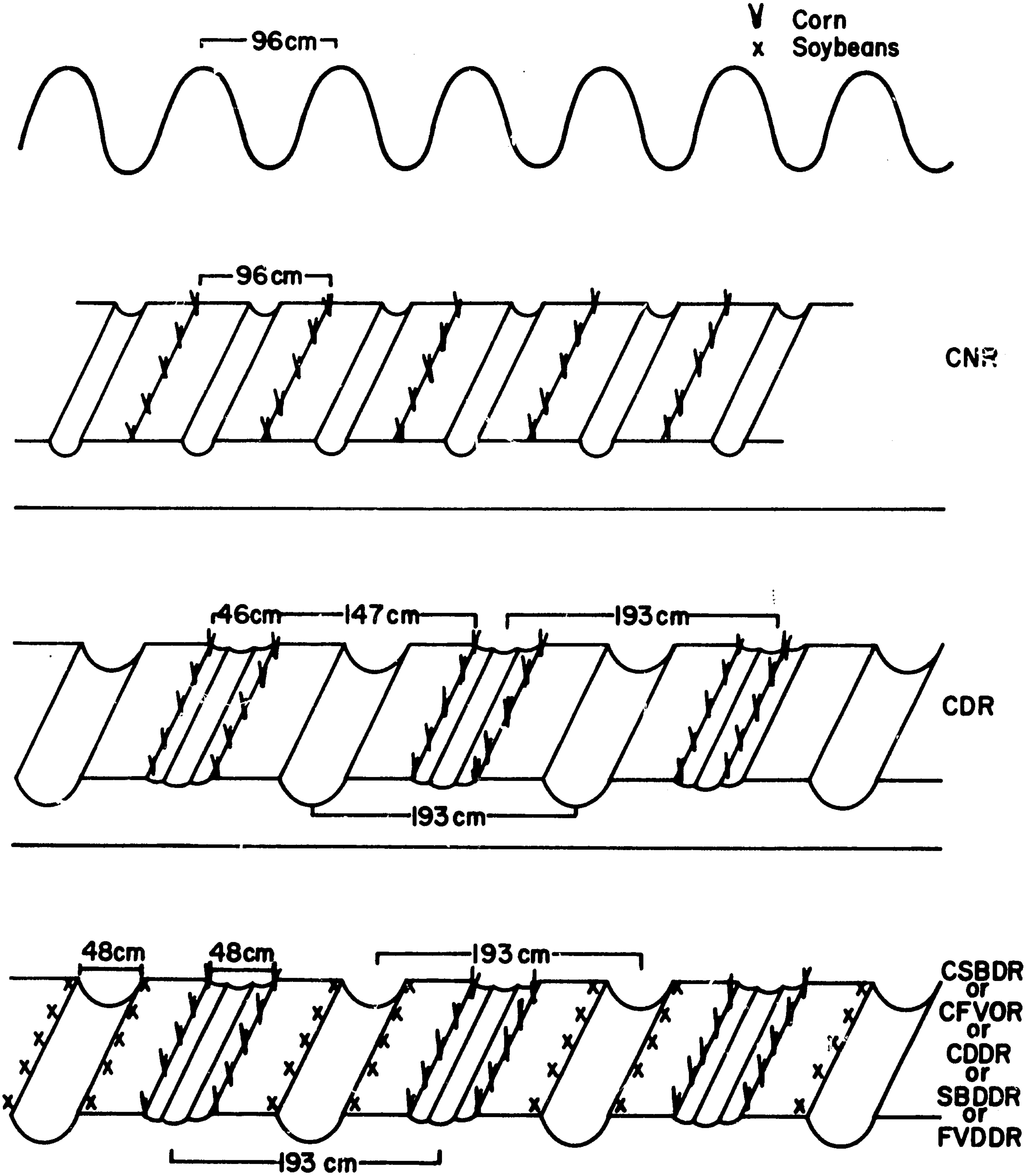



Figure 4.1:1. Seed bed preparation and row arrangement of plots used for intercropping study. Plymouth, North Carolina, 1975-1976.

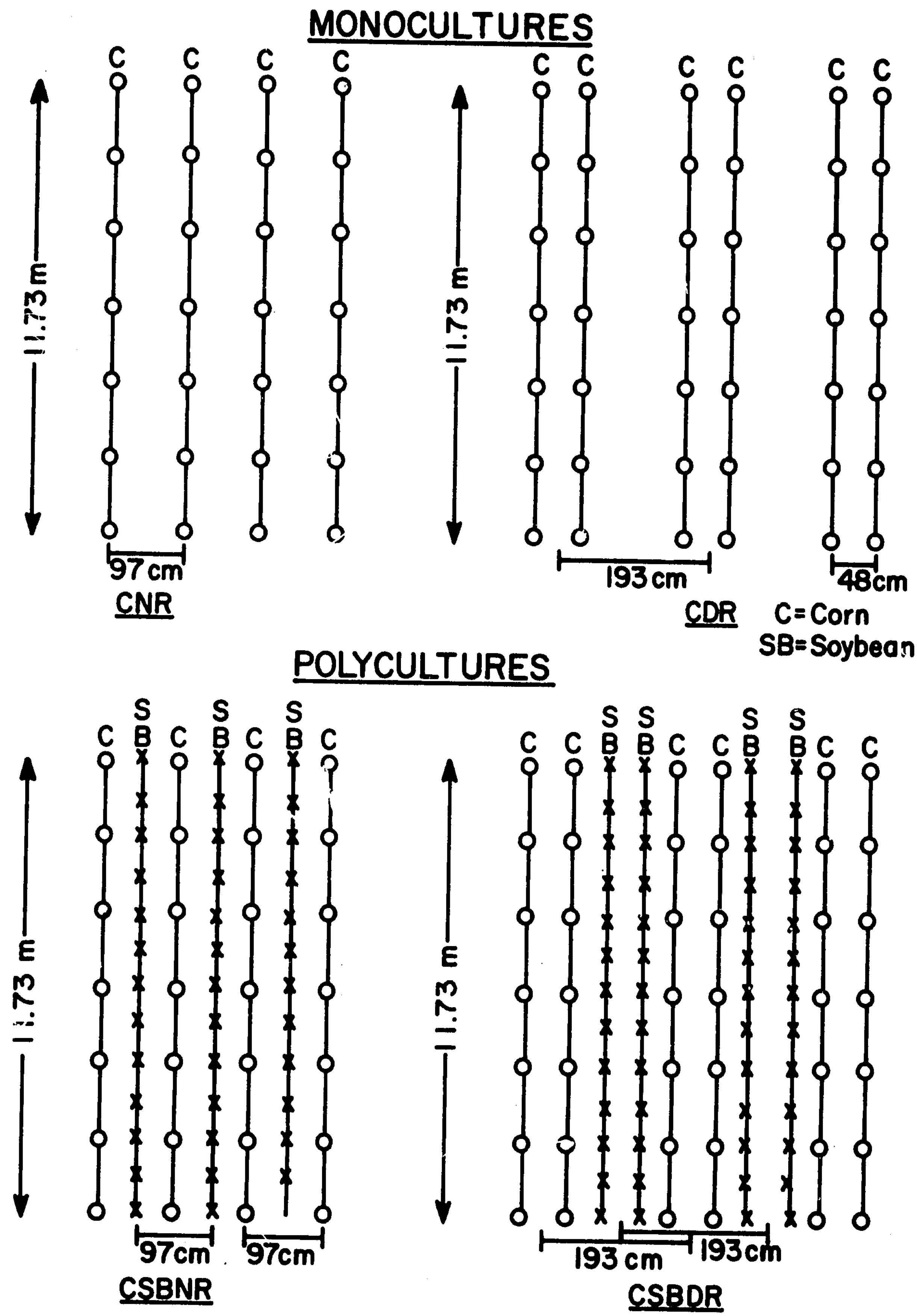



Figure 4.1:2. Size and shape of the plots used in the intercropping experiment. Plymouth, North Carolina, 1975-1976.

Table 4.1:1. Response of corn and soybeans in monoculture and polycultures to different N rates for the variables of corn yield, soybean yield, gross income, and total biomass, Plymouth, 1975

| Tr. no. | Planting pattern | N | Grain Yield Corn[a/] | Soybean[b/] | Total | Gross Value[c/] | Total biomass at 173 day |
|---|---|---|---|---|---|---|---|
| | | kg/ha | ------- t/ha | | --------- | $/ha | t/ha |
| 1 | CNR[d/] | 0 | 3.88 | -- | 3.88 | 419 | 7.81 |
| 2 | | 84 | 6.82 | -- | 6.82 | 737 | 11.60 |
| 3 | | 168 | 7.62 | -- | 7.62 | 823 | 14.92 |
| 4 | | 252 | 7.92 | -- | 7.92 | 856 | 14.65 |
| 5 | CDR | 0 | 3.84 | -- | 3.84 | 415 | 8.19 |
| 6 | | 84 | 5.43 | -- | 5.43 | 586 | 12.49 |
| 7 | | 168 | 6.64 | -- | 6.64 | 717 | 13.84 |
| 8 | | 252 | 6.73 | -- | 6.73 | 726 | 10.48 |
| 9 | CSBNR | 0 | 4.01 | 1.15 | 5.15 | 668 | 12.15 |
| 10 | | 84 | 6.36 | 0.91 | 7.27 | 873 | 14.84 |
| 11 | | 168 | 7.18 | 0.64 | 7.82 | 908 | 16.35 |
| 12 | | 252 | 6.61 | 0.78 | 7.39 | 875 | 17.21 |
| 13 | CSBDR | 0 | 4.87 | 1.64 | 6.51 | 865 | 13.47 |
| 14 | | 84 | 5.77 | 1.47 | 7.24 | 926 | 19.84 |
| 15 | | 168 | 5.59 | 1.70 | 7.29 | 954 | 15.86 |
| 16 | | 252 | 5.32 | 1.48 | 6.79 | 878 | 13.63 |
| 17 | SBNR | 0 | -- | 2.77 | 2.77 | 571 | 6.52 |
| 18 | | 168 | -- | 2.92 | 2.92 | 602 | 7.56 |
| | | | | Means | | | |
| | CNR[d/] | 126 | 6.56 | -- | 6.56 | 709 | 12.25 |
| | CDR | 126 | 5.66 | -- | 5.66 | 611 | 11.25 |
| | CSBNR | 126 | 6.04 | 0.87 | 6.91 | 831 | 15.13 |
| | CSBDR | 126 | 5.39 | 1.57 | 6.96 | 905 | 15.70 |
| | SBNR | 84 | -- | 2.85 | 2.85 | 586 | 7.05 |
| CV % | | | 15.17 | 25.41 | | 16.43 | 18.90 |
| LSD, Tr. 0.05 | | | 1.28 | 0.57 | | | |
| LSD, Tr. 0.01 | | | 1.71 | 0.77 | | | |

[a/] 15.5% moisture.

[b/] 13.5% moisture.

[c/] Gross value =(value of corn + value of soybean),

[d/] CNR = corn normal row (rows 96 cm); CDR = corn double row (pairs of rows every 193 cm); CSBNR = corn soybean normal row; CSBDR = corn soybean double row and SBNR = soybean normal row.

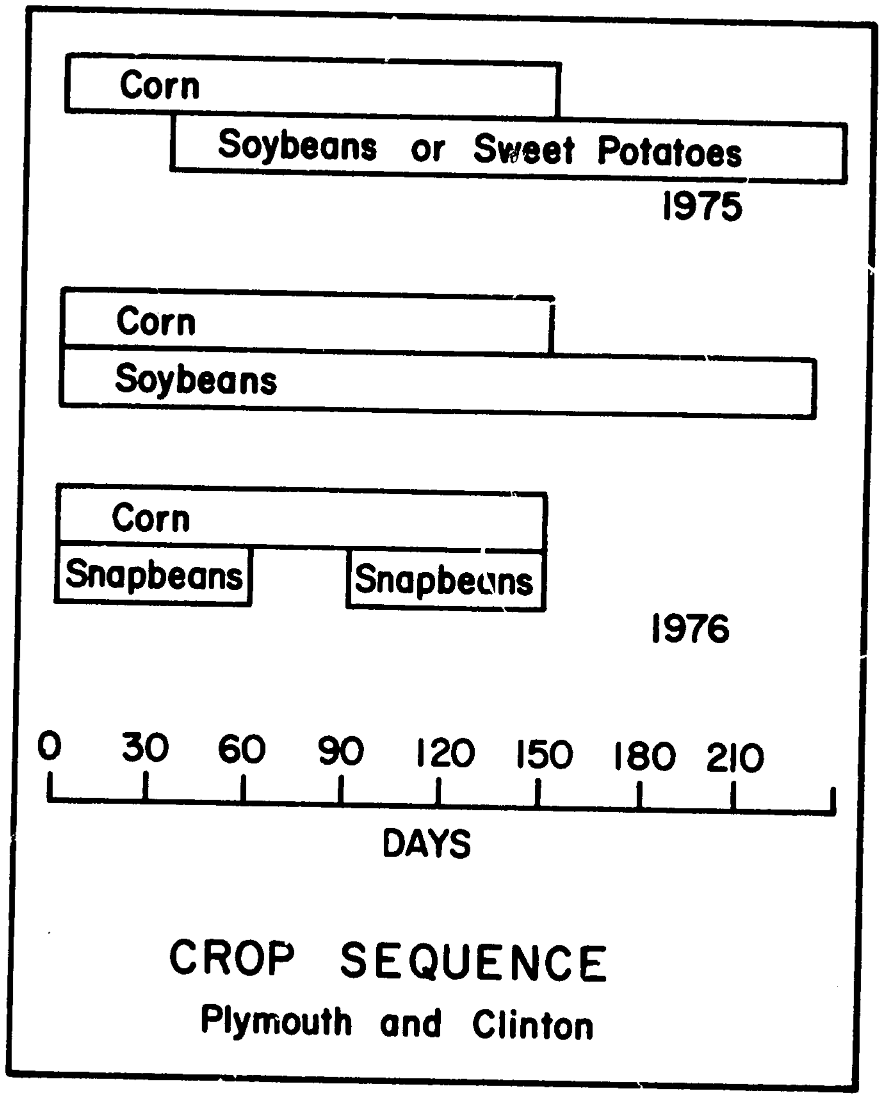



Figure 4.1:3. Planting patterns and time sequences employed in intercropping studies. Plymouth and Clinton, North Carolina, 1975-1976.

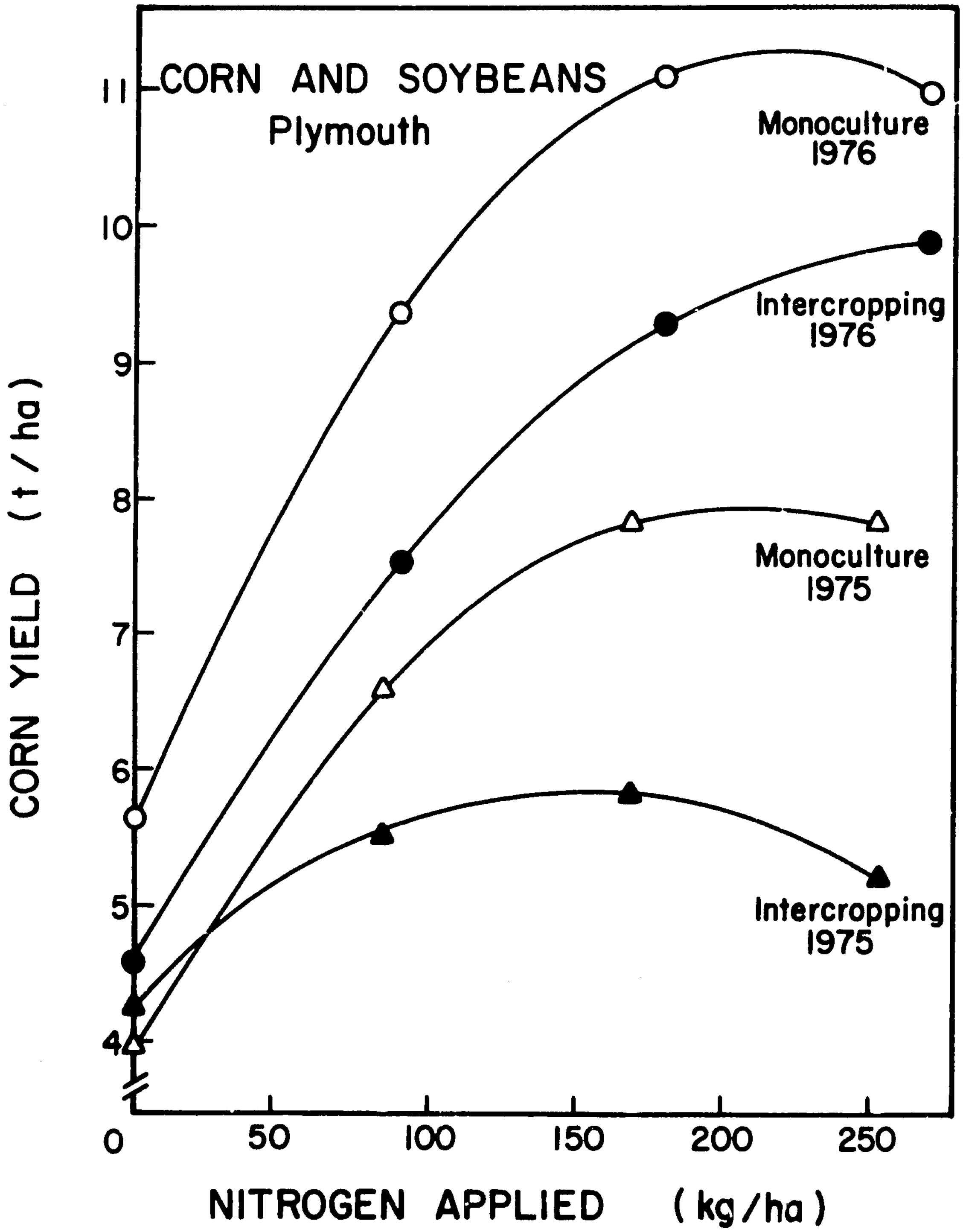



Figure 4.1:4. Corn yields under monoculture and intercrop systems. Plymouth, North Carolina, 1975-1976.

of the normal-row monoculture check; they were only about 25% of "normal" when planted into corn with 97 cm between rows (Table 4.1:2).

Clinton, 1975. Corn yields were not measurably reduced by interplanting sweet potatoes in corn, but yields of interplanted sweet potatoes were only about 10% of the monoculture check (Table 4.1:2). The herbicide used ("Vernam plus") gave good weed control until corn was nearly mature, but late-season grasses became competitive with sweet potatoes during August and September.

Results at Clinton also suggested a degree of "nutritional incompatibility" between corn and sweet potatoes. For example, when corn was fertilized with enough N to maximize yields, the interplanted sweet potatoes produced luxurious vine growth but few enlarged roots. At the low-N extreme, on the other hand, interplanted sweet potatoes had enlarged roots quite early in the growing period.

Plymouth, 1976. Main effects of planting system on yields of corn, snapbeans (fresh pods), and soybeans are shown in Table 4.1:3. The percentage reduction in corn yield due to altering the conventional row pattern was the same order of magnitude as in 1975, and a further reduction occurred when soybeans or snapbeans were interplanted in corn. But interplanted soybeans produced only about 33% of the monoculture check (versus a 55% yield in 1975). Snapbean yields, on the other hand, were about 55% of the monoculture check. It should be pointed out that the snapbeans at Plymouth were harvested some 3-5 days earlier than they should have been for optimal yields of fresh pods.

Clinton, 1976. Although the potential yield of corn at this site was obviously reduced by severe moisture stress during grain formation, the paired-row arrangement (both in the monoculture check and with interplanted soybeans or snapbeans) resulted in about the same percentagewise reduction in yield as at Plymouth (Table 4.1:4). Because snapbeans matured before the drought, yields of this crop were not seriously affected. Similarly, soybean yields were not drastically reduced by drought because the dry period did not extend into the principal seed-filling stage of this species (August-September). Results of this nature point-up the "insurance factor" provided by interplanting species with differing "critical periods" for moisture.

Efficiency index. All of the data generated by these experiments show that productivity (whether biological or economic) can be increased by forcing economic species to compete interspecifically. The increase in economic yield was in the order of 25-45% as calculated by Land Equivalent Ratio (Table 4.1:5).

## 4.2 COMPARING INTERCROPS WITH MONOCULTURES

C. Hiebsch

Intercropping is a crop management system which involves growing two or more crops together for at least a portion of their growing season and at sufficiently close spacing so that competition between the crops occurs

Table 4.1:2. Main effects of planting systems on yields of corn (C), soybeans (SB), and sweet potatoes (SP). 1975.

| Crop and row pattern[1/] | YIELD | | | |
|---|---|---|---|---|
| | Plymouth | | Clinton | |
| | C | SB | C | SP |
| | ---------- metric tons/ha ------------ | | | |
| $C_m$ (97 cm) | 6.59 | -- | 6.96 | -- |
| $C_m$-PR (46 cm/147 cm) | 5.64 | -- | 6.90 | -- |
| $CSB_i$-ALT (48 cm/48 cm) | 6.02 | 0.87 | -- | -- |
| $CSB_i$-PR (46 cm /147 cm) | 5.39 | 1.55 | -- | -- |
| $CSP_i$-ALT (48 cm/48 cm) | -- | -- | 6.84 | 2.58 |
| $CSP_i$-PR (46 cm/147 cm) | -- | -- | 7.02 | 2.80 |
| $SB_m$ (97 cm) | -- | 2.82 | -- | -- |
| $SP_m$ (97 cm) | -- | -- | -- | 28.00 |
| LSD (.05) | 0.69 | 0.40 | 0.75 (N.S.) | 5.94 |

[1/] m = monoculture; i = intercrop; PR = paired rows; ALT = alternate rows

Table 4.1:3. Effect of planting system on yields of corn (C), soybeans (SB), and snapbeans (FV). Plymouth, 1976.

| Planting pattern[1/] | Yield C | SB | FV (fresh pods) |
|---|---|---|---|
| | ---------------- | t/ha | --------------- |
| $C_m$ (97 cm) | 9.28 | -- | -- |
| $C_m$ (48 cm equiv.) | 8.48 | -- | -- |
| $C_m$-PR (46 cm/147 cm) | 8.15 | -- | -- |
| $CSB_i$-PR (46 cm/147 cm) | 7.84 | 0.87 | -- |
| $CFV_i$-PR (46 cm /147 cm) | 7.15 | -- | 3.25 |
| $SB_m$ (97 cm) | -- | 2.82 | -- |
| $SB_m$ (48 cm equiv.) | -- | 2.89 | -- |
| $FV_m$ (97 cm) | -- | -- | 5.82 |
| $FV_m$ (48 cm equiv.) | -- | -- | 7.50 |
| LSD (.05) | 0.82 | 0.20 | 2.80 |

1/ m = monoculture; i = intercropped; PR = paired rows. Numbers in ( ) show approximate spacing between rows or row pairs (see Figures 4.1:1 and 4.1:2).

Table 4.1:4. Effect of planting systems on yields of corn (C), soybeans (SB), and snapbeans (FV). Clinton, 1976.

| Planting pattern[1/] | Yield C | Yield SB | Yield FV |
|---|---|---|---|
| | ---------- t/ha | ---------- | ---------- |
| $C_m$ (97 cm) | 8.66 | -- | -- |
| $C_m$ (48 cm equiv.) | 8.53 | -- | -- |
| $C_m$-PR (46 cm/147 cm) | 7.71 | -- | -- |
| $CSB_i$-PR (46 cm/147 cm) | 6.40 | 1.14 | -- |
| $CFV_i$-PR (46 cm/147 cm) | 7.34 | -- | 7.62 |
| $SB_m$ (97 cm) | -- | 2.69 | -- |
| $SB_m$ (48 cm equiv.) | -- | 2.42 | -- |
| $FV_m$ (97 cm) | -- | -- | 18.14 |
| $FV_m$ (48 cm equiv.) | -- | -- | 12.88 |
| LSD (.05) | 0.94 | 0.27 | 5.71 |

[1/] m = monoculture; i = intercropped; PR = paired rows. Numbers in ( ) show approximate spacing between rows or row pairs (see Figures 4.1:1 and 4.1:2.

Table 4.1:5. Yield of interplanted corn (C), soybeans (SB), and snap-beans (FV) relative to their respective monoculture checks and land equivalent ratio (LER) of the mixture.

| Year (Loc)[3/] | System | Rel. Yield[1/] | | LER[2/] |
|---|---|---|---|---|
| | | C | Other | |
| 1975 (1) | C-SB | 0.80 | 0.55 | 1.35 |
| 1976 (1) | C-SB | 0.84 | 0.30 | 1.14 |
| 1976 (2) | C-SB | 0.74 | 0.48 | 1.22 |
| 1976 (1) | C-FV | 0.77 | 0.44 | 1.21 |
| 1976 (2) | C-FV | 0.85 | 0.59 | 1.44 |
| 1975 (2) | C-SP | 1.01 | 0.09 | 1.10 |

[1/] Relative yield = $\frac{\text{Yield of intercropped species " X "}}{\text{Yield of monoculture " X "}}$

[2/] LER = Summation of relative yields.

[3/] (LOC) (1) - Plymouth
(LOC) (2) - Clinton

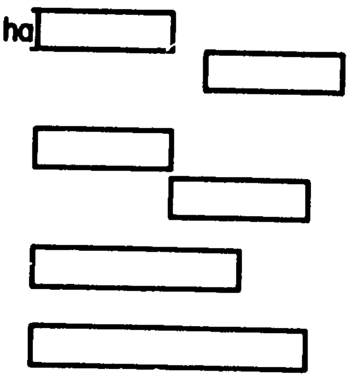
(Andrews and Kassam, 1976). The system is commonly practiced by small farmers in tropical countries. Because of increased efforts to design more productive cropping systems for these farmers and to find methods of increasing world food supplies, interest in quantifying the productivity of intercropped land is high. However, interpreting results of research on intercrops is hampered by the lack of satisfactory methods for comparing yields from mixed plant communities with those obtained when the mixture's components are grown in pure stands, referred to herein as monocultures. The purpose of this discussion is twofold: 1) to point out some inadequacies of methods which have been and are currently in vogue and, 2) to propose an alternative approach which this writer believes will remove some of these inadequacies and thus have wider applicability.

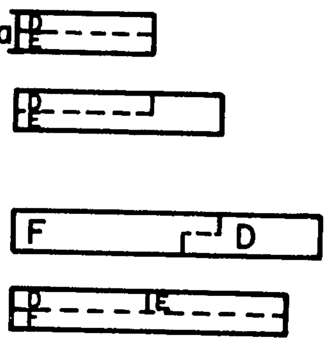
Interpretative difficulties arise because of two characteristics of intercrops and their monoculture checks. Briefly they are: 1) that it is often difficult to make any meaningful comparison of crop "A" with crop "B" and, 2) the time-span that the intercrop and its monoculture checks occupy the land are often not equal. These difficulties will be clarified and discussed through the rest of this article.

Total Yields

In many early reports on intercrops, the performance of the intercrop was evaluated by comparing the total yield of all crops in the intercrop directly with that of the monoculture checks. Since even in monocultures it is seldom possible to compare the yields of crop "A" and crop "B," total production by an "A-B" intercrop has a nebulous meaning. The dilemma is illustrated by some hypothetical yield figures for monocultures D1 and E1 and intercrop I in Fig. 4.2:1. In intercrop I, case a, crops D and E in mixture each yielded less than in pure stand and their total yield was 2.4 metric tons (t)/ha in the intercrop. How is this value to be used in comparing the productivity of the land under the two systems—monoculture versus intercrop? Is it more appropriate to say the intercrop is 20% less productive than monoculture D1, i.e., (100) (2.4 – 3.0)/3.0 = -20%, or 140% more productive than monoculture E1, i.e., (100) (2.4 – 1.0)/1.0 = 140%? It seems that neither is fair. Since the relative values of D and E are not known, it is not known whether the loss of 0.9 t of D (3.0 t D in monoculture – 2.1 t D in intercrop) is worth the gain of 0.3 t of E produced in intercrop.

If crops D and E were planted together with "half of the land to D and half to E" (for example in alternate rows), then perhaps it is more reasonable to compare the yield of the intercrop with the sum of 0.5 ha of D and 0.5 ha of E. If that is true, then in intercrop I, case a, there exists a 20% advantage for the intercrop, i.e., (100) [2.4 – (3.0/2 + 1.0/2)] /(3.0/2 + 1.0/2) = 20%. The problem with assuming the crops were planted at any given ratio is that crops usually differ in their relative competitiveness, and rarely will either crop use its "intended space." If, for example, crop D utilized 70% of the "space" in the ha of intercrop, but the area to which it is being compared is 0.5 ha of monoculture D, it is again necessary to know the relative value of crops D and E to know if the greater-than-expected quantity from D is worth the loss from E.

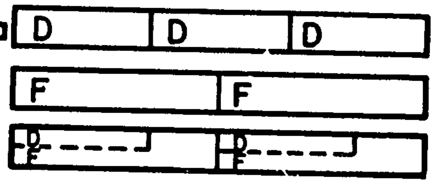





| SYSTEM | Case | Quantity Produced (metric tons): D | E | F | G | Total | LER | ATER |
|---|---|---|---|---|---|---|---|---|
| **Monocultures** | | | | | | | | |
| D 1 1 ha | | 3.0 | | | | 3.0 | | |
| D 2 | | 3.0 | | | | 3.0 | | |
| E 1 | | | 1.0 | | | 1.0 | | |
| E 2 | | | 1.0 | | | 1.0 | | |
| F | | | | 4.0 | | 4.0 | | |
| G | | | | | 2.5 | 2.5 | | |
| **Intercrops** | | | | | | | | |
| I 1 ha | a. | 2.1 | 0.3 | | | 2.4 | 1.00 | 1.00 |
| | b. | 1.2 | 0.6 | | | 1.8 | 1.00 | 1.00 |
| II | a. | 0.9 | | 3.4 | | 4.3 | 1.15 | 1.05 |
| | b. | 2.25 | | 2.0 | | 4.25 | 1.25 | 1.00 |
| | c. | 3.0 | | 1.0 | | 4.0 | 1.25 | 0.92 |
| III | | 2.17 | | 4.0 | | 6.17 | 1.72 | 1.00 |
| IV | | 1.8 | 0.2 | | 1.5 | 3.5 | 1.40 | 1.00 |

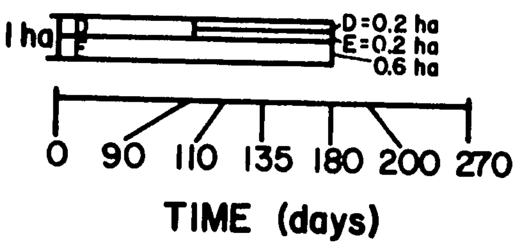
**Interpretive**

1. When time is equal for intercrop IV and monocultures D and F.




| System | Case | D | E | F | G | Total | LER | ATER |
|---|---|---|---|---|---|---|---|---|
| D (1 ha) | | 9.0 | | | | 9.0 | | |
| F | | | | 8.0 | | 8.0 | | |
| Intercrop | a. | 1.8 | | 6.8 | | 8.6 | | 1.05 |
| | b. | 4.5 | | 4.0 | | 8.5 | | 1.00 |
| | c. | 6.0 | | 2.0 | | 8.0 | | 0.92 |

2. Area·time required in monoculture to produce quantities of D, E and F = Intercrop IV.




| D | E | F | G | Total | LER | ATER |
|---|---|---|---|---|---|---|
| 1.8 | 0.2 | | 1.5 | 3.5 | 1.40 | 1.00 |

Figure 4.2:1. Examples of monocultures and intercrops using species D, E, F, and G to illustrate three methods of comparing crop production in these two systems, by summation of component yields, land equivalency ratio (LER), and area-time equivalency ratio (ATER).

Land Requirements

To avoid the problems encountered when comparing the yields or production of 2 or more crops directly, researchers at the International Rice Research Institute have advanced the concept of land equivalency ratio (LER) (IRRI, 1974). For a two component intercrop LER is calculated

$$LER = \frac{y^I_{c1}}{y^M_{c1}} + \frac{y^I_{c2}}{y^M_{c2}} \qquad [1]$$

where y is the yield of either crop 1 (c1) or crop 2 (c2) in either monoculture (M) or intercrop I. Yield (y) is defined as quantity per unit area. For the more general case with any number of components

$$LER = \sum_{c=1}^{N} \frac{y^I_c}{y^M_c} \qquad [2]$$

where y is the yield of crops 1, 2, 3, . . . , N. Two requirements for LER to be valid are that, 1) the monoculture checks be at their optimum populations and, 2) both monocultures and the intercrop be at the same management level.

Since the yield of crop c in intercrop is equal to the quantity (Q) of c in the intercrop per unit area (A) of intercrop $(y^I_c = Q^I_c/A^I)$ and since the yield of c in monoculture is equal to the quantity of c in monoculture per area of c in monoculture $(y^M_c = Q^M_c/A^M_c)$ equation [2] can thus be expanded and then rearranged as follows:

$$LER = \sum_{c=1}^{N} \frac{Q^I_c/A^I}{Q^M_c/A^M_c}$$

$$LER = \frac{1}{A^I} \sum_{c=1}^{N} A^M_c \frac{Q^I_c}{Q^M_c} \qquad [3]$$

In [3] the formula to the right of the summation sign expresses the amount of monoculture land required to produce the same quantity of crop c as was produced in the intercrop. By summing the amount of monoculture land needed for all crops, [3] becomes

$$LER = \frac{A^M}{A^I} \qquad [4]$$

The intended purpose of LER is then to answer the question: How many units of land area are required to produce in monocultures the same quantities of each crop produced by one land area unit of intercrop? According to proponents of LER, an LER greater than 1 indicates more land was required by the monocultures, and thus, the intercrop has greater productivity than the monoculture (this is not always the case as will be demonstrated later).

Using LER as expressed by equation [3] to compare intercrop I, case a, against monocultures D1 and E1 (Fig. 4.2:1).

$$LER = \frac{1}{A^I}\left(\frac{A_D^M \; Q_D^I}{Q_D^M} + \frac{A_E^M \; Q_E^I}{Q_E^M}\right)$$

$$= \frac{1}{1ha}\left[\frac{(1\,ha)(2.1t)}{3.0t} + \frac{(1\,ha)(0.3t)}{1.0t}\right]$$

$$= \frac{1}{1ha}(0.7\,ha + 0.3\,ha) = \frac{1ha}{1ha} = 1$$

We see that 1 ha of land is required either in monoculture or intercrop to produce 2.1 t of D and 0.3 t of E.

For case b of intercrop I (Fig. 4.2:1), the total yield of crops D and E of 1.8 t/ha (1.2 t of D and 0.6 t of E) is 10 percent less than the sum of 0.5 ha of each D and E in monoculture, i.e., (100) [1.8 – (3.0/2 + 1.0/2)] /(3.0/2 + 1.0/2) = -10%. However, an LER of 1 for this case indicates that 1 ha is required either in monoculture or intercrop to produce 1.2 t of D and 0.6 t of E. This is pointed out to reemphasize the potential errors in interpretation if the intercrop is compared directly against arbitrarily chosen amounts of monoculture land area.

Area-Time Requirements

The second interpretative difficulty concerns the time-span of the crops. The number of days from planting until final harvest is usually not the same for the intercrop and all of the monoculture checks. Again referring to Fig. 4.2:1, intercrop II and monoculture F occupy the land for 135 days while monoculture D1 is mature after only 90 days. Crop production is not solely a function of land area, crop, management, and environment, as implied by LER; but it is also related to the duration of crop growth or time. Therefore, where the time-span of the intercrop is different from any of the monoculture checks, it is important to account for this "time effect" upon the productivity of the crops in the two systems.

In the field of monoculture D1, the 45 uncropped, and thus unproductive, days between the maturation of D1 and the harvest of monoculture F and intercrop II could, in theory, be used productively. This additional productive capacity of the monoculture must be considered when comparing the productive potentials of the two systems.

I submit that the effect of time can be accounted for by redefining yield (Y) to be quantity (Q) per unit area (A) per unit time (T), i.e., Y = Q/AT. An area-time equivalency ratio (ATER), can then be calculated

$$ATER = \sum_{c=1}^{N} \frac{Y_c^I}{Y_c^M} \qquad [5]$$

Since the yield of crop "c" in intercrop is equal to the quantity of crop "c" in the intercrop per area-time of the intercrop $Y_c^I = Q_c^I/(AT)^I$, and since the yield of "c" in monoculture is equal to the quantity of "c" in monoculture per area-time of "c" in monoculture $Y_c^M = Q_c^M/(AT)_c^M$, equation [5] can be expanded and rearranged as follows:

$$ATER = \frac{Q_c^I/(AT)^I}{Q_c^M/(AT)_c^M}$$

$$= \frac{1}{(AT)^I} \sum_{c=1}^{N} (AT)_c^M \frac{Q_c^I}{Q_c^M} \quad [6]$$

For each crop "c," $(AT)_c^M Q_c^I/Q_c^M$ calculates the area-time [e.g., hectare-days (ha-dy)] required to produce in monoculture the quantity of "c" produced in the intercrop. A summation of the area-time needed for each crop "c" determines the total area-time required to produce in monoculture what was produced in the intercrop. The ATER is then the ratio of area-time required in monoculture to area-time used in the intercrop, i.e.,

$$ATER = \frac{(AT)^M}{(AT)^I} \quad [7]$$

Where the monocultures are at their optimum populations and spacings, and where the management is equal in both systems, ATER compares the relative productive capacities of the crops in the two systems (at times it may not be desirable to have the same management, i.e., with a legume and a cereal, N fertilizer may be applied only to the monoculture cereal and to the intercrop, and not to the monoculture legume).

To account for the effect of difference in time between intercrop II and monoculture D upon production of the systems (Fig. 4.2:1), ATER is used. To illustrate, ATER for case "a" of intercrop II is calculated by [6]

$$ATER = \frac{1}{(AT)^I}\left[\frac{(AT)_D^M Q_D^I}{Q_D^M} + \frac{(AT)_F^M Q_F^I}{Q_F^M}\right]$$

$$= \frac{1}{(1\,ha)(135\,dy)}\left[\frac{(1\,ha)(90\,dy)(0.9\,t)}{3.0\,t} + \frac{(1\,ha)(135\,dy)(3.4\,t)}{4.0\,t}\right]$$

$$= \frac{1}{135\,ha\text{-}dy}\left[(0.3\,ha)(90\,dy) + (0.85\,ha)(135\,dy)\right]$$

$$= \frac{1}{135\,ha\text{-}dy}(27\,ha\text{-}dy + 114.75\,ha\text{-}dy)$$

$$= \frac{141.75\,ha\text{-}dy\,(monoculture)}{135.00\,ha\text{-}dy\,(intercrop)} = 1.05$$

These calculations show that 0.9 t of D could be grown in monoculture on 0.3 ha in 90 days i.e., $Y_D^M = \frac{0.9\,t}{27\,ha\text{-}dy}$, for a total of 27 ha-dy and that 3.4 t of monoculture F would occupy 0.85 ha for 135 days, or 114.75 ha-dy. To produce 0.9 t of D and 3.4 t of F it would thus require 5% more area-time (ha-dy) in monoculture than in the intercrop. The system using the least area-time can then be referred to being the more productive. In this case it is the intercrop.

One way of visualizing what ATER does is illustrated in interpretative system 1 of Fig.

4.2:1. In this illustration assume that a constant and favorable environment for crop production exists for a season of 270 days duration. Further assume that three crops of monoculture D, 2 crops of monoculture F, or 2 D-F intercrops can be grown sequentially without changes in yields per crop. Under these conditions both time and area are equal. Yields of crops D and F in monoculture are 9 t/ha/270 days and 8 t/ha/270 days, respectively, and, for D and F in the intercrop (case b), they are 4.5 t/ha/270 days and 4.0 t/ha/270 days, respectively. The ATER by equation [5] is

$$\text{ATER} = \frac{Y_D^I}{Y_D^M} + \frac{Y_F^I}{Y_F^M}$$

$$= \frac{4.5\,t/270\text{ ha-dy}}{9.0\,t/270\text{ ha-dy}} + \frac{4.0\,t/270\text{ ha-dy}}{8.0\,t/270\text{ ha-dy}}$$

$$= 1$$

Under these conditions, then 1 ha for 270 dy is needed in each system to produce 4.5 t of D and 4.0 t of F. The productivity of these two systems are, therefore, identical.

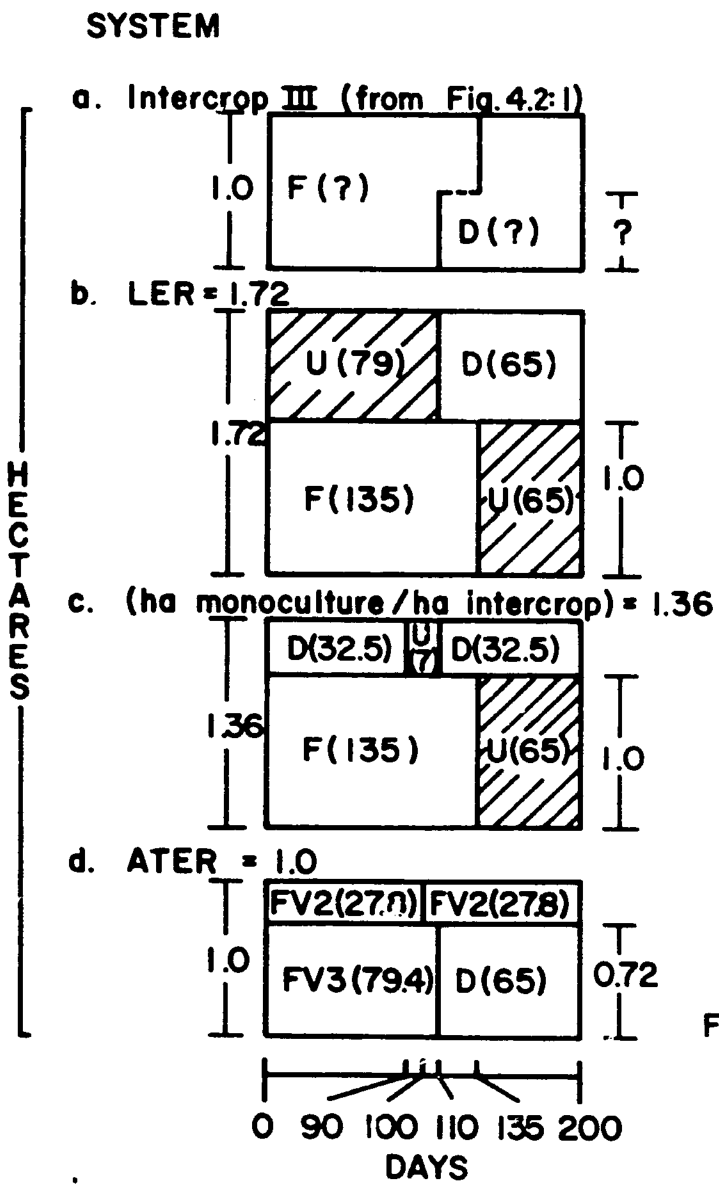
Two-Crop Systems

Let's ignore for a moment the role of time and use LER alone in the analysis of intercrop II in Fig. 4.2:1. We find LER's of 1.15, 1.25, and 1.25 for cases a, b, and c, respectively. These LER's may invoke the following types of interpretations: 1) growing crops D and E in monoculture would require 15, 25, and 25% more land than in intercrops IIa, IIb, and IIc, respectively and, 2) the productivity of intercrops IIb is equal to that of IIc and both are greater than intercrop IIa.

Thus, LER indicates at least a 15% increase in land-use efficiency for intercrops in all three cases of intercrop II (Fig. 4.2:1). Where time is equal in all the monocultures and the intercrop, however, the ATER shows that only case a—where LER is lowest—makes better use of the land (cf., interpretative system 1, Fig. 4.2:1). In fact, an ATER of 0.92 for case c indicates an 8% disadvantage for the intercrop, whereas LER suggests a 25% advantage.

The LER of 1.72 for intercrop III (Fig. 4.2:1) suggests by itself a large (but possibly erroneous) advantage for intercropping. The ATER of 1.0 indicates that theoretically equal quantities of D and F could be produced in monoculture in an equal number of ha-dy, i.e., 200 ha-dy. Which value is real? Fig. 4.2:2a illustrates the use of the land and time in intercrop III of Fig. 4.2:1 and Fig. 4.2:2b portrays the way area and time are used in monoculture to achieve an LER of 1.72. From this illustration it can be seen that land remains unproductive for a substantial amount of time (0.72 ha for 110 dy = 79 ha-dy before the planting of monoculture D, and 1.0 ha for 65 dy = 65 ha-dy after the maturation of monoculture F). The total unproductive ha-dy in the monoculture system (Fig. 4.2:2b) is 144 while the cropped productive ha-dy is 200. Thus, all of the advantage as expressed by LER is due to uncropped, unproductive area-time, i.e., (100) (144 + 200)/200 = 1.72.

The monoculture land could be better utilized by fitting in another crop of D before the original D, thereby only 36% more land is required in monoculture than in the intercrop (Fig. 4.2:2c). This illustrates another major in-




| Crop | Yield t/ha·dy | Yield t/ha | Quantity t | Cropped ha·dy | Bare ha·dy | Total ha·dy | Ratio ha·dy Total: Cropped |
|---|---|---|---|---|---|---|---|
| D | ? | ? | 2.17 | ? | | | |
| F | ? | ? | 4.00 | ? | | | |
| System | | | | 200 | 0 | 200 | 1.00 |
| | | | | | | | |
| D | 0.0333 | 3.0 | 2.17 | 65 | | | |
| F | 0.0296 | 4.0 | 4.00 | 135 | | | |
| System | | | | 200 | 144 | 344 | 1.72 |
| | | | | | | | |
| D | 0.0333 | 3.0 | 2.17 | 65 | | | |
| F | 0.0296 | 4.0 | 4.00 | 135 | | | |
| System | | | | 200 | 72 | 272 | 1.36 |
| | | | | | | | |
| D | 0.0333 | 3.00 | 2.17 | 65 | | | |
| FV2 | 0.0296 | 2.96 | 2.35 | 55.6 | | | |
| FV3 | 0.0296 | 3.26 | 1.65 | 79.4 | | | |
| F total | | | 4.00 | 135 | | | |
| System | | | | 200 | 0 | 200 | 1.00 |

Figure 4.2:2. The area (hectares, ha) by time (days, dy) requirements of Intercrop III from Figure 4.2:1 and three possible monoculture systems, all producing equal quantities of crop species D and F. Two additional varieties of crop F, V2 and V3, appear in section d. Unproductive, bare ha·dy are indicated by U. Numbers or ? in parentheses are the number of ha·dy for that crop or bare soil.

adequacy of LER, i.e., it does not account for the possibility that sequences of monoculture checks may be used for comparison with the intercrop. Neither LER nor ATER describes the type of land use illustrated in Fig. 4.2:2c; it may be desirable in the future to define additional terms which better describe this type of land use.

The point here, however, is that the number of ha-dy cropped in Fig. 4.2:2c to produce equal to the intercrop is still 200 as in the intercrop and the monoculture check represented by Fig. 4.2:2b. The unproductive ha-dy still account for the discrepancy between Fig. 4.2:2c and ATER.

It is most important to be aware that where more total area-time is needed than predicted by ATER, it is due to the relationship between crop maturity and season length and not to differences in "productive capacities" of the crops in the two systems. It is possible to grow in monoculture on 1 ha in 200 days, quantities of D and F equal to the intercrop. This can be achieved by using varieties of D and F which have maturities "compatible with the season" of 200 days and which have yields (Q/AT) equal to the original varieties of D and F. By using two other varieties of crop F, a 100- and a 110-day variety, each with the same yield as the original variety of F (0.0296 t/ha-dy), it is possible to match the performance of the intercrop (Fig. 4.2:2d). It is important to note again that it is the yield (Q/AT) that is constant among the three varieties of crop F and that yield (Q/A) varies with maturation.

More–Than–Two–Crop Systems

Under many circumstances both total yield and LER indicate ever-increasing advantages for the intercrop as the number of intercrop components increases. This phenomena is also a function of time. Imagine an intercrop similar to I (Fig. 4.2:1), but with 5 components all planted together the same date and harvested together 90 days later. The 5-component intercrop and all 5 monoculture checks would occupy the land for the same area-time, thus, LER would equal ATER. Intercrop IV (Fig. 4.2:1), however, occupies the field for 180 days, the same as monoculture G, but twice as long as either monoculture D or E. Just as in the example in Fig. 4.2:2b, LER automatically assumes there is no sequence of monocultures, thus, leaving 90 unproductive days following monoculture D1 and again preceding E2 (Fig. 4.2:1). The advantage of 40 percent for intercrop IV as expressed by LER does not, then, express the productive capacities of just the crops in the two systems. Since the maturity of crops D and E are equal, and together they equal the duration of the intercrop season (hence of monoculture G), it is easy in practice to achieve the theoretical ATER of 1.0 (interpretative system 2, Fig. 4.2:1), by growing 0.2 ha of D and 0.2 ha of E after the 0.4 ha of D.

Total Production, LER, and ATER

Where do total production, LER, and ATER fit into the analysis of an intercrop? Total production can be quickly eliminated from the discussion because it seems to clarify very little.

A method of calculating the amount of land required in monoculture for production equal to the intercrop would be a useful technique. The LER does this for two or more crops in a mixture only where the season under consideration is too short for sequential plantings of any of the monoculture checks or where within-season environmental changes (e.g., dry weather, insect pressures) prevent such sequences. For the general case, which must account for season duration, environmental limitations within the season, and perhaps the use of alternative varieties as in Fig. 4.2:2d, a method has not been developed.

The ATER provides a technique for comparing relative production potentials of the two systems, intercrop versus monoculture. In practice monoculture crops may require more area-time (ha-days), including productive and unproductive area-time, than predicted by ATER because "crop duration" is not synchronized with "season duration." This lack of compatibility between crop and season is of little consequence when the objectives are to quantify the relative productivity of the two systems and then to determine the origin of any differences which may exist. To illustrate, using intercrop IIb in Fig. 4.2:1, let us assume the following: 1) It is desirable for some unspecified reason to produce 2.25 t of D and 2.0 t of F, 2) the season lasts for 135 days and no other crop can be grown after either monoculture, and 3) there are no alternative varieties of D and F. Under these conditions an LER of 1.25 does show that the best use of the land for producing D and F is the D-F intercrop because monocultures would require 25% more land to produce the same quantities of D and F. A cropping-systems researcher, observing intercrop IIb and its monoculture checks, could conclude, based solely upon the LER of 1.25, that the results were due to a "beneficial interaction" of the crops when mixed (e.g., more efficient use of solar radiation or more complete exploiting of the soil volume for water and nutrients). Such a conclusion could misdirect a whole research program. Variety trials may be set up to improve upon this "beneficial interaction" or solar radiation and root measurements may be taken to discover its origin. If, however, the researcher had been aware of the role of time, he would have known, based on an ATER of 1.0, that the advantage in the intercrop in terms of land use was due wholly to .75 ha, i.e., (2.25 t/300 t) (1 ha) = .75 ha, being left bare and unproductive for 45 days, i.e., (.75 ha) (45 dy) = 33.75 ha-dy, (100) (33.75 ha-dy/ (134 intercrop ha-dy) = 25%.

Neither LER nor ATER can be used alone for making recommendations to farmers because neither term directly evaluates other important management factors, such as pest control, fertilizer use efficiency, soil erosion, labor requirements, or socio-economics. They are, however, two of several important quantities necessary in the comparison of intercrops with monocultures.

<u>Literature Cited</u>

Andrews, D. J. and A. H. Kassam. 1976. The importance of multiple cropping in increasing world food supplies. p. 1-10 <u>In</u> Papendick, R. I., P. A. Sanchez, and G. B. Triplett (eds.) Multiple Cropping. American Society of Agronomy, Madison, Wisconsin.

International Rice Research Institute. 1974. Annual Report for 1973. Los Baños, Philippines. p. 16.

SOIL CHARACTERIZATION

Dr. Stanley Buol, after collecting characterization data, prepares to photograph the soil profile of an Ultisol.

## 5.1 INFLUENCE OF IRON OXIDES ON SOIL COLOR

J. M. Bigham and S. W. Buol

The nature and distribution of iron oxide minerals in selected soil materials from Brazil and North Carolina have been studied in detail. The objective of this study was to evaluate the influence of iron oxides on several soil chemical and physical properties, especially soil color.

Pairs of red and yellow soils that, aside from B-horizon coloration, are as similar as possible in their chemical, physical, and mineralogical properties were sampled. Members of each sample pair occurred in close proximity on the landscape and appeared to be developing from similar parent materials. Sample pairs included a red-yellow Ustox (5YR) and a dark red Ustox (2.5YR) from the Central Plateau of Brazil, a Norfolk (10YR) soil and an Orangeburg (5YR) soil (Paleudults) from the Coastal Plain of North Carolina, and an Appling (7.5YR) soil and a Cecil (2.5YR) soil (Hapludults) from the North Carolina Piedmont. A single Davidson (2.5YR) profile (Rhodic Paleudult) was also sampled for comparative purposes. Homogeneously colored material from the B-horizon of each of these soils was analyzed.

### Iron and Color Distribution

The selected soil materials were dispersed ultrasonically utilizing 1N NaOH as a dispersant and subsequently were fractionated by standard sieve and sedimentation techniques. The iron content and color of the resulting size fractions are presented in Table 5.1: 1.

In general, the iron content increased with decreasing particle size. The relatively high value obtained for the >50μm fraction of the red-yellow Ustox was due to sand-sized nodules or iron oxides which resisted dispersion. In every case, most of the non-concretionary iron was concentrated in the fine clay ( < 0.2 μm) fraction. Since the colors of the fine clays corresponded closely with those of the whole soil materials and since the <0.2μm fractions constituted much simpler systems than did the whole soils, almost all chemical, physical, and mineralogical analyses were restricted to this fraction.

### Composition of the <0.2μm Clays

Chemical data obtained by total and selective dissolution techniques are shown in Table 5.1: 2. The < 0.2μm clays from all seven soils were, in general, quite similar in their total content of Fe, Al, and Si. Only in the Davidson clay was a significant amount of Mn detected, and most of this appeared to be citrate-bicarbonate-dithionite (CBD) extractable.

Substantial amounts of Al were also obtained in the CBD extracts. Current literature suggests that natural iron oxides seldom occur in pure form and, even though other sources cannot be excluded, much of the Al detected in the CBD extracts was probably derived from the iron oxides.

The amount of Si extracted with both CBD and acid ammonium oxalate was quite low. Oxalate also appeared to be a rather mild extractant of Fe and Al in these materials. If, as the literature implies, acid ammonium oxalate

Table 5.1:1. Iron content and color of selected particle size fractions.

| Size Fraction | Weight Fraction | Fe | Weight Fraction x %Fe | Munsell Color Moist | Munsell Color Dry |
|---|---|---|---|---|---|
| um | % | -------- % | --------- | | |
| | | Red-Yellow Ustox B1 (5YR 4/8, 7.5YR 5/8) | | | |
| >50 | 0.920 | 9.78 | 2.84 | 7.5RY 4/4 | 7.5YR 7/4 |
| 50-20 | 0.103 | 1.76 | 0.18 | 10YR 5/4 | 10YR 7/4 |
| 20-5 | 0.103 | 3.16 | 0.33 | 10YR 4/4 | 10YR 6/4 |
| 5-2 | 0.010 | 9.14 | 0.09 | 7.5YR 4/4 | 10YR 6/6 |
| 2-0.2 | 0.158 | 7.83 | 1.24 | 7.5YR 5/5 | 7.5YR 6/6 |
| <0.2 | 0.337 | 14.17 | 4.78 | 5YR 4/8 | 7.5YR 5/8 |
| <2000 | | 9.23 | 9.46 | | |
| | | Dark Red Ustox, B1 (2.5YR 3/6, 5YR 4/6) | | | |
| >50 | 0.394 | 1.22 | 0.48 | 7.5YR 7/4 | 7.5YR 8/4 |
| 50-20 | 0.072 | 1.34 | 0.10 | 7.5YR 5/4 | 7.5YR 8/4 |
| 20-5 | 0.082 | 2.89 | 0.24 | 7.5YR 4/4 | 7.5YR 6/4 |
| 5-2 | 0.006 | 7.60 | 0.05 | 5YR 3/4 | 7.5YR 6/6 |
| 2.0.2 | 0.104 | 5.68 | 0.59 | 5YR 5/6 | 5YR 6/6 |
| <0.2 | 0.341 | 10.83 | 3.69 | 2.5YR 3/4 | 4YR 4/8 |
| <2000 | | 5.04 | 5.15 | | |
| | | Norfolk B21t (10YR 5/6, 10YR 6/6) | | | |
| >50 | 0.625 | 0.01 | 0.01 | 5Y 6/1 | 5Y 8/1 |
| 50-20 | 0.030 | 0.06 | 0.06 | 5Y 6/1 | 5Y 8/1 |
| 20-5 | 0.035 | 0.43 | 0.02 | 2.5Y 6/2 | 2.5Y 8/2 |
| 5-2 | 0.009 | 1.10 | 0.01 | 2.5Y 6/4 | 2.5Y 8/2 |
| 2-0.2 | 0.086 | 4.04 | 0.35 | 2.5Y 6/4 | 2.5Y 7/4 |
| <0.2 | 0.214 | 6.97 | 1.49 | 10YR 5/6 | 10YR 6.5/8 |
| <2000 | | 1.84 | 1.88 | | |
| | | Orangeburg, B22t (4YR 4/8, 5YR 5/8) | | | |
| >50 | 0.620 | 0.02 | 0.01 | 5Y 6/1 | 5Y 8/1 |
| 50-20 | 0.021 | 0.09 | 0.00 | 10YR 6/1 | 10YR 8/1 |
| 20-5 | 0.026 | 0.40 | 0.01 | 10YR 6/3 | 10YR 8/1 |
| 5-2 | 0.003 | 1.34 | 0.00 | 10YR 5/4 | 10YR 7/2 |
| 2-0.2 | 0.094 | 4.81 | 0.45 | 7.5YR 6/6 | 7.5YR 7/6 |
| <0.2 | 0.236 | 7.22 | 1.70 | 4YR 4/6 | 5YR 5/8 |
| <2000 | | 2.09 | 2.17 | | |

Table 5.1:1. (Continued)

| Size Fraction | Weight Fraction | Fe | Weight Fraction x%Fe | Munsell Color Moist | Munsell Color Dry |
|---|---|---|---|---|---|
| um | % | -------- % ------- | | | |
| | | Appling B21t (7.5YR 5/6, 10YR 7/6 | | | |
| >50 | 0.306 | 0.04 | 0.01 | 5Y 6/1 | 5Y 8/1 |
| 50-20 | 0.024 | 0.47 | 0.01 | 2.5Y 6/2 | 2.5Y 8/2 |
| 20-5 | 0.054 | 1.43 | 0.08 | 2.5Y 6/4 | 2.5Y 7/4 |
| 5-2 | 0.008 | 1.99 | 0.02 | 2.5Y 5/4 | 2.5Y 7/4 |
| 2-0.2 | 0.255 | 3.65 | 0.93 | 10YR 6/6 | 10YR 7/4 |
| <0.2 | 0.353 | 8.51 | 3.00 | 7.5YR 5/6 | 10YR 6/8 |
| <2000 | | 4.00 | 4.05 | | |
| | | Cecil B21t (2.5YR 4/8, 2.5YR 5.5/8 | | | |
| >50 | 0.181 | 0.44 | 0.08 | 10YR 6/1 | 10YR 8/1 |
| 50-20 | 0.029 | 0.90 | 0.03 | 7.5YR 6/2 | 7.5YR 8/2 |
| 20-5 | 0.063 | 1.58 | 0.10 | 7.5YR 6/6 | 7.5YR 8/4 |
| 5-2 | 0.011 | 1.92 | 0.02 | 7.5YR 6/6 | 7.5YR 8/4 |
| 2-0.2 | 0.306 | 4.11 | 1.26 | 5YR 5.5/5 | 5YR 7/6 |
| <0.2 | 0.410 | 10.44 | 4.28 | 2.5YR 4/6 | 2.5YR 5/8 |
| <2000 | | 5.56 | 5.77 | | |
| | | Davidson B21t (2.5YR 3/4, 5YR 4/6) | | | |
| >50 | 0.157 | 2.92 | 0.46 | 10YR 5/1 | 10YR 8/1 |
| 50-20 | 0.033 | 3.52 | 0.12 | 10YR 3/2 | 10YR 6/2 |
| 20-5 | 0.112 | 4.52 | 0.51 | 5YR 3/4 | 7.5YR 6/4 |
| 5-2 | 0.014 | 9.04 | 0.13 | 5YR 3/4 | 7.5YR 5/4 |
| 2-0.2 | 0.299 | 8.71 | 2.60 | 5YR 4/8 | 5YR 6/6 |
| <0.2 | 0.384 | 10.21 | 3.92 | 5R 3/4 | 2.5YR 3.5/6 |
| <2000 | | | 7.74 | | |

Table 5.1:2. Total, citrate-bicarbonate-ditionite (CBD) and acid ammonium oxalate extractable Fe, Al, Si, and Mn in the <0.2μm clay fractions.

| | Total | | | | CBD Extractable | | | | Oxalate Extractable | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample | Fe | Al | Si | Mn | Fe | Al | Si | Mn | Fe | Al | Si |
| | % | | | | | | | | | | |
| Red-Yellow Ustox B1 | 14.5 | 19.0 | 8.8 | t | 14.2 | 4.2 | 0.16 | t | 0.34 | 0.46 | 0.03 |
| Dark Red Ustox B1 | 11.0 | 18.0 | 13.1 | t | 10.8 | 2.1 | 0.21 | t | 0.47 | 0.55 | 0.03 |
| Norfolk B21t | 7.7 | 20.4 | 12.4 | t | 7.0 | 1.6 | 0.13 | t | 0.16 | 0.36 | 0.04 |
| Orangeburg B22t | 7.6 | 19.9 | 14.2 | 0.01 | 7.2 | 1.2 | 0.14 | t | 0.16 | 0.28 | 0.04 |
| Appling B21t | 9.6 | 19.0 | 14.1 | 0.01 | 8.5 | 1.7 | 0.10 | t | 0.15 | 0.26 | 0.04 |
| Cecil B21t | 11.6 | 19.1 | 14.2 | 0.01 | 10.4 | 1.3 | 0.13 | t | 0.24 | 0.24 | 0.04 |
| Davidson B21t | 12.0 | 19.3 | 14.8 | 0.14 | 10.2 | 0.8 | 0.16 | 0.12 | 0.72 | 0.38 | 0.07 |

t* = <0.005%

was selective for amorphous iron compounds, then no more than 7% of the free (CBD extractable) iron in these clays occurred in a disordered state.

Mineralogy of the <0.2μm Clays

Data accumulated through standard X-ray diffraction and differential thermal techniques have shown kaolinite (25-35%), gibbsite (3-13%) and hydroxy Al-interlayered silicates to be the predominant non-iron minerals in all the fine clay fractions. The primary difference between the Oxisol and Ultisol clays is the lower content of intergrade minerals in the former.

Although these clays contained substantial amounts of iron oxides (Table 5.1: 2), the small particle size of these minerals makes them practically amorphous to X-rays. Since iron mineralogy is believed to have an important effect on the color of clay and soil materials. Mössbauer spectroscopy was utilized in an attempt to identify and partially characterize the iron minerals present in these samples.

In all the clays analyzed by Mössbauer spectroscopy, only goethite, or hematite, or mixtures of these two iron minerals were detected. By integrating the adsorption bands obtained from these minerals, estimates of the relative amounts of goethite and hematite in each sample were obtained (Fig. 5.1: 1). The red member of each sample pair was always found to contain a higher proportion of hematite than its yellow counterpart and, in general, as the redness of the clays increased, the ratio of hematite to goethite also increased.

The magnetic properties of the soil goethites and hematites were found to be somewhat abnormal. As noted previously, a fraction of the Fe in many natural iron oxides is often replaced by other elements, especially Al. This substitution disrupts the magnetic ordering of these minerals and thereby reduces the strength of their effective internal magnetic fields. Such reductions are readily detected by Mössbauer spectroscopy. As an example, representative magnetic field data obtained at 78$^{o}$ Kelvin (K) are reproduced in Table 5.1: 3. The observed field values for the soil goethites ranged from 422 to 448 kg, all of which were significantly lower than the accepted value of 509 kg for pure goethite. Likewise, the field values for hematite ranged from 475 to 509 as compared to 544 for pure hematite. If the Al contained in the CBD extracts from these clays (Table 5.1: 2) was indeed, derived from the iron oxides, then the observed field values resulted from Al substitutions in the range of 7 to 23 mole percent.

The effect, if any, of Al substitution on the color of iron oxides and, therefore, of clay and soil materials is unknown. However, Al substitution produced marked reductions in the particle size of both goethite and hematite. Particle size, in turn, influenced the chemical activity of these oxides and modified their spectral properties.

In conclusion, the color of the selected clay materials appears to be primarily related to

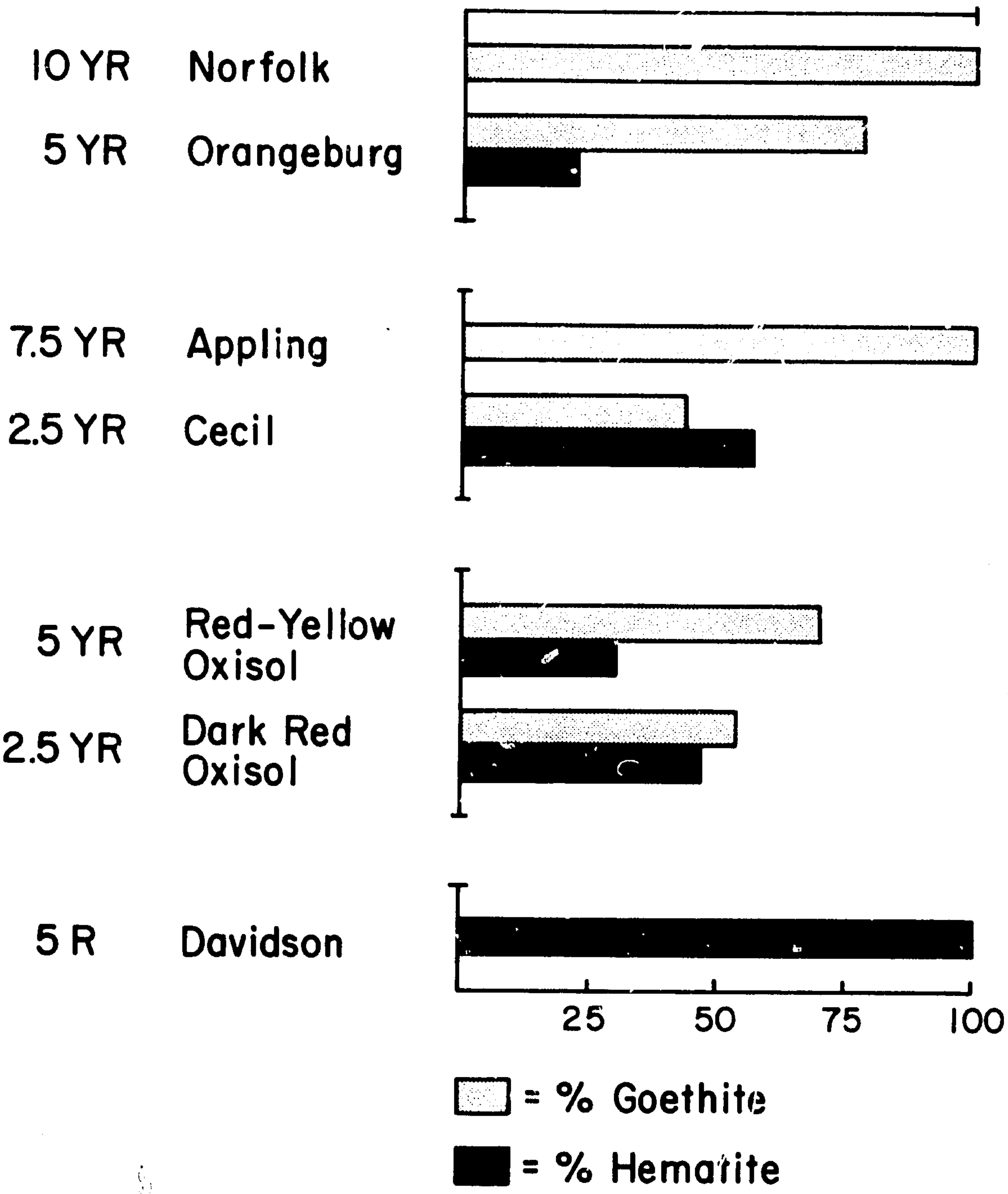



Figure 5.1:1. Mineralogy of the <0.2μm iron oxides as determined by Mössbauer spectroscopy.

Table 5.1:3. Magnetic field and CBD extractable Al data.

| Sample | $H_{eff}$(78°K) | | $\frac{Al}{Al+Fe}$ |
| --- | --- | --- | --- |
| | Goethite | Hematite | |
| | ------- (mm/sec) ----- | | % |
| Orangeburg | 422 | 494 | 14 |
| Cecil | 434 | 509 | 11 |
| Norfolk | 439 | | 19 |
| Appling | 448 | | 16 |
| Red-Yellow Oxisol | --- | 483 | 23 |
| Dark Red Oxisol | --- | 479 | 16 |
| Davidson | | 475 | 7 |
| Goethite | 509 | | |
| Hematite | | 544 | |

Mrs. Jan Green determines clay mineralogy of a sample by X-ray diffractometer.

iron mineralogy, that is, to the type and relative amounts of iron oxides present in each. Other factors, such as the particle size and purity of the iron oxides may also influence the spectral properties of the clays and their parent soils.

## 5.2 CHARACTERISTICS OF SOME WELL DRAINED OXISOLS AND ULTISOLS OF THE SAVANNAS AND RAINFORESTS OF VENEZUELA[1]

R. Schargel and S. W. Buol

The study of physical, chemical, mineralogical and micromorphological characteristics of six Oxisols and five Ultisols is presented herein. An Alfisol intergrading to the Oxisol order was also included in this study.

The profiles sampled are representative of soils which occupy considerable area in the lowlands of Venezuela. Presently most of them are subjected to limited or no use, due to their low natural fertility and/or difficult accessibility. However, they are an important potential resource for agricultural development in the future. Information provided through this research is expected to help in the identification of their utilization and in the transference of technology.

Four profiles (B, I, M, R) are located in the plains (Llanos), within the northern part of the Orinoco Basin. They have developed from alluvial sediments derived from the Andes and Coastal mountain ranges. These soils have an ustic moisture regime with the mean annual rainfall varying between 1300 and 2000 mm (Table 5.2: 1). Soils B, M, R have an ustic moisture regime nearly every year, while soil I might have an udic moisture regime for 2 to 3 years out of 10.

Of the soils studied, B has received the most intensive use. Cotton and sorghum are the most common crops and a considerable area is under improved pasture. However, most of this soil is under savanna vegetation and is used as a natural pasture for cattle. Soil I has been cleared from the forest vegetation to a large extent and is utilized for improved pastures. Soils M and R are mostly under savanna vegetation; however, soil M is increasingly used for the production of peanuts, sorghum and improved pastures for which lime and fertilizers are required.

Eight profiles are located in the southern half of Venezuela, in areas with sparse population, little development and agriculture. Three profiles (C, L, P) are from the northern and northeastern edge of the Guayana Shield, derived from granite rock materials. They have an ustic moisture regime. However, soils L and P with a mean annual rainfall of about 2000 mm have an udic moisture regime for 3 to 4 years out of 10. For soil C the moisture regime will be nearly always ustic.

Five profiles (E, F, S, T, Y) have an udic moisture regime and a mean annual rainfall between 2500 and 3400 mm. However, soils E and Y might have an ustic moisture regime

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[1] Ph.D. Thesis, North Carolina State University, Raleigh, N. C., 1977. Partially supported by the Ministerio del Ambiente y de los Recursos Naturales Renovables formerly part of the Ministerio de Obras Publicas of Venezuela.

Table 5.2:1. Classification of the profiles studied.

| Profile | Classification | Parent Material | Mean Annual Rainfall | Vegetation | Slope |
|---|---|---|---|---|---|
| B | Oxic Paleustalf, fine-loamy, mixed, isohyperthermic | Mixed alluvium | 1500 mm | Savanna | 1% |
| C | Haplic[a/] Acrustox, clayey, kaolinitic, isohyperthermic | Local alluvium from granite | 1400 mm | Savanna | 1% |
| E | Rhodic Paleudult, clayey, oxidic, isohyperthermic | Diorite | 2500 mm | Forest | 2.5% |
| F | Typic Acrorthox, fine-loamy, siliceous, isohyperthermic | Mixed alluvium | 3300 mm | Forest | 1% |
| I | Oxic[a/] Paleustult, clayey, mixed, isohyperthermic | Mixed alluvium | 2000 mm | Forest | 1% |
| L | Typic Haplustox, clayey, kaolinitic, isohyperthermic | Granite | 2200 mm | Forest | 3% |
| M | Typic[a/] Paleustult, fine-loamy, siliceous, isohyperthermic | Mixed alluvium | 1300 mm | Savanna | 0.5% |
| P | Haplic[a/] Acrustox, clayey kaolinitc, isohyperthermic | Granite | 2200 mm | Savanna | 1.5% |
| R | Oxic[a/] Paleustult, clayey, kaolinitic, isohyperthermic | Mixed alluvium | 1500 mm | Savanna | 2% |
| S | Typic Acrorthox, clayey, mixed isohyperthermic | Mixed alluvium | 3300 mm | Forest | 0.5% |
| T | Tropeptic Haplorthox, clayey, kaolinitic, isohyperthermic | Granite | 3400 mm | Forest | 35% |
| Y | Plinthic Paleudult, clayey, oxidic, isohyperthermic | Mica schist | 2500 mm | Forest | 2.5% |

a/ Presently these subgroups are not defined in soil taxonomy for 2 to 3 years out of 10. The parent material of these soils varies from quartz rich alluvium (F) to a relatively mafic diorite (E).

Classification

The classification of the soils in the U. S. Soil Taxonomy is shown in Table 5.2: 1. Clay contents of all the soils studied have sufficiently large increases with depth to meet the requirements for an argillic horizon. Consequently guided by the criteria of clay increase alone, the Oxisols could be classified as Ultisols. As in addition to clay illuviation, other processes can cause clay increases in soil profiles, the argillic horizon requires the identification of sufficient clay skins in the field or by the means of thin sections. An additional criteria utilized for soils with expansive clay minerals or lithologic discontinuities is a 30% increase in the fine clay total clay ratio of the argillic horizon in relation to overlying or underlying horizons.

For the classification of the soils indicated on Table 5.2: 1, argillic horizons were only recognized when clay skins were positively identified in the field description, observing soil material with a binocular microscope and in thin sections.

During the surveys where these soils were mapped, several of the Ultisols were classified as Oxisols and vice versa. Soils E, Y, and I have been classified previously as Oxisols. Soils L, P, T have been previously classified as both Oxisols and Ultisols in different soil surveys. These differences in the classification of these soils arose from the fact that they have clay content increases, a CEC sufficiently low to meet the requirements of an oxic horizon and that the clay skins when present are not very abundant, especially in the upper part of the profile. Also, the identification of clay skins in the field is somewhat subjective when they are not very common.

In order to obtain additional criteria for a consistent identification of the argillic horizon, fine clay-coarse clay ratios were obtained with and without iron removal [organic matter was removed in all cases with hydrogen peroxide] (Table 5.2: 2). The change in the $< 0.2\mu/2\mu$ ratio is less pronounced than the $< 0.2\mu/2\text{-}0.2\mu$ ratio indicated in Table 5.2:2. None of the soils studied showed an increase of the $< 0.2\mu/2\mu$ ratio of 30% or more at the top of the argillic horizon.

Taking the largest increase in the $< 0.2\mu/2\text{-}0.2\mu$ ratio without iron removal over a 30 cm distance from the A horizon towards the B horizon, all Ultisols except soil Y show an increase of more than 20% ranging up to 45% for soil I. In soil Y only a slight increase is observed from horizon A1 and A3 followed by a decrease towards the B horizon. This is probably related to the fact that the surficial horizons of this soil, which have more than 30% by weight of iron oxide nodules larger than 2 mm, have been reworked on a local scale and more intensely weathered and subjected to physical breakdown of particles than the deeper horizons which have less concretions and much higher silt contents.

The clay translocation has not been able to erase a very large decrease in the fine clay content. On the other hand, this soil has

Table 5.2:2. Texture, fine-coarse clay ratios, free iron oxide and moisture retention.

| Profile<br>Horizon Designation | Depth | >2mm*/ | Textural Class | Clay | Without Iron Removal | With Iron Removal | $Fe_2O_3$*/ | $\frac{Fe_2O_3}{Clay}$ | 0.3-15 Bar Water |
|---|---|---|---|---|---|---|---|---|---|
| | cm | % | | % | $\left(\frac{< 2}{2\text{-}0.2\mu}\right)$ | $\left(\frac{< 2}{2\text{-}0.2\mu}\right)$ | % | | % |
| B | | | | | | | | | |
| A1 | 0-8 | - | sl | 17.1 | 0.95 | 0.89 | 1.30 | 0.08 | 3.3 |
| A3 | 8-26 | - | scl | 24.1 | 1.13 | 1.14 | 1.84 | 0.08 | 4.3 |
| B1 | 26-47 | - | scl | 30.6 | 1.17 | 1.16 | 2.26 | 0.07 | 5.1 |
| B21t | 47-100 | - | sc | 36.0 | 1.12 | 1.11 | 2.60 | 0.07 | 4.9 |
| B22t | 100-160 | - | c | 40.9 | 1.00 | 1.08 | 2.53 | 0.06 | 5.8 |
| B23t | 160-180 | - | sc | 35.6 | 0.75 | 0.85 | 2.59 | 0.07 | 6.1 |
| B3 | 180-240 | - | scl | 34.3 | nd | nd | 2.37 | 0.07 | 6.8 |
| C | | | | | | | | | |
| A1 | 0-6 | - | scl | 24.4 | 0.87 | 0.68 | 1.09 | 0.04 | 4.1 |
| A3 | 6-20 | 1 | scl | 26.4 | 0.83 | 0.62 | 1.21 | 0.05 | 4.9 |
| B1 | 20-42 | 5 | scl | 31.6 | 0.70 | 0.60 | 1.51 | 0.05 | 5.8 |
| B21 | 42-97 | 11 | sc | 35.9 | 0.68 | 0.52 | 1.73 | 0.05 | 4.3 |
| B22 | 97-153 | 8 | c | 43.0 | 0.73 | 0.43 | 2.09 | 0.05 | 5.0 |
| B22 | 152-200 | 8 | c | 43.5 | 0.67 | 0.36 | 2.04 | 0.05 | 3.5 |
| E | | | | | | | | | |
| A1 | 0-10 | - | c | 53.3 | 0.26 | 0.67 | 19.97 | 0.37 | 9.0 |
| B21t | 10-42 | - | c | 66.8 | 0.37 | 0.67 | 20.64 | 0.31 | 6.3 |
| B22t | 42-95 | - | c | 69.1 | 0.49 | 0.57 | 21.09 | 0.31 | 7.4 |
| B23t | 95-200 | - | c | 68-9 | 0.43 | 0.40 | 21.82 | 0.32 | 5.4 |
| B23t | 300-350 | - | c | 66.5 | 0.53 | 0.46 | 20.82 | 0.31 | 4.7 |
| F | | | | | | | | | |
| A11 | 0-8 | 2 | cls | 6.1 | 0.79 | 1.61 | 1.88 | 0.31 | 1.1 |
| A12 | 8-32 | 2 | cosl | 16.0 | 0.88 | 1.30 | 3.05 | 0.19 | 3.4 |
| A3 | 32-55 | 2 | sl | 20.1 | 0.90 | 1.25 | 3.29 | 0.16 | 5.6 |
| B1 | 55-75 | 1 | sl | 20.2 | 0.93 | 1.08 | 3.65 | 0.18 | 3.3 |
| B21 | 75-125 | 1 | scl | 24.0 | 0.62 | 1.01 | 4.14 | 0.17 | 3.6 |
| B22 | 125-200 | 1 | scl | 29.8 | 0.71 | 0.77 | 4.32 | 0.15 | 4.8 |
| B22 | 200-250 | 1 | sl | 20.8 | - | - | 4.25 | 0.20 | 1.8 |
| B23 | 250-300 | 2 | scl | 21.3 | - | - | 3.96 | 0.19 | 1.6 |
| B23 | 300-350 | 2 | sl | 19.0 | - | - | 3.79 | 0.20 | 2.8 |

Table 5.2:2 (Continued)

| Profile Horizon Designation | Depth | >2mm*/ | Textural Class | Clay | Without Iron Removal | With Iron Removal | $Fe_2O_3$**/ | $\frac{Fe_2O_3}{Clay}$ | 0.3-15 Bar Water |
|---|---|---|---|---|---|---|---|---|---|
| | cm | % | | % | $\left(\frac{<2}{2-0.2\mu}\right)$ | $\left(\frac{<2}{2-0.2\mu}\right)$ | % | | % |
| <u>I</u> | | | | | | | | | |
| Ap | 0-9 | - | cl | 34.8 | 0.44 | 0.58 | 4.18 | 0.12 | 11.4 |
| A3 | 9-21 | - | sic | 41.2 | 0.61 | 0.60 | 4.71 | 0.11 | 10.8 |
| B1t | 21-32 | - | c | 45.8 | 0.64 | 0.58 | 5.57 | 0.12 | 10.6 |
| B21t | 32-60 | - | c | 49.6 | 0.50 | 0.50 | 5.86 | 0.12 | 9.0 |
| B22t | 60-82 | 2 | c | 46.5 | 0.45 | 0.48 | 6.20 | 0.14 | 9.6 |
| IIB23t | 82-120 | 12 | c | 48.5 | 0.51 | 0.55 | 6.17 | 0.13 | 9.0 |
| IIB24t | 120-155 | 24 | c | 44.0 | 0.42 | 0.40 | 6.29 | 0.14 | 9.6 |
| IIIB25t | 155-178 | 4 | c | 42.3 | 0.39 | 0.37 | 6.36 | 0.16 | 9.0 |
| IIIC1 | 300-350 | 2 | cl | 35.5 | - | 0.28 | 6.07 | 0.17 | 11.1 |
| <u>L</u> | | | | | | | | | |
| A1cn | 0-6 | 15 | sc | 40.1 | 0.43 | 0.31 | 1.82 | 0.05 | 1.8 |
| A3cn | 6-24 | 15 | sc | 45.5 | 0.47 | 0.30 | 1.99 | 0.04 | 5.2 |
| B1cn | 24-45 | 34 | c | 50.5 | 0.47 | 0.27 | 2.28 | 0.05 | 8.7 |
| B21cn | 45-80 | 17 | sc | 44.3 | 0.46 | 0.23 | 2.00 | 0.05 | 3.2 |
| IIB22 | 80-165 | 14 | scl | 24.5 | 0.49 | 0.34 | 1.06 | 0.04 | 4.5 |
| IIB23 | 165-250 | 12 | scl | 23.0 | 0.39 | 0.32 | 1.06 | 0.05 | 4.9 |
| IIC1 | 250-330 | 21 | sl | 14.5 | - | - | 0.27 | 0.02 | 2.6 |
| <u>M</u> | | | | | | | | | |
| A11 | 0-11 | - | sl | 12.2 | 1.10 | 1.24 | 0.88 | 0.07 | 5.7 |
| A12 | 11-51 | - | sl | 15.2 | 1.30 | 1.39 | 0.99 | 0.07 | 3.2 |
| A3 | 51-78 | - | sl | 20.5 | 1.80 | 1.24 | 1.57 | 0.08 | 6.1 |
| B21t | 78-147 | - | scl | 32.0 | 1.80 | 1.29 | 1.97 | 0.06 | 4.2 |
| B22t | 147-200 | - | sc | 39.3 | 1.77 | 1.39 | 2.79 | 0.07 | 4.4 |
| B23t | 200-305 | - | sc | 39.8 | 1.46 | 1.27 | 3.91 | 0.10 | 7.0 |
| IIC | 350-370 | 50 | sl | 18.0 | - | 0.73 | 1.21 | 0.07 | 2.2 |
| <u>P</u> | | | | | | | | | |
| A1cn | 0-5 | 35 | scl | 24.4 | 0.48 | 0.52 | 1.34 | 0.05 | 3.5 |
| A3cn | 5-29 | 16 | scl | 26.2 | 0.36 | 0.48 | 1.48 | 0.06 | 4.6 |
| B21cn | 29-51 | 22 | c | 42.8 | 0.30 | 0.31 | 2.07 | 0.05 | 5.4 |

Table 5.2:2. (Continued)

| Profile Horizon Designation | Depth | >2mm*/ | Textural Class | Clay | Without Iron Removal | With Iron Removal | $Fe_2O_3$**/ | $\frac{Fe_2O_3}{Clay}$ | 0.3-15 Bar Water |
|---|---|---|---|---|---|---|---|---|---|
| | cm | % | | % | $\left(\frac{< 2}{2-0.2\mu}\right)$ | $\left(\frac{< 2}{2-0.2\mu}\right)$ | % | | % |
| P (Cont.) | | | | | | | | | |
| B22cn | 51-76 | 49 | c | 48.5 | 0.25 | 0.23 | 2.17 | 0.04 | 5.5 |
| IIB3cn | 76-107 | 16 | sc | 44.1 | 0.24 | 0.21 | 1.71 | 0.04 | 2.9 |
| IIC1 | 107-175 | 35 | sc | 44.7 | 0.18 | 0.21 | 1.62 | 0.04 | 3.2 |
| IIC2 | 175-295 | 24 | sc | 40.8 | - | - | 1.60 | 0.04 | 6.0 |
| R | | | | | | | | | |
| A1 | 0-12 | 1 | sl | 20.5 | 1.30 | 1.01 | 1.14 | 0.06 | 6.2 |
| B1 | 12-36 | 1 | c | 40.6 | 1.76 | 1.08 | 2.19 | 0.05 | 7.5 |
| B21t | 36-73 | 3 | cl | 34.8 | 1.41 | 1.10 | 2.16 | 0.06 | 7.3 |
| B22t | 73-106 | 6 | c | 42.7 | 1.10 | 1.10 | 2.19 | 0.05 | 7.4 |
| B23t | 106-152 | 6 | c | 50.8 | 1.12 | 0.97 | 2.91 | 0.06 | 8.8 |
| B24tcn | 152-200 | 43 | c | 47.1 | 0.99 | 0.88 | 5.09 | 0.11 | 7.5 |
| S | | | | | | | | | |
| A11 | 0-11 | - | sc | 37.2 | 0.56 | 0.54 | 2.53 | 0.07 | 5.6 |
| A12 | 11-28 | - | sc | 49.3 | 0.45 | 0.53 | 2.82 | 0.06 | 2.6 |
| A3 | 28-53 | - | c | 61.5 | 0.41 | 0.43 | 3.31 | 0.05 | 4.6 |
| B1 | 53-72 | - | c | 66.4 | 0.32 | 0.42 | 3.56 | 0.05 | 6.0 |
| B21 | 72-132 | - | c | 64.1 | 0.38 | 0.23 | 3.58 | 0.06 | 6.9 |
| B22 | 132-200 | - | c | 55.5 | 0.44 | 0.20 | 3.64 | 0.07 | 7.3 |
| B22 | 200-250 | - | c | 54.0 | - | - | 3.44 | 0.06 | 6.4 |
| B23 | 250-300 | - | c | 51.5 | - | - | 3.51 | 0.07 | 6.1 |
| B24 | 300-350 | - | c | 50.1 | - | - | 3.63 | 0.07 | 4.8 |
| T | | | | | | | | | |
| A1cn | 0-10 | 24 | sl | 21.0 | 0.78 | 0.69 | 0.91 | 0.04 | 7.0 |
| A3cn | 10-25 | 13 | scl | 30.8 | 0.70 | 0.75 | 1.18 | 0.04 | 7.7 |
| B1cn | 25-47 | 14 | scl | 34.1 | 0.78 | 0.57 | 1.24 | 0.04 | 7.8 |
| B21cn | 47-77 | 15 | scl | 34.4 | 0.73 | 0.54 | 1.30 | 0.04 | 7.2 |
| B22cn | 77-101 | 43 | cl | 39.9 | 0.63 | 0.39 | 1.39 | 0.03 | 8.0 |
| B23 | 101-132 | 18 | sc | 37.8 | 0.49 | 0.34 | 1.39 | 0.04 | 6.8 |
| B24 | 132-180 | 11 | scl | 31.5 | 0.36 | 0.22 | 1.31 | 0.05 | 7.7 |

Table 5.2:2. (Continued)

| Profile Horizon Designation | Depth | >2mm */ | Textural Class | Clay | Without Iron Removal | With Iron Removal | $Fe_2O_3$ **/ | $\frac{Fe_2O_3}{Clay}$ | 0.3-15 Bar Water |
|---|---|---|---|---|---|---|---|---|---|
| | cm | % | | % | $\left(\frac{< 2}{2-0.2\mu}\right)$ | $\left(\frac{< 2}{2-0.2\mu}\right)$ | % | | % |
| T (Cont.) | | | | | | | | | |
| B24 | 180-232 | 10 | scl | 28.5 | 0.38 | - | 1.24 | 0.05 | 6.4 |
| B3 | 232-271 | 16 | scl | 26.5 | - | 0.23 | 1.19 | 0.07 | 6.6 |
| C1 | 271-320 | 4 | scl | 24.5 | - | - | 1.23 | 0.11 | 8.5 |
| C1 | 320-350 | - | scl | 26.8 | - | - | 1.20 | 0.08 | 8.5 |
| Y | | | | | | | | | |
| A11cn | 0-11 | 32 | sc | 37.5 | 0.38 | 0.43 | 11.42 | 0.30 | 7.8 |
| A12cn | 11-35 | 37 | c | 45.9 | 0.41 | 0.45 | 11.03 | 0.24 | 10.5 |
| A3cn | 35-55 | 37 | sc | 42.1 | 0.39 | 0.40 | 19.63 | 0.47 | 10.9 |
| B1cn | 55-80 | 48 | sc | 38.4 | 0.37 | 0.34 | 20.08 | 0.52 | 10.6 |
| B21tcn | 80-124 | 20 | c | 48.2 | 0.29 | 0.22 | 16.80 | 0.35 | 13.3 |
| B22tcn | 124-180 | 14 | c | 44.8 | 0.27 | 0.19 | 14.05 | 0.31 | 21.0 |
| B3cn | 180-254 | 18 | c | 43.0 | - | - | 12.07 | 0.28 | 22.3 |
| C1cn | 254-330 | 11 | sis | 44.0 | - | 0.18 | 7.87 | 0.18 | 26.0 |

*/ Percent by weight
**/ Citrate-bicarbonate-dithionate extractable iron

many clay skins covering the peds and within the pores, especially in the B22cn horizon. Point counts (1500) performed on the thin sections of two peds from this horizon yielded nearly 5% by volume of oriented clay, mostly as clay skins on the surfaces of the peds and of pores within the peds.

The variability of the $<0.2\mu/2\text{-}0.2\mu$ ratio of all Oxisols with depth was slight.

After iron removal most Ultisols showed much less increase in the $<0.2\mu/2\text{-}0.2\mu$ ratio with depth, although the $Fe_2O_3$/clay ratio showed relatively small fluctuations throughout the profiles in most cases. Where strong fluctuations are observed as in the case of soil Y, they seem to be related to the presence of varying amounts of iron nodules in the sand fraction rather than different amounts of iron oxides associated with the clay.

The weakening or disappearance of the increase in $<0.2\mu/2\text{-}0.2\mu$ ratio after iron removal could be related to differential effects of the iron removal on the dispersability of the soil materials of the different horizons. Using the surface area by $N_2$ adsorption of the deferrated clay as an evaluation of particle size, a larger surface area would suggest a finer particle size. In Ultisols I, M, R and Alfisol B the surface area increased with depth from surface horizon towards the argillic horizon. This is followed by a decrease towards the C horizon in all cases except soil B in which the increase continued to the bottom of the profile (240 cm depth). In all Oxisols except soil T, and in Ultisols E and Y the surface area of the deferrated clay decreased from the surface through the B horizon. For soil Y a possible reason for the decrease in fine clay in the argillic horizon was indicated above. Soil E, in spite of showing clay skins in thin sections, might have suffered only a small amount of clay translocation. The increase in clay content from the A horizon towards the B might be the consequence of a more pronounced aggregation within the A horizon of clay into silt and sand sized aggregates which resisted dispersion. This is supported by the fact that a large proportion of the sand in this soil is formed by iron oxide nodules. The increase in the $< 0.2\mu/2\text{-}0.2\mu$ ratio without iron removal in this soil could have resulted from differences in the strength of microaggregation within the different horizons. Data obtained on the A and B horizons of a Dark Red Latosol from Brazil support this view. Clay content of this soil decreases with depth; however, the $< 0.2\mu/2\text{-}0.2\mu$ ratio without iron removal increases markedly with depth as if a translocation of fine clay had occurred. With free iron oxide removal the $<0.2\mu/2\text{-}0.2\mu$ ratio decreased from the A to the B horizon.

Comparing the increases in the fine clay-coarse clay ratios of the Ultisols with similar data obtained on Ultisols from North Carolina (Cecil, Davidson, Orangeburg and Norfolk series), it was observed that the increase in these ratios with depth was much more pronounced in the latter soils, suggesting a greater magnitude in the clay translocation.

The data obtained suggest that the fine clay-coarse clay ratio can serve as supporting information for the identification of argillic horizons when other evidences of clay translocation are scarce. However, it is very much influenced by the procedure used for its determination and might be completely useless or misleading in some cases. A careful search for evidences of clay translocation in the field supported by thin section work seems to be the most adequate procedure in most cases for separating soils with argillic horizons from soils which show clay increases due to other causes. However, the presence of clay skins does not necessarily indicate that important amounts of illuviation have occurred.

Mineralogy

The soils from northern Venezuela (B, I, M, R) have between 25 and 70% kaolinite in the clay fraction, gibbsite is absent and 2: 1 minerals are more abundant than in the soils from southern Venezuela (C, E, F, L, P, S, T, Y) (Table 5.2: 3). Soil I has 36 to 44% mica (% $K_2O$ x 10) in the clay fraction. Appreciable amounts of 2: 1-2: 2 intergrade clay mineral (Hydroxy-interlayer clay mineral) were found, especially in the surficial horizons. Small amounts of vermiculite were present, especially in the deeper horizons. In the upper part of the profile these three minerals seemed, to a large extent, randomly interstratified.

Soil M, in addition to the kaolinite, had moderate amounts of 2: 1-2: 2 intergrades and quartz in the clay fraction. Small amounts of mica and vermiculite were observed and some smectite in the C horizon. The amount of 2: 1-2: 2 intergrade decreased with depth.

The B soil has kaolinite followed by mica as the dominant clay minerals. Smaller amounts of 2: 1-2: 2 intergrades and vermiculite are also present; the latter increase in amount with depth is mostly randomly interstratified with the mica. The clay mineralogy of this soil seems to be mostly inherited from the parent material; only slight differences were observed in the X-ray diffraction patterns throughout the profile.

Soil R shows the highest kaolinite content amount the profiles from northern Venezuela and has smaller amounts of 2: 1 and 2: 1-2: 2 intergrade minerals.

The soil profiles from southern Venezuela had less 2: 1 and 2: 1-2: 2 intergrade clay minerals. Kaolinite is much more abundant in most of the soils, except some which are very high in gibbsite. The latter mineral is present in all profiles except profile C, which has kaolinite contents about 80% and has the least rainfall and most strongly ustic moisture regime of the southern Venezuelan soils.

It seems that gibbsite content increases with higher rainfall. This can be appreciated comparing the gibbsite content of soils C, L, P, and T which were derived from similar parent material (granite) but with varying amounts of rainfall.

Soils F and S have very high gibbsite contents in the clay and fine silt fractions. The gibbsite content is probably interited, in part, from the parent material and, in part, formed in the soil, favored by the intense leaching to which these soils were subjected due to the

Table 5.2:3. Mineralogical composition of the deferrated clay.

| Profile Horizon Depth | Kaolinite*+ | Gibbsite* | Mica** | Others in order of importance++ |
|---|---|---|---|---|
| cm | % | % | % | |
| B | | | | |
| 0-8 | 45 | - | 25 | 2:1-2:2 intergrade, vermiculite |
| 47-100 | 45 | - | 20 | 2:1-2:2 intergrade, vermiculite |
| 180-240 | 51 | - | 20 | 2:1-2:2 intergrade, vermiculite |
| C | | | | |
| 0-6 | 80 | - | 4 | Small amounts of 2:1-2:2 inter- |
| 42-97 | 78 | - | 5 | grade and quartz, the latter |
| 153-200 | 76 | - | 5 | mostly in the surficial horizons |
| E | | | | |
| 0-10 | 50 | 11 | 2 | Small amounts of 2:1-2:2 inter- |
| 42-95 | 57 | 15 | 1 | grades |
| 250-350 | 62 | 21 | 2 | |
| F | | | | |
| 55-75 | 21 | 40 | 1 | Small amounts of anatase and |
| 125-200 | 20 | 41 | 1 | quartz |
| 300-350 | 25 | 46 | 1 | |
| I | | | | |
| 0-9 | 26 | - | 36 | 2:1-2:2 intergrade and vermi- |
| 32-60 | 26 | - | 36 | culite decreasing with depth |
| 82-120 | 37 | - | 40 | |
| 155-178 | 31 | - | 43 | |
| 300-350 | 30 | - | 44 | |
| L | | | | |
| 0-6 | 70 | 5 | 1 | None detected |
| 45-80 | 73 | 5 | 1 | |
| 80-165 | 87 | 3 | 1 | |
| M | | | | |
| 0-11 | 33 | - | 4 | 2:1-2:2 intergr., quartz, verm. |
| 51-78 | 39 | - | 5 | 2:1-2:2 intergr., quartz, verm. |
| 78-147 | 45 | - | 5 | 2:1-2:2 intergr., quartz, verm. |
| 350-370 | 34 | - | 10 | 2:1-2:2 intergr., quartz, smectite |

Table 5.2:3. (Continued)

| Profile Horizon Depth | Kaolinite*+ | Gibbsite* | Mica** | Others in order of importance++ |
|---|---|---|---|---|
| cm | % | % | % | |
| P | | | | |
| 0-5 | 79 | 4 | 1 | None detected |
| 51-76 | 77 | 3 | 1 | |
| 76-107 | 70 | 3 | 1 | |
| 107-175 | 85 | 2 | 1 | |
| R | | | | |
| 0-12 | 63 | - | 9 | Small amounts of 2:1-2:2 inter- |
| 73-106 | 68 | - | 10 | grades and quartz |
| 152-200 | 67 | - | 10 | |
| S | | | | |
| 0-11 | 22 | 52 | 1 | Small amounts of anatase |
| 72-132 | 18 | 52 | 1 | |
| 300-350 | 18 | 49 | 1 | |
| T | | | | |
| 0-10 | 66 | 9 | 3 | Small amounts of 2:1-2:2 inter- |
| 47-77 | 72 | 12 | 2 | grades |
| 77-101 | 66 | 11 | 2 | |
| 232-271 | 70 | 9 | 2 | |
| Y | | | | |
| 0-11 | 62 | 3 | 3 | Small amounts of 2:1-2:2 inter- |
| 35-55 | 65 | 3 | 3 | grades |
| 80-124 | 71 | 6 | 2 | |
| 254-330 | 79 | 1 | <3 | |

* Determined by DTA.

** $K_2O$ x 10.

\+ Mostly akolinite, but small amounts of halloysite in most soils. Soil T showed appreciable amounts of rod shaped halloysite particles with electron microscopy.

++ By x-ray diffraction.

high rainfall, slight slope and high soil permeability.

The mineralogy of the 20 to 2000μ fraction of the profiles studied is dominated by quartz in the cases of soils C, F, I, M, R, S, T and in the upper part of profiles L and P. Large amounts of kaolinite aggregates were found in the sand and coarse silt fractions of the deeper horizons of the latter profiles. These aggregates seem to be feldspar grains which weathered completely to kaolinite. They are quite resistant to the common procedures used for dispersing soils.

Soils Y and E contain large amounts of iron oxide nodules in the 20 to 2000μ fraction.

The combination of texture and mineralogy of soil S originates a somewhat unreasonable classification at the family level. Adding the gibbsite content of the clay and coarser fractions, this soil has about 36% gibbsite in the less than 2mm fraction. This is slightly less than the 40% required for a gibbsite mineralogy class. On the other hand, the 20 to 2000μ fraction is dominated by quartz ( > 90%), consequently the oxidic mineralogy class cannot be applied. Using the clay fraction for the classification at the family level a mixed mineralogy class results in spite of more than 50% gibbsite in the clay fraction. It seems reasonable to exclude the requirement of less than 90% quartz in the 20 to 2000μ fraction from the oxidic mineralogy class for soils with clayey particle size class ( > 35% clay). With this modification, soil S would be classified within the oxidic mineralogy class.

Physical Characteristics

Soil E shows throughout the profile the strong microaggregation (fine or very fine granular structure) described as characteristic for many Oxisols. This also is expressed somewhat less strongly in the $B_2$ horizons of profiles S and F, where it increased with depth.

Soil C has only weak microaggregation, especially in the deeper part of the B horizon. None of the other Oxisols show evidences of microaggregation. With the exception of soil E, none of the Ultisols have clear evidences of microaggregation. However, a tendency to microaggregation was observed in the deeper part of the B horizon of the Alfisol.

The 0.2-15 bar moisture content which is often taken as an evaluation of available water is rather low in most of the soils. The highest values were observed in soils I and Y which have high silt contents.

Chemical Characteristics

The pH in 0.01M $CaCl_2$ is below 5 in most of the soil profiles studied (Table 5.2:4). Only soil B, an Alfisol, and soil E, which developed from mafic rocks, have pH values above 5. Soil B has a higher base saturation in the B horizon than the Ultisols and Oxisols. Soil E has a very high content of free iron oxides throughout the profile and considerable accu-

Table 5.2:4. Selected chemical properties.

| Profile Horizon Depth | pH,1:2" ($CaCl_2$) (0.01M) | Exchangeable Cations Ca[1] | Mg[1] | K[1] | Na[1] | Al[2] | H[2] | Ext. acidity[3] | Effective CEC[4] | Sum[5] Cations | Organic Carbon | Base Sat. | Al[6] Sat. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cm | | ---me/100g soil--- | | | | | | | | | ---%--- | | |
| B | | | | | | | | | | | | | |
| 0-8 | 5.1 | 2.1 | 1.4 | 0.4 | 0.1 | t | 0.3 | 4.1 | 4.0 | 8.1 | 1.01 | 49 | 0 |
| 8-26 | 4.9 | 1.4 | 0.9 | 0.2 | 0.1 | t | 0.4 | 5.0 | 2.6 | 7.6 | 0.74 | 34 | 0 |
| 26-47 | 4.7 | 0.9 | 0.6 | 0.1 | 0.1 | 0.2 | 0.4 | 5.5 | 1.9 | 7.2 | 0.55 | 24 | 12 |
| 47-100 | 4.9 | 1.0 | 0.7 | 0.2 | 0.1 | t | 0.4 | 5.7 | 2.0 | 7.7 | 0.23 | 26 | 0 |
| 100-160 | 5.2 | 1.6 | 1.4 | 0.3 | 0.1 | t | 0.2 | 4.6 | 3.4 | 8.0 | 0.08 | 43 | 0 |
| 160-180 | 5.3 | 1.9 | 1.8 | 0.3 | 0.1 | t | 0.3 | 5.1 | 4.0 | 9.1 | 0.04 | 44 | 0 |
| 180-240 | 5.3 | 2.0 | 1.8 | 0.3 | 0.2 | t | 0.3 | 4.5 | 4.3 | 8.8 | t | 49 | 0 |
| C | | | | | | | | | | | | | |
| 0-6 | 4.1 | 0.4 | 0.3 | 0.1 | 0.1 | 0.3 | 0.4 | 3.6 | 1.2 | 4.5 | 0.59 | 20 | 25 |
| 6-20 | 3.9 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 0.5 | 3.0 | 0.9 | 3.4 | 0.39 | 12 | 56 |
| 20-42 | 4.0 | 0.2 | 0.1 | t | 0.1 | 0.3 | 0.4 | 2.8 | 0.7 | 3.2 | 0.23 | 13 | 43 |
| 42-97 | 4.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.4 | 0.4 | 2.8 | 0.9 | 3.3 | 0.12 | 15 | 50 |
| 97-153 | 4.2 | 0.1 | t | t | 0.1 | 0.4 | 0.4 | 2.8 | 0.6 | 3.0 | 0.16 | 7 | 67 |
| 153-200 | 4.3 | 0.1 | t | 0.1 | 0.1 | 0.3 | 0.3 | 2.7 | 0.6 | 3.0 | 0.12 | 10 | 60 |
| E | | | | | | | | | | | | | |
| 0-10 | 5.9 | 12.8 | 1.6 | 0.3 | 0.1 | 5 | 0.2 | 10.1 | 14.8 | 24.9 | 2.89 | 59 | 0 |
| 10-42 | 4.3 | 0.5 | 0.2 | 0.1 | 0.1 | 0.4 | 0.4 | 16.6 | 1.3 | 17.5 | 1.25 | 5 | 31 |
| 42-95 | 4.9 | 0.4 | 0.2 | 0.1 | 0.1 | t | 0.2 | 11.0 | 0.8 | 11.8 | 0.62 | 7 | 0 |
| 95-200 | 5.3 | 0.2 | 0.1 | 0.1 | 0.1 | t | 0.1 | 8.9 | 0.5 | 9.4 | 0.31 | 5 | 0 |
| 250-350 | 5.5 | 0.1 | t | t | 0.1 | t | 0.2 | 7.1 | 0.2 | 7.3 | 0.12 | 3 | 0 |
| F | | | | | | | | | | | | | |
| 0-8 | 3.4 | 0.3 | 0.1 | 0.1 | 0.1 | 1.4 | 0.8 | 10.0 | 2.0 | 10.6 | 1.40 | 6 | 70 |
| 8-32 | 4.0 | 0.1 | t | 0.1 | 0.1 | 1.0 | 0.3 | 11.8 | 1.3 | 12.1 | 1.52 | 2 | 77 |
| 32-55 | 4.1 | 0.2 | t | t | 0.1 | 0.5 | 0.3 | 6.3 | 0.8 | 6.6 | 0.59 | 5 | 63 |
| 75-125 | 4.2 | 0.2 | t | t | 0.1 | 0.1 | 0.3 | 5.0 | 0.4 | 5.3 | 0.27 | 6 | 25 |
| 125-200 | 4.6 | 0.2 | t | t | 0.1 | t | 0.2 | 3.7 | 0.3 | 4.0 | 0.23 | 8 | 0 |
| 200-250 | 4.7 | 0.2 | t | t | 0.1 | t | 0.3 | 2.6 | 0.3 | 2.9 | 0.23 | 10 | 0 |
| 250-300 | 4.9 | 0.1 | t | 0.1 | 0.1 | t | 0.2 | 2.4 | 0.2 | 2.6 | 0.20 | 8 | 0 |
| 300-350 | 5.1 | 0.2 | t | 0.1 | 0.1 | 5 | 0.2 | 2.2 | 0.3 | 2.5 | 0.16 | 12 | 0 |
| I | | | | | | | | | | | | | |
| 0-9 | 5.2 | 6.6 | 0.9 | 0.5 | 0.1 | t | 0.3 | 9.9 | 8.1 | 18.0 | 1.91 | 45 | 0 |
| 9-21 | 4.3 | 2.5 | 0.5 | 0.2 | 0.1 | 1.2 | 0.4 | 12.0 | 4.5 | 15.3 | 0.98 | 22 | 27 |
| 21-32 | 4.0 | 1.3 | 0.3 | 0.2 | 0.1 | 2.2 | 0.5 | 12.5 | 4.1 | 14.4 | 0.66 | 13 | 54 |
| 32-60 | 4.2 | 0.4 | 0.2 | 0.2 | 0.1 | 1.4 | 0.5 | 10.0 | 2.3 | 10.9 | 0.39 | 8 | 61 |
| 60-82 | 4.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.7 | 0.4 | 8.4 | 1.2 | 8.9 | 0.23 | 6 | 58 |
| 82-120 | 4.3 | 0.2 | 0.1 | 0.2 | 0.1 | 0.9 | 0.5 | 10.0 | 1.5 | 10.6 | 0.16 | 6 | 60 |
| 120-155 | 4.2 | 0.3 | 0.1 | 0.2 | 0.2 | 1.0 | 0.4 | 8.0 | 1.8 | 8.8 | 0.08 | 9 | 56 |
| 155-178 | 4.2 | 0.1 | 0.1 | 0.1 | 0.1 | 1.2 | 0.4 | 7.3 | 1.6 | 7.7 | 0.04 | 5 | 75 |
| 300-350 | 4.2 | 0.3 | 0.6 | 0.1 | 0.1 | 1.2 | 0.4 | 6.1 | 2.3 | 7.2 | 0.04 | 15 | 52 |

Table 5.2:4. (Continued)

| Profile Horizon Depth | pH, 1:2" ($CaCl_2$) (0.01M) | Exchangeable Cations Ca[1] | Mg[1] | K[1] | Na[1] | Al[2] | H[2] | Ext. acidity[3] | Effective CEC[4] | Sum[5] Cations | Organic Carbon | Base Sat. | Al[6] Sat. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cm | | ------- | ------- | me/100g soil | ------- | ------- | ------- | ------- | ------- | ------- | ---- | % | ---- |
| L | | | | | | | | | | | | | |
| 0-6 | 3.9 | 0.4 | 0.1 | 0.2 | 0.1 | 1.0 | 0.5 | 9.6 | 1.8 | 10.4 | 1.25 | 8 | 56 |
| 6-24 | 4.0 | 0.1 | t | 0.1 | 0.1 | 1.1 | 0.2 | 8.0 | 1.4 | 8.3 | 0.82 | 4 | 79 |
| 24-45 | 4.0 | 0.1 | t | 0.1 | 0.1 | 1.1 | 0.3 | 7.5 | 1.4 | 7.8 | 0.74 | 4 | 79 |
| 45-80 | 4.1 | 0.2 | t | 0.1 | 0.1 | 0.5 | 0.3 | 3.5 | 0.9 | 3.9 | 0.31 | 10 | 56 |
| 80-165 | 4.3 | 0.3 | t | t | t | 0.2 | 0.3 | 1.3 | 0.6 | 1.7 | t | 24 | 33 |
| 165-210 | 4.3 | 0.1 | t | t | 0.1 | 0.2 | 0.2 | 1.3 | 0.4 | 1.5 | t | 13 | 50 |
| 250-300 | 4.3 | 0.1 | t | t | 0.1 | 0.1 | 0.3 | 1.3 | 0.3 | 1.7 | t | 12 | 33 |
| M | | | | | | | | | | | | | |
| 0-11 | 4.0 | 0.6 | 0.4 | 0.1 | 0.1 | 1.2 | 0.3 | 6.7 | 2.4 | 7.9 | 1.09 | 15 | 50 |
| 11-51 | 3.9 | 0.4 | 0.2 | 0.1 | 0.1 | 1.5 | 0.5 | 5.4 | 2.2 | 6.2 | 0.70 | 13 | 68 |
| 51-78 | 3.9 | 0.5 | 0.2 | 0.1 | 0.1 | 1.9 | 0.5 | 4.5 | 2.8 | 5.4 | 0.27 | 17 | 68 |
| 78-147 | 4.0 | 0.6 | 0.7 | 0.1 | 0.1 | 2.7 | 0.5 | 8.1 | 4.2 | 9.6 | 0.12 | 16 | 64 |
| 147-200 | 3.9 | 0.5 | 0.7 | 0.1 | 0.1 | 3.4 | 0.5 | 7.5 | 4.8 | 8.9 | 0.08 | 16 | 71 |
| 200-305 | 3.8 | 0.8 | 0.7 | 0.1 | 0.1 | 4.3 | 0.7 | 9.2 | 6.0 | 10.9 | 0.08 | 16 | 72 |
| 350-370 | 3.8 | 0.3 | 0.3 | 0.1 | 0.1 | 1.6 | 0.6 | 2.8 | 2.4 | 3.6 | t | 22 | 67 |
| P | | | | | | | | | | | | | |
| 0-5 | 4.2 | 0.2 | t | 0.1 | 0.1 | 0.4 | 0.3 | 2.9 | 0.8 | 3.3 | 0.66 | 12 | 50 |
| 5-29 | 4.2 | 0.1 | t | t | 0.1 | 0.4 | 0.3 | 2.6 | 0.6 | 2.8 | 0.51 | 7 | 67 |
| 29-51 | 4.4 | 0.1 | t | t | 0.1 | t | 0.1 | 2.7 | 0.2 | 2.9 | 0.23 | 7 | 0 |
| 51-76 | 4.5 | 0.1 | t | t | 0.1 | t | 0.3 | 2.7 | 0.2 | 2.9 | 0.16 | 7 | 0 |
| 76-107 | 4.4 | 0.1 | t | t | 0.1 | 0.2 | 0.3 | 2.2 | 0.4 | 2.4 | 0.04 | 8 | 50 |
| 107-175 | 4.3 | 0.1 | t | 0.1 | 0.1 | 0.4 | 0.2 | 2.7 | 0.7 | 3.0 | 0.04 | 10 | 57 |
| 250-295 | 4.3 | 0.1 | t | 0.1 | 0.1 | 0.3 | 0.3 | 2.4 | 0.6 | 2.7 | 0.04 | 11 | 50 |
| R | | | | | | | | | | | | | |
| 0-12 | 3.8 | 0.4 | 0.4 | 0.2 | 0.1 | 1.3 | 0.3 | 6.0 | 2.4 | 7.1 | 0.82 | 15 | 54 |
| 12-36 | 3.7 | 0.3 | 0.3 | 0.2 | 0.1 | 2.8 | 0.8 | 9.7 | 3.7 | 10.6 | 0.62 | 8 | 76 |
| 36-73 | 3.8 | 0.2 | 0.1 | 0.2 | 0.2 | 2.1 | 0.5 | 7.0 | 2.8 | 7.7 | 0.35 | 9 | 75 |
| 73-106 | 3.9 | 0.1 | 0.1 | 0.2 | 0.2 | 2.0 | 0.4 | 6.3 | 2.6 | 6.9 | 0.23 | 9 | 77 |
| 106-152 | 3.8 | 0.1 | t | 0.3 | 0.6 | 2.4 | 0.5 | 7.7 | 3.4 | 8.7 | 0.20 | 11 | 71 |
| 152-200 | 3.9 | 0.2 | 0.1 | 0.1 | 0.1 | 2.7 | 0.5 | 7.9 | 3.2 | 8.4 | 0.12 | 6 | 84 |
| S | | | | | | | | | | | | | |
| 0-11 | 3.6 | 0.2 | 0.1 | 0.2 | 0.1 | 1.9 | 0.8 | 17.3 | 2.5 | 17.9 | 2.77 | 3 | 76 |
| 11-28 | 3.9 | 0.2 | t | 0.1 | 0.1 | 1.1 | 0.3 | 12.0 | 1.6 | 12.5 | 1.68 | 4 | 69 |
| 28-53 | 4.1 | 0.2 | t | 0.1 | 0.1 | 0.5 | 0.4 | 8.4 | 0.9 | 8.8 | 1.05 | 5 | 56 |
| 53-72 | 4.3 | 0.2 | t | t | 0.1 | 0.2 | 0.2 | 5.7 | 0.5 | 6.0 | 0.62 | 5 | 40 |
| 72-132 | 4.7 | 0.2 | t | 0.1 | 0.1 | t | 0.4 | 4.1 | 0.4 | 4.5 | 0.35 | 9 | 0 |
| 132-200 | 4.9 | 0.2 | t | 0.1 | 0.1 | t | 0.2 | 3.5 | 0.4 | 3.9 | 0.27 | 10 | 0 |
| 200-250 | 5.1 | 0.2 | t | t | 0.1 | t | 0.2 | 32 | 0.3 | 3.5 | 0.23 | 9 | 0 |
| 250-300 | 5.3 | 0.1 | t | t | 0.1 | t | 0.2 | 3.3 | 0.2 | 3.5 | 0.16 | 6 | 0 |
| 300-350 | 5.3 | 0.2 | t | t | o.1 | t | 0.2 | 3.1 | 0.3 | 3.4 | 0.12 | 9 | 0 |

Table 5.2:4. (Continued)

| Profile Horizon Depth | pH,1:2" ($CaCl_2$) (0.01M) | Exchangeable Cations $Ca^{1/}$ | $Mg^{1/}$ | $K^{1/}$ | $Na^{1/}$ | $Al^{2/}$ | $H^{2/}$ | Ext. acid-ity3/ | Effect-tive CEC4/ | Sum5/ Cations | Organic Carbon | Base Sat. | Al6/ Sat. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cm | | ---------------me/100g soil | | | | | | | | | -------%-------- | | |
| T | | | | | | | | | | | | | |
| 0-10 | 3.5 | 0.1 | 0.1 | 0.3 | 0.1 | 2.5 | 1.0 | 17.9 | 3.1 | 18.5 | 3.20 | 3 | 81 |
| 10-25 | 4.0 | 0.3 | t | 0.1 | 0.1 | 1.4 | 0.5 | 8.9 | 1.9 | 9.4 | 1.29 | 5 | 74 |
| 25-47 | 4.1 | 0.2 | t | 0.1 | 0.1 | 1.1 | 0.5 | 8.0 | 1.5 | 8.4 | 0.98 | 5 | 73 |
| 47-77 | 4.1 | 0.1 | t | 0.1 | 0.1 | 0.9 | 0.4 | 6.1 | 1.2 | 6.4 | 0.55 | 5 | 75 |
| 77-101 | 4.2 | 0.2 | t | 0.1 | 0.1 | 0.6 | 0.4 | 4.3 | 1.0 | 4.7 | 0.35 | 9 | 67 |
| 101-132 | 4.3 | 0.1 | t | 0.1 | 0.1 | 0.4 | 0.4 | 3.9 | 0.7 | 4.2 | 0.20 | 7 | 57 |
| 132-180 | 4.3 | 0.1 | t | 0.1 | 0.1 | 0.6 | 0.2 | 2.5 | 0.9 | 2.8 | 0.12 | 11 | 67 |
| 180-232 | 4.3 | 0.1 | t | 0.1 | 0.1 | 0.4 | 0.3 | 2.2 | 0.7 | 2.5 | 0.04 | 12 | 57 |
| 232-271 | 4.3 | 0.1 | t | 0.1 | 0.1 | 0.5 | 0.3 | 1.8 | 0.8 | 2.1 | 0.04 | 14 | 63 |
| 271-320 | 4.2 | 0.1 | t | 0.1 | 0.1 | 0.7 | 0.4 | 2.2 | 1.0 | 2.5 | 0 04 | 12 | 70 |
| 320-350 | 4.2 | 0.1 | t | 0.1 | 0.1 | 0.6 | 0.3 | 2.2 | 0.9 | 2.5 | 0.08 | 12 | 67 |
| Y | | | | | | | | | | | | | |
| 0-11 | 4.9 | 4.4 | 1.6 | 0.3 | 0.1 | t | 0.5 | 14.9 | 6.4 | 21.3 | 2.81 | 30 | 0 |
| 11-35 | 4.5 | 1.6 | 0.9 | 0.2 | 0.1 | 0.3 | 0.4 | 12.0 | 3.1 | 14.8 | 1.72 | 19 | 10 |
| 35-55 | 4.2 | 0.2 | 0.1 | t | 0.1 | 0.5 | 0.4 | 7.6 | 0.9 | 8.0 | 0.51 | 5 | 56 |
| 55-80 | 4.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.3 | 0.5 | 7.3 | 0.8 | 7.8 | 0.43 | 6 | 38 |
| 80-124 | 4.5 | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 5.8 | 0.7 | 6.3 | 0.12 | 8 | 29 |
| 124-254 | 4.7 | 0.3 | 0.1 | 0.1 | 0.1 | 0.3 | 0.2 | 5.3 | 0.9 | 5.9 | 0.08 | 10 | 33 |
| 254-330 | 4.6 | 0.2 | t | 0.1 | 0.1 | 0.8 | 0.3 | 5.0 | 1.2 | 5.4 | 0.04 | 7 | 67 |

1/ Extracted with 1N $NH_4OAc$ pH 7

2/ Extracted with 1N KCl

3/ Extracted with $BaCl_2$.TEA pH 8.2

4/ Bases plus aluminum

5/ Bases plus extractable acidity

6/ Al/ECEC x 100

t = Trace amount

mulation of bases in the A horizon. In the B horizon the base saturation is very low, but the pH value is above 5 once the content of organic matter decreases and the ion exchange is strongly influenced by the free iron oxides.

Soils I and Y have a pH value of 5 or more in the surface horizons; this is related to a considerable accumulation of exchangeable bases. Soils F and S have pH values above 5 in the deeper horizons; these soils have a high amount of gibbsite in the clay fraction and relatively high pH values in those horizons which are low in organic matter, in spite of a very low base saturation.

Exchangeable Al is observed in the profiles studied at pH values below 4.9 in 0.01M $CaCl_2$. Soil P does not have exchangeable Al in part of the B horizon where pH values are from 4.6 to 4.7. However, these horizons have an extremely low effective CEC; consequently, only small amounts of exchangeable Al (about 0.05 me/100g) which might not have been detected could produce an Al saturation of close to 25%. This, in fact, is the case in some of these soils.

Ultisols I, M, R contain more than 2 me exchangeable Al/100g in parts of their B horizons. These soils have a low pH value and higher effective CEC values than the Oxisols.

Soil T has more than 2 me exchangeable Al/100g in the surface horizon and less than 1 me exchangeable Al/100g in the B horizon where the effective CEC is very low. Soil M which has the highest effective CEC per 100g of clay and the largest amount of 2: 1-2: 2 intergrade clay minerals also had the highest amount of exchangeable Al in the B horizon.

Most of the Oxisols contain more exchangeable Al in the A horizon than in the B horizon. This is related to the larger effective CEC in the A horizon due to the influence of the organic matter.

The effective CEC per 100g of clay of the horizons low in organic matter (B and C horizons) is higher in the soil profiles from northern Venezuela. Soils B and R have effective CEC values greater than 5 me/100g clay and soil M above 12 me/100g clay. Soil I has low values between 2.5 and 3 me/100g clay in parts of the B horizon.

The soils from southern Venezuela have effective CEC values below 2.5 me/100g clay in the B horizons. Values below 1 me/100g clay are common.

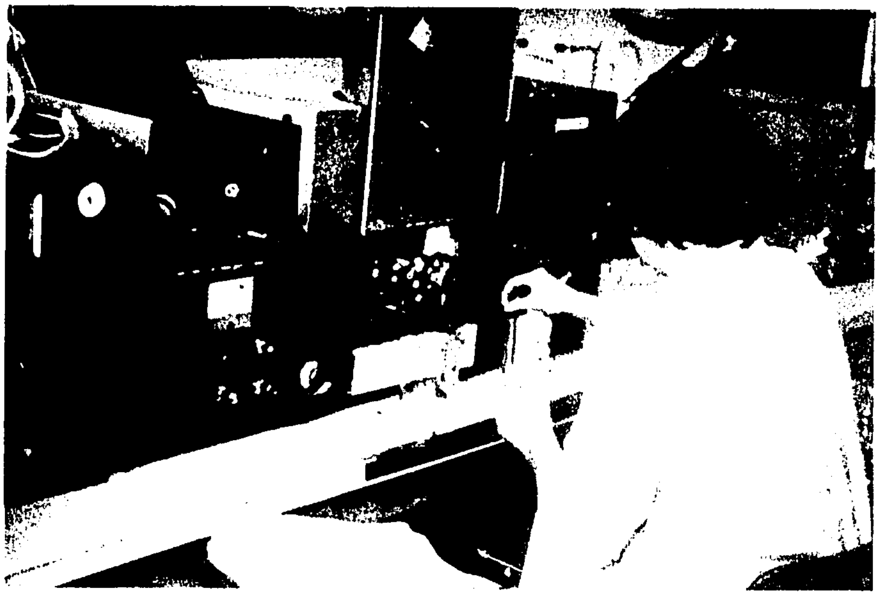
The CEC/100g clay by sum of cations at pH 8.2 also tends to be lower in the soils of southern Venezuela for those horizons which show little influence of organic matter.

## Conclusions

Comparing the profiles from northern and southern Venezuela, it can be concluded that the latter are more intensively weathered and contain higher amounts of kaolinite and/or gibbsite and less 2: 1 and 2: 1-2: 2 intergrade clay minerals. Their effective CEC is much lower in the subsurface horizons.

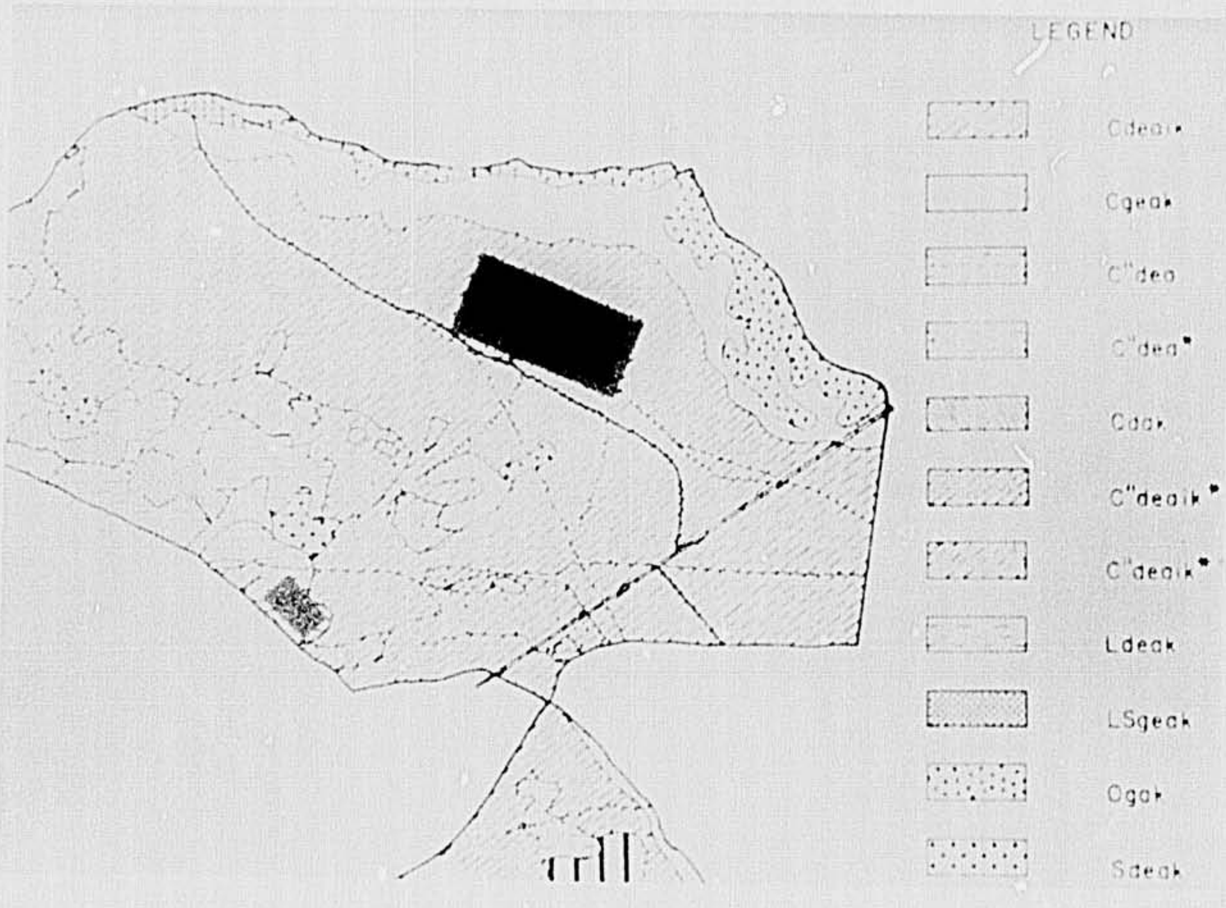
Although all the profiles studied have sufficient clay increase to recognize an argillic horizon, six soils were considered to be lacking an argillic horizon and classified as Oxisols. These soils showed insufficient evidences of clay translocation (clay skins) in the field and thin sections. Fine clay/coarse clay ratios seem to support this classification. All soils classified as Oxisols are from southern Venezuela.

Five soils were classified as Ultisols, two of them from southern Venezuela. One soil was classified as an Alfisol. Four of the Ultisols and the Alfisol have effective CEC's in the B horizon lower than 10 me/100g clay and are intergrades to Oxisols in the case where this criteria is applicable (Soils B, I, R). The two Ultisols from southern Venezuela are classified as Paleudults and belong to the oxidic mineralogy class at the family level of classification.



Mrs. Bertha Crabtree analyzes soil extracts for Mn by atomic absorption spectrophotometer.

SOIL FERTILITY CAPABILITY CLASSIFICATION SYSTEM




An example of the application of the FCC legend as applied to the Brazilian soil survey of the CPAC Station.

Since Project initiation in 1972, part of its activity has been devoted to the development of a technical system of soil classification aimed to obtain the maximum usefulness of information provided by soil survey in soil fertility studies. The technical system, Fertility Capability Classification System, uses soil survey and characterization information for detecting the most important limiting factors for most common crops in large areas where soils have not been substantially changed by men.

A description of the System has been published in an earlier Annual Report and other publications. The ability of the System to group soils that are alike from the point of view of soil fertility limitations or management requirements has been checked using experimental and soil properties information collected in several countries. Working with information obtained from Brazil, it was shown in earlier Annual Reports that there was in general good agreement between field experimental results and the expected crop response to fertilizers according to the limitations indicated by the FCC System. However, soils with high P-fixing capacities were not always well identified by the presence of the "i" modifier. This was noted especially when applied to soils with a free iron oxide/clay content ratio greater than 0.2. Improvement of the System in its ability to separate those soils with high P fixation capacities was considered through an improved expression for the "i" modifier. Some results of laboratory work oriented to develop an improved version of this modifier and to study several aspects of P fixation are presented herein. Also presented are the results of the application of the FCC System to soil and experimental data of southeastern U. S. as an example of its applicability to soil survey interpretations.

## 6.1 MODIFICATION OF "i" MODIFIER

R. A. Pope

The Fertility Capability Classification System is a technical classification system designed to group soils on the basis of soil factors that have a direct influence on soil–fertilizer–plant relationships. The "i" condition modifier of this system is intended to identify soils in which P fixation by iron compounds is of major importance to soil management. The ratio of free iron oxides to percent clay used to assign the condition modifier was found inadequate to separate soils on the basis of P fixation characteristics.

Many of the soil characteristics commonly examined in soil survey work are correlated with P fixation. Clay content, exchangeable Al, and free iron oxides, for example, are nearly always found to be closely correlated with P sorption. The extent to which any single constituent will contribute to P fixation depends on the amount and reactivity of the constituent.

Evaluation of indirect variables to predict and group soils according to P fixation characteristics will require using a consistent method to evaluate P sorption, and a range of the soils with possible soil management limitations due to P fixation.

Phosphate adsorption isotherms provide a consistent means of assessing relative P fixation characteristics between soils. However, the time and number of chemical determinations per isotherm make the approach impractical for routine screening of large numbers of samples. A rapid assessment of P fixation characteristics would be possible if a good correlation of P fixation variables with other soil properties commonly measured in soil survey investigations could be found.

A laboratory study was conducted to determine the effectiveness of commonly available soil survey data like clay percentage, free iron oxides and exchangeable Al for identifying soils that fix large amounts of P.[1]

The soils studied presented a broad range of soil properties found in Oxisols, Ultisols and Alfisols of tropical and subtropical regions. Some of their properties are presented in Table 6.1: 1.

Quantity of P sorbed to maintain 0.2 ppm in solution was determined. This characteristic, determined from sorption curves, estimated sorption in a concentration range compatible with many soil-crop systems and did not imply adherence to a specific adsorption model. In a previous test it was observed that soils adsorbing large amounts of P tended to hold most of the P in a relatively unavailable form.

Exchangeable Al was poorly correlated with P adsorption over all samples (Fig. 6.1: 1). Constituents other than exchangeable Al apparently controlled P fixation in these soils having low CEC and little exchangeable Al.

Free iron extracted by citrate-dithionite-bicarbonate (CDB) was fairly well correlated (r=0.75) with P sorption. The results suggested, however, that factors other than this iron fraction contributed to P fixation.

Surface area measured by $N_2$ adsorption on whole soil samples was well correlated (r=0.90) with P adsorption (Fig. 6.1: 2). The close association between surface area and clay percentage suggested a similar relationship between P sorption and clay percentage– a routine determination in soil characterization. This relationship is shown in Fig. 6.1: 3 and it suggested the possibility of using the clay ( > 35%) as an indicator of high P sorption. Nevertheless, the use of this sole criterion for predicting P fixation is questionable if all soils are to be considered. Soil constituents with a greater affinity for P other than solely clay, must be present before P fixation becomes an agronomic problem.

The fairly close correlations observed between P retention and free iron oxides extracted by CDB indicated the importance of this constituent.

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[1] This is part of a broader study by Robert A. Pope. "Use of Soil Survey Information to Estimate Phosphate Sorption by Highly Weathered soils." Ph.D. Thesis, North Carolina State University. 1976. 82 pp.

Table 6.1:1. Range in characteristics of the soils used in P sorption studies.

| Property | Alfisols | | Ultisols | | Oxisols | |
|---|---|---|---|---|---|---|
| Horizon = | A | B | A | B | A | B |
| | n=2 | n=2 | n=9 | n=14 | n=3 | n=5 |
| Surface Area ($m^2/g$) | 17 -38.5 | 16.6-36.5 | 1.6-23.2 | 11.3-54.8 | 6.7-26.3 | 9.9-33.5 |
| Clay (%) | 9 -45 | 30 -50 | 6 -34 | 21 -64 | 16 45 | 16 -45 |
| pH (1:1 in $H_2O$) | 4.3- 4.7 | 4.4- 4.8 | 4.8- 6.7 | 4.3- 6.8 | 4.5- 5.3 | 4.3- 5.3 |
| pH (1:1 in KCl) | 3.6- 4.3 | 3.3- 4.9 | 4.2- 5.7 | 4.0 6.1 | 3.9- 4.2 | 4.0- 4.4 |
| Exch $Al^{+3}$ (me/100 g) | 0.1-10.7 | 0.1-20.1 | 0 - 0.5 | 0 - 5.2 | 0.3- 1.5 | 0.0- 1.7 |
| ECEC (me/100 g) | 3.8-18.7 | 2.4-27.2 | 0.6-12.2 | 2.4- 8.6 | 0.9- 4.5 | 0.3- 2.7 |
| Extractable P (ppm) | 1.0- 7.0 | 0.3- 4.6 | 0.6-20.9 | 0.1- 9.0 | 0.7- 2.8 | 0.2- 3.4 |
| Organic C (%) | 0.8 | 0.1 | 0.2- 2.9 | 0 0.4 | 0.8- 1.6 | 0.2- 1.0 |
| Free $Fe_2O_3$ (%) | 4.2- 5.7 | 1.9- 3.2 | 0.5-12.4 | 2.2-23.6 | 2.1-14.9 | 2.7-15.0 |

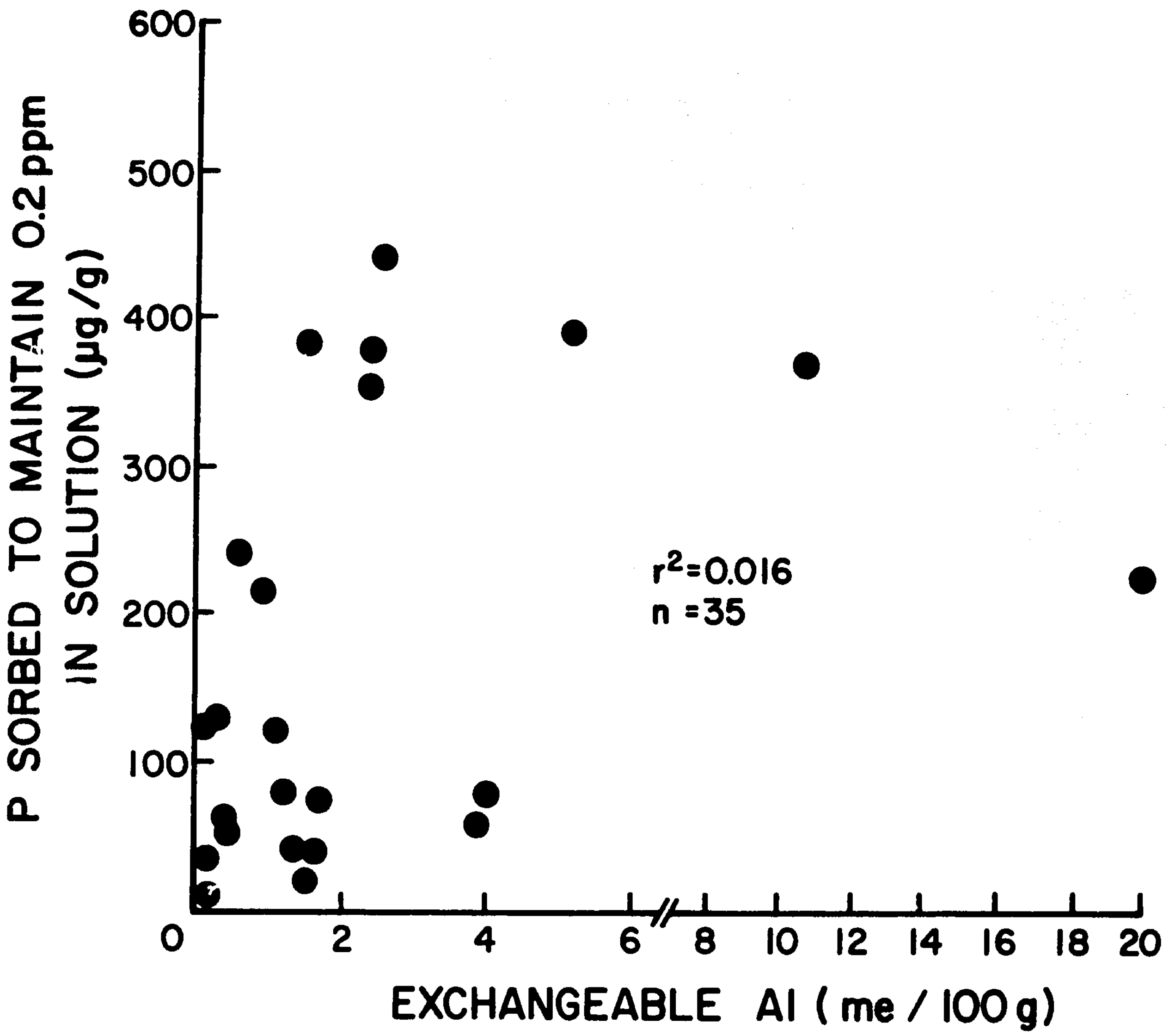


Figure 6.1:1. Relationship between P sorption at 0.2 ppm P in solution and exchangeable Al.

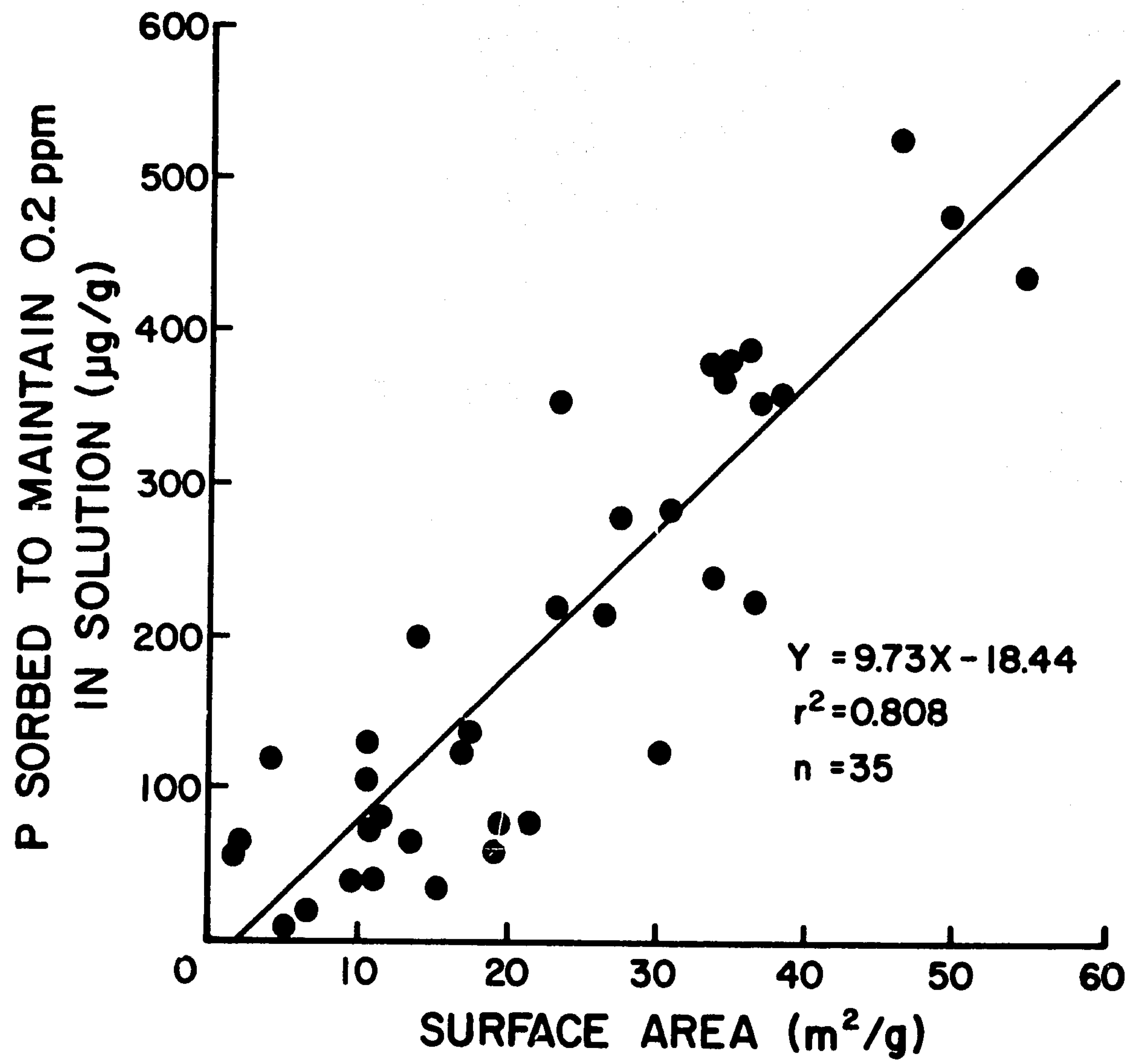


Figure 6.1:2. Relationship between P sorption at 0.2 ppm P in solution and surface area.

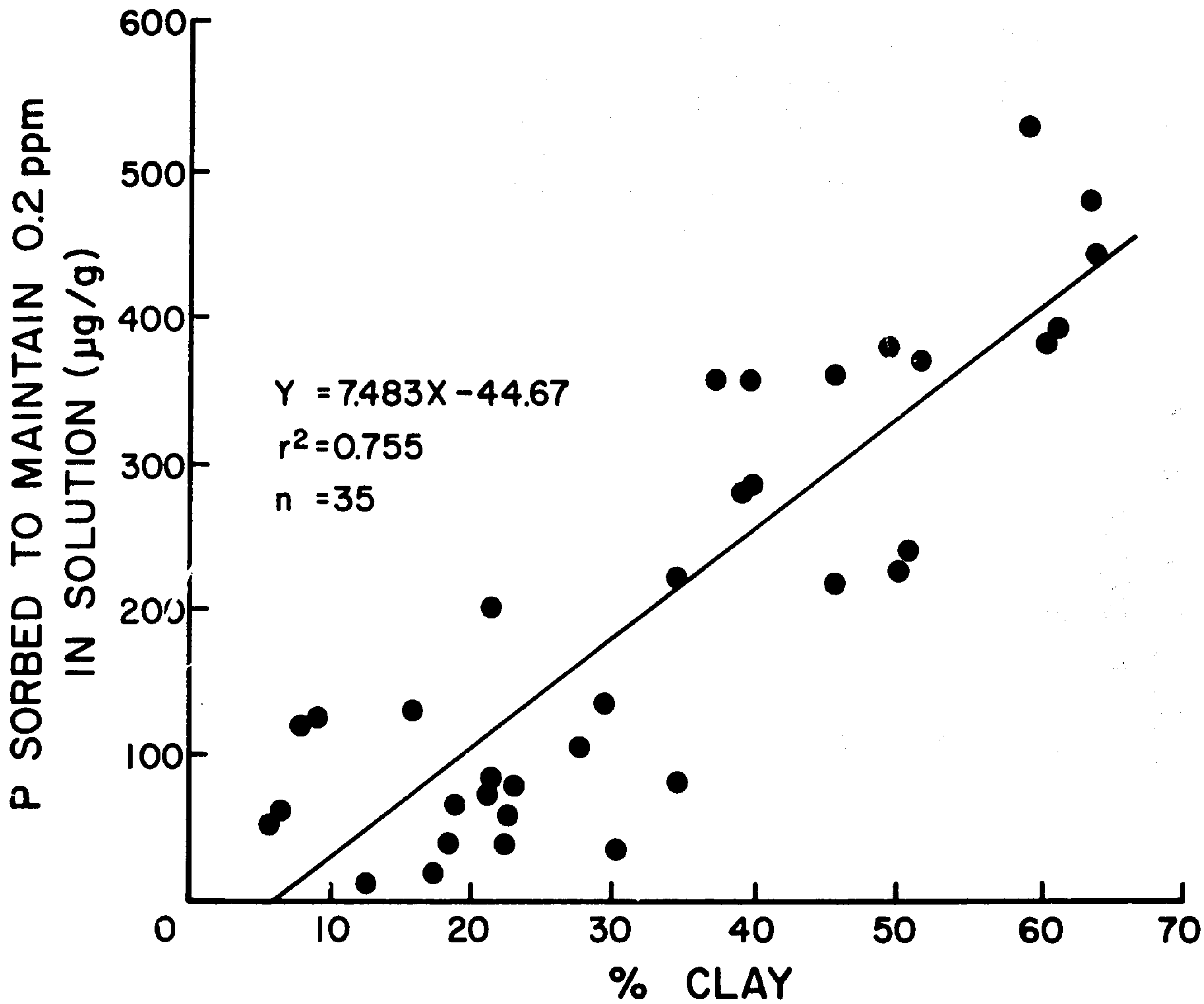


Figure 6.1:3. Relationship between P sorption at 0.2 ppm P in solution and percent clay.

The free iron oxide to clay ratio is also used in Soil Taxonomy to define highly weathered soils dominated by oxide minerals. The ratio does not separate soils on the basis of P sorption characteristics (Fig. 6.1: 4), but it does appear to provide a "threshold" value (0.15) above which excessive P sorption may occur if P-sorbing constituents are present in sufficient quantity. The quantity of active P-sorbing constituents is related to the clay percentage.

Therefore, the proposed criterion for rapidly identifying soils with a high P-sorption capacity is both a ratio of free iron oxides to percent clay greater than 0.15 and more than 35 percent clay in the plow layer.

## 6.2 SYSTEM ASSESSMENT IN THE U.S.

W. Couto

Information obtained from reports on experiments on soybeans (Glycine max L.) conducted between 1968 and 1973 by USDA/ARS, in cooperation with several Agricultural Experiment Stations was used for this study (U. S. Regional Soybean Laboratory, Program Reports, 1968-1973).[1] The total number of sites considered in this six-year period was 184 and were spread throughout the southeastern United States.

Properties and classification of soil series were obtained from official soil series descriptions of the National Cooperative Soil Survey, SCS and USDA. Analytical data were also taken from Soil Survey Investigations Reports (SCS, USDA). Actual pH values and nutrient availability were obtained from the experiment reports. Rainfall information was obtained from records from stations throughout the region (U. S. Department of Commerce).

For the purpose of this study a single soybean variety (Lee 68) was considered. The same five subregions considered originally for reporting results were considered separately early in this analysis. However, a preliminary F test to check differences in yields between the five regions showed no significant differences when tested against an "error mean square" composed of differences among years within areas and soils plus differences among sites within areas, soil, and years.

Sites were sorted according to both Soil Taxonomy categories and FCC units. When the 184 sites were sorted by FCC, 26 groups were created (Table 6.2: 1). It can be seen that a few number of groups accounted for most of the sites and there are also several groups with just a few observations. When grouped according to the Soil Taxonomy (Table 6.2: 2) a comparable number of units were observed at the level of subgroups.

It is interesting to note that soil types belonging to the same classification unit by FCC

[1] Appreciation is given to Dr. E. E. Hartwig for his authorization to use this information for the present study.

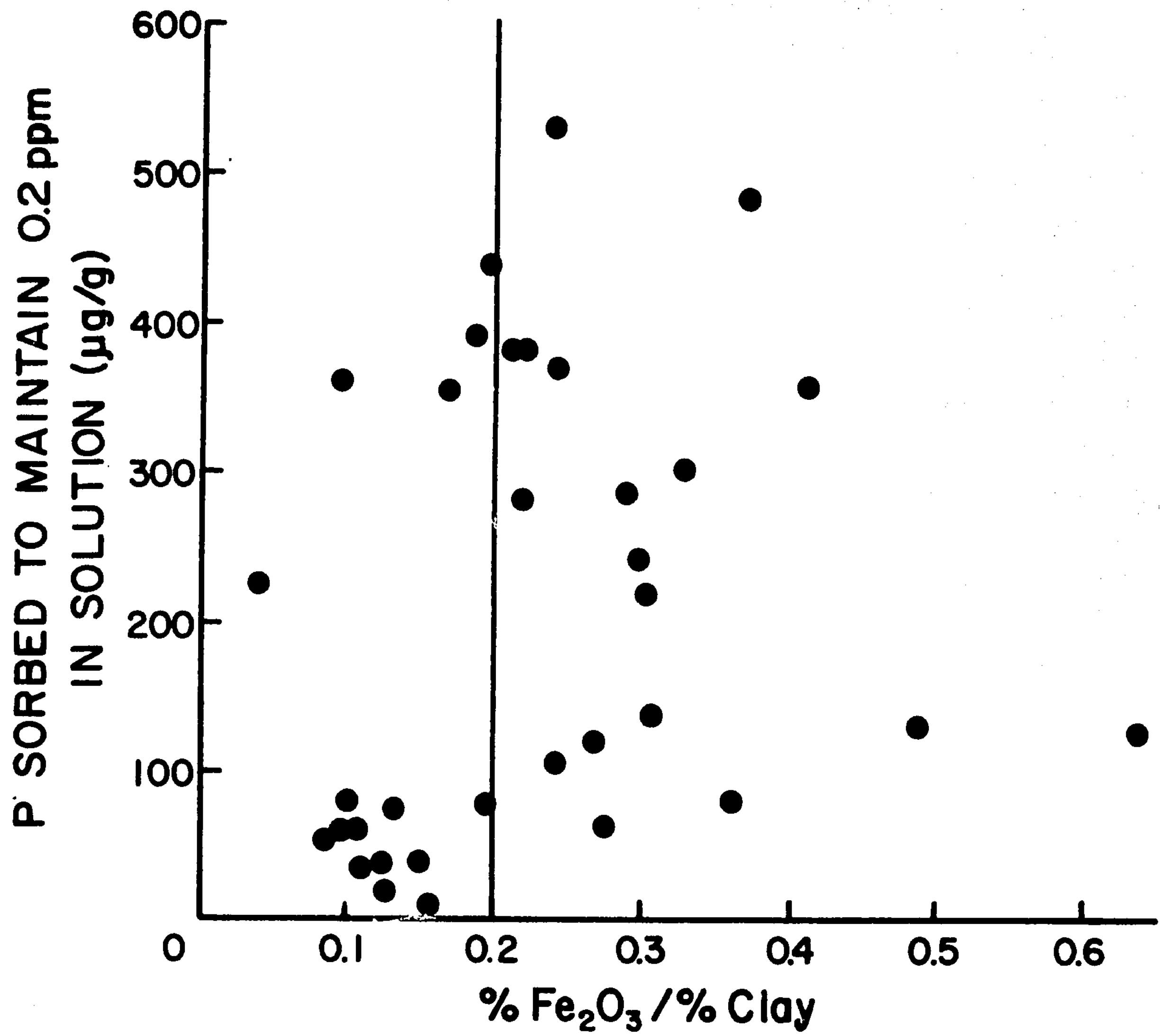


Figure 6.1:4. Relationship between P sorption and the free iron to clay ratio.

Table 6.2:1. Observed frequencies in FCC groups.*

| Type Subtype | Modifiers | Frequency | Total type Sub-type |
|---|---|---|---|
| | Frequencies in FCC groups | | |
| C | d g b | 4 | |
| C | e h k | 1 | |
| C | g h v | 2 | |
| C | g v b | 21 | 28 |
| L | - | 4 | |
| L | a | 3 | |
| L | d b | 14 | |
| L | e a k | 1 | |
| L | e h k | 38 | |
| L | e k | 4 | |
| L | g | 8 | |
| L | g e a k | 2 | |
| L | g h | 10 | |
| L | h | 18 | 102 |
| L C | d g b | 1 | |
| L C | e a k | 1 | |
| L C | e h k | 15 | |
| L C | e k | 1 | |
| L C | g a | 6 | |
| L C | g e a k | 4 | |
| L C | g h | 12 | 40 |
| S C | - | 1 | |
| S C | g h | 2 | 3 |
| S L | e h k | 9 | |
| S L | g h | 1 | |
| S L | h | 1 | 11 |
| Total of observations in 26 groups | | | 184 |

*Fertility Capability Classification System type, subtype, and modifiers as defined by Buol et al., 1975. "Soil Fertility Capability Classification" found in Soil Management in Tropical America edited by Bornemisza and Alvarado, NCSU, Raleigh, North Carolina.

Table 6.2:2. Number of classification units according to soil taxonomy and FCC.

| Fertility Capability Classifications | Units |
|---|---|
| Type-Subtype | 5 |
| Type-Subtype, Modifiers | 26 |
| U.S. Soil Taxonomy | Units |
| Orders | 5 |
| Suborders | 11 |
| Great Groups | 19 |
| Subgroups | 30 |
| Families | 38 |
| Series | 41 |

(Lehk) corresponded to different great groups of the soil taxonomy. On the other hand, some series (Norfolk, Tifton) belonged to different FCC units because of differences in surface texture which are given only at the level of soil type (Table 6.2:3). The most striking result was observed with Olivier, Morey and Collins series belonging to the orders Alfisol, Mollisol and Entisol, respectively, classified in the same FCC unit (Table 6.2:3).

The small number of observations in some of the classification units did not allow for a strong test of significance of the difference between means; however, some tendencies can be pointed out (Table 6.2:4). It was observed in all textural types that there was a trend towards lower yields when e and k modifiers were present. These modifiers indicated low CEC and low ability to supply K, respectively. Modifiers g, h, a and d were generally present in soils with high yields. This probably was due to the high level of soil management of all sites.

An attempt was also made to establish whether soil management practices were associated with soil fertility properties according to FCC. Records on liming were not available for all sites. It was assumed that all these soils presenting a pH value higher than the upper limit of the pH category indicated in the description of the series received lime. The upper part of Table 6.2:5 shows the number of sites and relative frequencies by FCC units of sites that were assumed to be limed. In those soils without an h modifier, the percent of sites that received lime was only 20% while 70% of the sites received lime when the h modifier was present. Eight out of ten sites with the a modifier were assumed to have been limed.

Potassium fertilizer, as estimated by soil test, was applied each year prior to planting date as required. When the k modifier was not present, 49% of the sites were fertilized with K fertilizers but 76% of the sites received K fertilizers when the k modifier was present (Table 6.2:5).

The observed yield for each site also was affected by factors other than those of the soil. Rainfall was considered one of the most important single factors responsible for yield variation. Variation between years, within a given soil and area was an important part of the error term in the general analysis of variance. As normal rainfall in each site of the area covered a rather large range, departure from the normal rainfall of each site was considered as a better index for explaining variation in yields from year to year. In an attempt to reduce the residual error, rainfall departures from normal for June, July and August were included in the analysis of variance as a covariable. Not one of these single variables had a significant effect in reducing the residual error. When sites were sorted by the g modifier, however, departure in excess of the normal for August had a significant effect. It is interesting to note that when the g modifier

Table 6.2:3. Classification of some soil series according to soil taxonomy and FCC.

| Type Subtype | Modifier | Series | Sub-groups |
|---|---|---|---|
| L | e h k | Sassafras sandy loam | Typic Hapludult |
| L | e h k | Norfolk fine sandy loam | Typic Paleudult |
| L | e h k | Tifton fine sandy loam | Plinthic Paleudult |
| L | e h k | Humphrey sandy loam | Humic Hapludult |
| L | e h k | Malbis fine sandy loam | Plinthic Paleudult |
| S L | e h k | Norfolk loamy fine sand | Typic Paleudult |
| S L | e h k | Tifton loamy sand | Plinthic Paleudult |
| L | g h | Olivier | Aquic Fragiudalf |
| L | g h | Morey | Typic Argiaquoll |
| L | g h | Collins | Aquic Udifluvent |

Table 6.2:4. Mean yields of some FCC units.

| FCC Modifiers | Soybean yields, kg/ha | Number of observations |
|---|---|---|
| L Type | | |
| none | 2760 | 4 |
| a | 2760 | 3 |
| h | 2659 | 18 |
| g | 2598 | 8 |
| d b | 2585 | 14 |
| e h k | 2430 | 38 |
| g h | 2322 | 10 |
| g e a k | 2262 | 2 |
| e k | 2161 | 4 |
| e a k | 1447 | 1 |
| LC Type | | |
| d g b | 3157 | 1 |
| g a | 2982 | 6 |
| e h k | 2787 | 15 |
| e k | 2787 | 1 |
| g e a k | 2598 | 4 |
| g h | 2450 | 12 |
| e a k | 1299 | 1 |
| C Type | | |
| d g b | 2450 | 4 |
| g v b | 2349 | 21 |
| g h v | 2187 | 2 |
| e h k | 2006 | 1 |

Table 6.2:5. Percent of limed sites in relation to the presence or absence of h, a, and k modifiers.

FCC Units and Liming

| Lime, % of a and/or h Modifiers | Limed % of total sites | Total number of sites |
|---|---|---|
| none | 20 | 44 |
| h | 70 | 74 |
| a | 80 | 10 |

FCC Units and Fertilization

| K Modifier | K fertilizer applied, % of total sites | Total number of sites |
|---|---|---|
| absent | 49 | 108 |
| present | 76 | 76 |

was not present, the excess rain did not affect yields but when the g modifier was present, the excess of rain reduced yields as shown by a negative regression coefficient. The results suggested a negative effect if excess summer rainfall occurs on soils with a poor drainage while well-drained soils were not affected.

## Summary

The results of this study with yield data from high level management practices, as related to units in the FCC System rather candidly illustrate the following points.

One, high level yields can be obtained on a variety of different soil conditions, if appropriate management practices are applied. The management practices needed are determined in a large part by soil properties.

Two, not all soil properties influence yield in the same way every year.

Three, although a wide variety of soils were included in the data it is obvious that only soils in which soybeans can be successfully and economically grown were selected by the researchers. Thus, the most useful aspects of soil classification, prediction of unsatisfactory soils, could not be tested with this data.

# ECONOMIC INTERPRETATION

To these small farmers in Latin America, the net return for their improved crop yields is as important as the actual yield increase produced by improved agronomic systems.

## 7.1 ECONOMIC INTERPRETATION

R. B. Cate, Jr. and A. J. Coutu

The initial economic analysis of experimental agronomic data relates to the area of Yurimaguas, Peru. The objective of the first phase of the analysis was to determine the economic viability of continuous cropping options under conditions of low-energy, modest-capital and labor-intensive production systems. Further, the analysis focused on the issue of the costs of isolation or low product and high factor prices.

The agronomic-economic analysis has involved the integration of Liebig's Law of the Minimum and standard linear programming procedures. Application of the Law of the Minimum has been put in mathematical form. R. B. Cate and Y. T. Hsu have developed an algorithm for least squares fitting and a PI-1 computer program has been written. N. C. Agriculture Experiment Station Bulletin No. 253, which presents a detailed example of how to use the Law of the Minimum to define production activities, is available. A modified example of this approach is explained by Table 7.1:1 and Fig. 7.1:1.

The initial analysis on experimental agronomic data was directed at isolating the way in which the various crops have responded to chemical applications when other environmental factors have not been limiting. Thus, a straightline response function has been estimated for each factor under "ideal" conditions. In this preliminary analysis, the equations for these responses have been combined, and the intersection points have been determined, graphically, where one or another factor has limited the response. These intersection points have been the basis for defining alternative ways of producing the crops. At this stage of the analysis, we have only attempted to define the combination of factors needed to produce at conservative maximum yield levels during different seasons. In the next stage, we plan to evaluate varying levels of fertilizer, pesticides, etc.

The various ways of producing the different crops, including the labor requirements when these production alternatives are carried out at different times, have been quantified, based on project experience, and introduced into an adaptation of the standard linear programming format. Specifically, the labor, working capital and land requirements for producing a ton of each crop studied have been defined using varying technologies, or combinations of production factors. These data were used in a linear programming technique to estimate the maximum net return to a family's land, labor and management. Considered were the size of the family labor force, alternative levels of operating capital, the farm-gate values of the various crops, and the farm-gate costs of the inputs.

This initial analysis focused on the potential of continuous cropping systems replacing conventional migratory systems on small family farms with no mechanization. The following conditions were assumed:

1. The land has been brought to a stable equilibrium after clearing and cultivation for roughly five years at adequate fertilizer and

Table 7.1:1. A modified example of the Cate-Hsu approach for agronomic production alternatives.

Step 1. Given data on mean yield levels as follows:

| Variable | Level | Observations | Mean Yield |
|---|---|---|---|
| | | No. | (ton/ha) |
| N | 0 | 3 | 10.0 |
| | 1 | 2 | 40.0 |
| | 2 | 1 | 50.0 |
| P | 0 | 2 | 20.0 |
| | 1 | 1 | 45.0 |
| | 2 | 0 | - |

Step 2. These reduce to the following:

$Y_N = 10 + 30N$

$Y_P = 20 + 25P$

$Y_{max} = 50$

Step 3. The number of production alternatives is equal to the number of variables plus one (for the maximum). In this example, they are:

Zero N = 10 tons/ha
.33N = 20 tons/ha
1.33N + 1.2P = 50 tons/ha

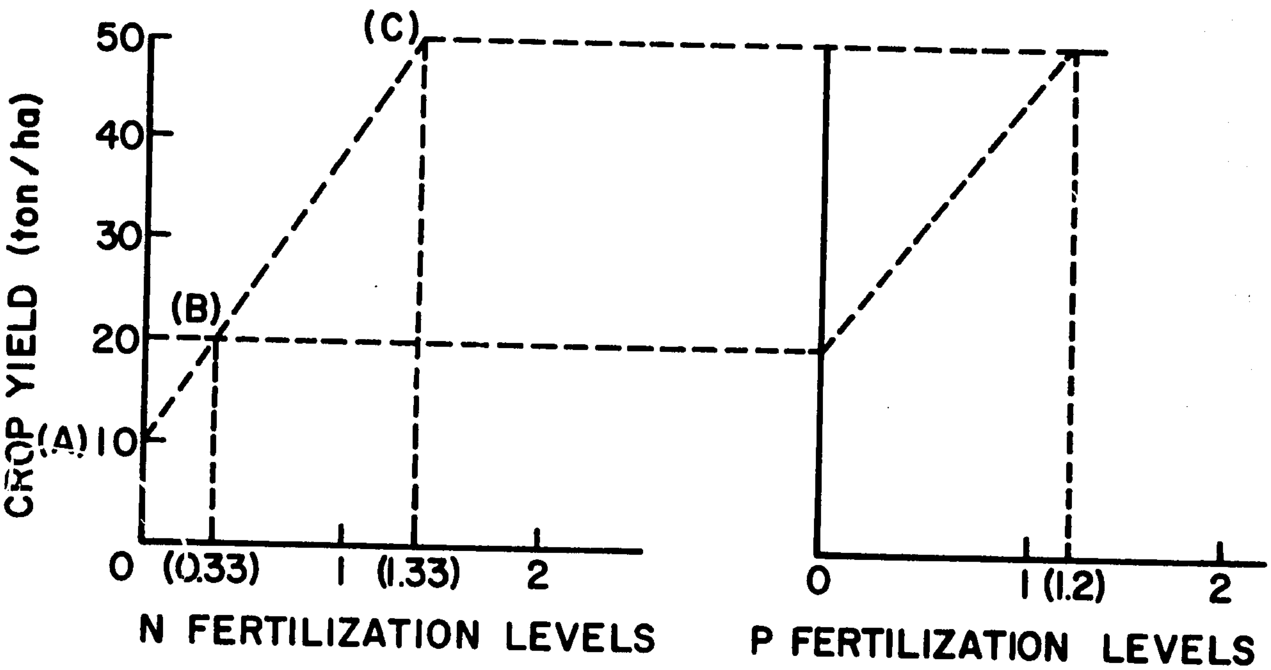


Figure 7.1:1. A graphical presentation of fertilization alternatives according to the Cate-Hsu approach.

lime rates which now permit the use of only maintenance applications. The only non-fertilized activity is a "slash-burn" rotation alternative which includes rice, cassava meal and plantains in a fixed proportion.

2. Only non-mechanized family labor is available.

3. Production can be marketed at the farm-gate at national prices discounted for the transfer and handling costs of a marketing system to centers for consumption. Estimates of transport costs are based on the existence of improved gravel roads from Yurimaguas to Lima.

4. All values are in Peruvian soles adjusted to December, 1975. (S/45 = $1.00).

5. Land availability is unlimited.

6. Cassava must be processed to meal before sale.

7. All crops except rice can be either hand-weeded or grown with herbicides. Rice is considered to not require weeding if planted immediately after burning. Otherwise, it must be cultivated with herbicide.

8. All crops can be planted over a month period without affecting yields. Cassava can be planted in any month with constant yields.

The most significant conclusions drawn from these preliminary analyses are summarized below:

1. Net income for a small farm family (net returns to labor, land, capital and management) can reach $6,000 per year assuming modest operating and investment capital requirements are each about $1,000 with the investment capital prorated over three years. Continuous cropping is estimated to require the use of between 3 and 4 hectares per family during any one month, totaling about 7 hectares per year. These potential family income levels can be compared with present average annual rural family incomes of $750 in the Yurimaguas area and $1,500 per year for the top 25 percent of families in the barriadas of Lima. These expected family incomes are premised on a family labor force of 1 male, the equivalent of one full-time child, and ½ of a female's time with no mechanization (Table 7.1:2).

2. Assuming only male labor, and similar capital restraints, continuous cropping of peanuts and soybeans still replaces the traditional slash/burn rotation, but net family income is estimated at only $2,000. Thus, the addition of the equivalent of one full-time child plus ½ a female results in more than doubling family net income (Table 7.1:2). Maximum area cultivated monthly varies from 1.6 hectares with just male labor to 3.9 hectares with the total family labor conditions. Because of the geometric problem introduced by varying planting dates, the total amount of land required varies from 3 to 7 hectares. An additional male would add only $3,000 to net family income as opposed to the $6,000 he could earn if he established an equivalent family farm. This suggests that commercial or communal farms based solely on male labor may be much less efficient than "nuclear family" operations.

3. At very minimal operating capital levels of less than $100, which replicates present farm capital levels obtained from foregone

Table 7.1:2. Estimated net returns, production and resources values with male labor only.

| Indicators | Unit | Operating Capital at $60/yr | Operating Capital at $460/yr | Operating Capital Unlimited |
|---|---|---|---|---|
| Net Revenue | ($) | 1,000 | 2,400 | 2,400 |
| Crops: | (tons) | | | |
| Cassava meal | | 1.32 | .54 | .54 |
| Soybeans | | - | 3.45 | 3.45 |
| Peanuts | | .11 | 3.12 | 3.12 |
| Typical rotation | | | | |
| Rice | | .93 | - | - |
| Cassava meal | | 1.05 | - | - |
| Plantains | | 1.85 | - | - |
| Cash used | ($) | 60 | 370 | 370 |
| Cash VMP | ($/day) | .16 | - | - |
| Range of Male VMP | ($/day) | 1.60-6.00 | 2.90-16.00 | 2.90-16.00 |
| Maximum area Used | (ha/month) | 1.81 | 1.55 | 1.55 |
| | | With male + child + 1/2 female | | |
| Net Revenue | ($) | 1,200 | 4,200 | 6,000 |
| Casava meal | (tons) | .68 | 2.74 | .54 |
| Soybeans | | | - | 8.03 |
| Peanuts | | | 8.04 | 10.81 |
| Typical rotation | | | | |
| Rice | | 1.61 | .28 | - |
| Cassava meal | | 1.83 | .32 | - |
| Plantains | | 3.23 | .56 | - |
| Cash used | ($) | 60 | - | - |
| Maximum area used | (ha/month) | 2.81 | 2.93 | 3.91 |

consumption, slash/burn rotations are optimal on some 2.8 hectares yielding a family net income of only $1,200. This compared favorably with current practices and income levels of some producers in the Yurimaguas area.

4. Throughout the many cropping, resource and marketing conditions considered, conventional intercropping options do not enter the optimal solutions. This preliminary result may be due to incomplete input/output coefficients on the effects of residual fertility and shading, or to the rigidity of the crop mix options. However, it seems likely that the true reason is that what has been described as intercropping is actually comparable to U.S.–style home gardens. If so, there may be large economies in research since recommendations can be based on monocrop experiments, as is done in the U. S.

5. There are marked effects from varying technological practices when the comparison is made with the complete family labor situation and no capital constraints. These preliminary estimates suggest that restrictions on planting dates (i.e., not permitting staggered planting options) can decrease net family income by $2,400 (Table 7.1:3). Similarly, the failure to use herbicides in place of labor to control weeds results in a similar decline in net family income. The agronomically desirable practice of forced fallowing to control pests has almost the same impact where net family incomes decline by some $1,300 per year. This raises the question of the cost of plant sanitation measures.

6. Peru is annually importing an increasing quantity of plant oil products. However, a marked structure for soybeans, peanuts cowpeas and sorghum does not exist in the Yurimaguas area. Assuming that this condition persists and no markets are developed, net family incomes assuming no capital constraints decline from $6,000 to about $2,000 (Table 7.1:4). The production system moves to continuous cropping of rice, cassava and beans with small amounts of the traditional rotation. However, even if prices for peanuts and soybeans are assumed at levels of 40 percent below the original estimated, net family incomes decline by only $2,200. Obviously, soybeans and peanuts in a continuous cropping system utilizing fertilizers, lime and herbicides are very profitable alternatives.

7. These results have several implications for agronomic research priorities. Among the points which should be emphasized are:

a. Herbicide alternatives

b. Tools for peak periods

c. Grain legumes

d. Varietal tolerance to Al toxicity and P deficiency.

e. Intercropping effects (shading, weed control, residual fertility and disease)

As initially programmed the next agro–economic analysis for the Yurimaguas area will involve the following:

1. Specification of input/output coefficients for varying yield levels for all major crops–this component of the improved model involved the aggregation of controlled agronomic experiments in the Yurimaguas area.

2. Development of a land-use capability system providing for livestock options in the model.

Table 7.1:3. Estimated net revenues, production and resource values with changes in production practices with unlimited operating capital.

| Indicators | Unit | Base* | No herbicide option | No planting Date options | Forced Fallow |
|---|---|---|---|---|---|
| Net revenue | ($) | 6,000 | 3,600 | 3,600 | 4,700 |
| Crops: | (tons) | | | | |
| Cassava meal | | .54 | .96 | .55 | 1.55 |
| Soybeans | | 8.04 | .57 | 4.22 | 8.51 |
| Peanuts | | 10.81 | 7.53 | 5.42 | 6.16 |
| Rice | | 1.03 | 1.94 | 1.5 | 2.14 |
| Sorghum | | - | - | 2.36 | |
| Cowpeas | | - | - | .77 | - |
| Cash Used | ($) | 950 | 480 | 620 | 750 |
| | ($/day) | 2.80-20.00 | 2.00-20.00 | 0-27.00 | 1.00-29.00 |
| Range of female VMP | ($/day) | 0-25.00 | 0-16.00 | 0-27.00 | 0-24.00 |
| Range of Child VMP | ($/day) | 0-11.00 | - | 0-9.00 | 0-12.00 |
| Maximum area used | (ha/mo) | 3.91 | 2.2 | 3.3 | 3.3 |

*Base assumes unlimited operating capital; male plus child plus 1/2 female labor with full transferability of male labor.

Table 7.1:4. Estimated net revenues, production and resources values with changes in marketing options with unlimited operating capital.

| Indicators | Unit | Base* | No markets Peanuts, Soybeans Sorghum & Cowpeas | Double Chemical Costs | Peanut & Soybean Prices reduced 20% | Peanut & Soybean Prices reduced 40% |
|---|---|---|---|---|---|---|
| Net revenue | ($) | 6,000 | 2,030 | | 4,600 | 3,100 |
| Crops: | | | | | | |
| Cassava meal | | .54 | 1.86 | 2.34 | .54 | .41 |
| Cassava meal** | | 8.03 | .05 | | | |
| Soybeans | | 8.03 | - | | 8.03 | 6.37 |
| Peanuts | | 10.81 | - | 10.08 | 10.81 | 11.15 |
| Rice | | 1.03 | 5.02 | | 1.03 | 1.78 |
| Beans | | | 2.69 | | | |
| Sorghum | | - | | | - | .46 |
| Typical rotation: | | | | | | |
| Rice | | - | .46 | | - | - |
| Cassava meal | | - | .53 | | - | - |
| Plantains | | - | .93 | | - | - |
| Cash used | ($) | 940 | 460 | 1,150 | 930 | 930 |
| Range of male VMP | ($/day) | 3.00-28.00 | 4.00-9.00 | 2.30-8.00 | 4.50-21.00 | 3.00-14.00 |
| Range of female VMP | ($/day) | 0.25.00 | 0-5.00 | 2.30-8.00 | 0-16.00 | 0-9.00 |
| Range of child VMP | ($/day) | 0-12.00 | 0-2.00 | 0-5.00 | 0-9.00 | 0-0.00 |
| Maximum area used | (ha/mo) | 3.91 | 4.8 | 2.6 | 3.9 | 4.05 |

*Base assumes unlimited operating capital; male + child + 1/2 female with full transferability of male labor
**Cassava meal produced without use of herbicide.

3. Development of input/output coefficients for perennial crops such as sugar cane, pineapple, etc.

4. Introduction of simple mechanical investments as a means to enhance labor productivity.

These additional components will serve to further describe the economic potential of chemical and staggered continuous planting options over the slash/burn system.

Also, as originally structured, another important agro-economic analytical component involves the study of alternative developmental paths to achieve these results from continuous cropping systems on small family farms. Knowledge of such options may be important to regional developers and potential settlers in the Yurimaguas area.

# EXTRAPOLATION

Ings. Eduardo [illegible], Luis Aguirre, Carlos Roca (Bolivia's Comite de Obras Publicas) and Dr. Walter Couto (formerly NCSU) (left to right) sample soils in eastern Bolivia for extrapolation purposes. 1977.

Experimental information obtained at Yurimaguas and Brasilia can be applicable to other areas of similar soil—crop—climate characteristics. To verify this applicability to other areas of the world, the Tropical Soils Research Program is developing a network of experimental sites in which soil and crop management practices are tested and adapted to local needs. The extrapolation is a cooperative work with local institutions which provide local facilities, personnel and inputs for experimental work. NCSU provides advice on research planning, experimental design and interpretation, soil characterization, short term consultants, and library and laboratory support. Formal training of selected host institution scientists is also foreseen. This will include academic work at Raleigh and host country-based thesis research under NCSU faculty supervision.

As a first step, extrapolation will be conducted in tropical South America. Later on, the extrapolation network will include areas of Africa and Southeast Asia. Several institutions from South America have indicated their interest in joining the extrapolation network. Actual work was initiated at Pucallpa, Peru, in cooperation with the Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA) in 1976.

## 8.1 PUCALLPA

W. Couto

The Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA) is a specialized research institution atttached to the Universidad Nacional Mayor de San Marcos, under the direction of Dr. Dante Castagnino. The Estación Principal del Trópico (Main Tropical Station) is part of IVITA and is located near Pucallpa, about 30 km SE from Yurimaguas in the Amazon Jungle of Peru on the Ucayali River.

A cooperative program was developed with IVITA as part of the present one operating in Peru since 1972 in cooperation with the Ministerio de Alimentación. Objectives of the Extrapolation Network were as outlined earlier. The executive unit at Pucallpa is the Linea de Investigación en Producción y Evaluación de Pasturas Tropicales (Tropical Pasture Production and Evaluation Research Line) and the Soil Science Department of "La Molina" Experiment Station. Dr. José Toledo is in charge of the Tropical Pasture Production and Evaluation Research Line and, as such, he is directing all extrapolation-related activities at Pucallpa.

Most agricultural soils in Pucallpa are Typic Paleudults with similar fertility management problems, Leak or LCeak, as the Leak soils of Yurimaguas. A detailed soil map of the Experimental Station is being made to facilitate location of field experiments of the most representative sites. Soil characterization and classification also are being completed. Based on Yurimaguas findings, Brachiaria (Bracharia decumbens) and yaragua (Hyparrhenia rufa) response to lime, P and N rates were investigated in field experiments in 1977 at Pucal-

Ipa. Data are undergoing analysis. Continuous cropping experiments are being initiated in a newly cleared area of the representative soils.

## 8.2 OTHER EXTRAPOLATION SITES

W. Couto

Plans for expanding the extrapolation network to other South American countries are underway. Research and educational institutions from Colombia, Ecuador, Guyana, Paraguay and Venezuela have expressed their interest in joining the network. In addition, the Universidad Nacional de la Amazonia Peruana (UNAP) joined the extrapolation program in 1977. Field experiments on kudzu fallow and cropping systems for newly cleared areas were started at their research farm near Iquitos, Peru in 1977.

# COMMUNICATIONS OF RESULTS

From left to right in foreground listening to Wilson Soares (former research scientist at CPAC) explain the joint CPAC NCSU/Cornell agronomic research are Alysson Paulinelli (Minister of Agriculture of Brazil), Ernesto Geisel (President of Brazil), Ricardo Pereira Carvalho, (former Director of CPAC), Wenceslau Goedert (Associate Technical Director of CPAC) and Dale Bandy (former Cornell graduate researcher at CPAC). Directly behind President Geisel (with his face partially hidden) is Almiro Blumenschein (Executive Director of EMBRAPA). CPAC, Planaltina, Federal District, Brazil. January, 1976.

The Program's utilization philosophy is to disseminate its results as quickly as possible to the national research and extension organizations, which are responsible for delivering this information to farmers in tropical countries. This is accomplished by technical publications, including this Annual Report, mailing such publications in the appropriate language to the desired audience and active participation in scientific and policy-making meetings upon invitation from developing country authorities.

## 9.1 PUBLICATIONS

B. I. Monar

The following papers were published by program staff in scientific journals, books or theses during the report period of 1976 through mid-1977.


**1976**

Gonzalez-Erico, Enrique. 1976. Effect of depth of lime incorporation on the growth of corn in Oxisols of Central Brazil. Ph.D. Thesis. North Carolina State University, Raleigh. 126 pp.

Moura-Filho, W. and S. W. Buol. 1976. Studies of a Latosol Roxo (Eutrustox) in Brazil: Micromorphology effect on ion release. Experientiae 21:161-177.

Oelsligle, D. C., R. E. McCollum, and B. T. Kang. 1976. Soil fertility management in tropical multiple cropping. ASA Special Publication No. 27, American Society of Agronomy. p. 275-292.

Perrin, R. K. 1976. The value of information and the value of theoretical methods in crop response research. Amer. Jour. of Agr. 58:54-61.

Pope, R. A. 1976. Use of soil survey information to estimate phosphate sorption by highly weathered soils. Ph.D. Thesis, North Carolina State University, Raleigh. 82 pp.

Sanchez, P. A. 1976. Multiple Cropping: An appraisal of present knowledge and future needs. ASA Special Publication No. 27, American Society of Agronomy. p.373-378.

Salinas, J. G. and P. A. Sanchez. 1976. Soil-plant relationships affecting varietal and species differences in tolerance to low available soil phosphorus. Ciência e Cultura 28 (2):156-168 (A Portuguese version of the article is also available).

Sanchez, P. A. 1976. Properties and Management of Soils in the Tropics. John Wiley and Sons, New York, New York. 618 pp.

Smyth, T. J. 1976. Comparison of the effects of phosphorus, lime and silicate applications on phosphorus sorption, ion exchange and rice growth in an Oxisol from the Cerrado of Brazil. M. S. Thesis. North Carolina State University, Raleigh. 138 pp.

**1977**

Bigham, J. M. 1977. Iron mineralogy of red-yellow hued Ultisols and Oxisols as determined by Mössbauer spectroscopy, X-ray diffraction and supplemental laboratory techniques. Ph.D. Thesis. North Carolina State University, Raleigh. 165 pp.

Cordero, A. 1977. Principles of intercropping: Effects of nitrogen fertilization and row arrangement on growth, nitrogen accumulation, and yield of corn and interplanted understory annuals. Ph.D. Thesis. North Carolina State University, Raleigh. 158 pp.

Visitors Who Have Toured Experiments at CPAC

On January 3, 1976, President Geisel and the Minister of Agriculture, Alysson Paulinelli, toured our experiments and the following week Minister of the Interior, Rangel Reis, visited our experiments during a tour of the CPAC.

In March 1976 more than 30 extension agents, representing the staff of the crop-farming area of the State of Goiás participated in an intensive tour of CPAC and our experiments.

## 9.4 UTILIZATION AT FARMER LEVEL

Results of our research were presented at a meeting of 60 extension agents, researchers and farmers of the Minas Triangle at Patrocinio, Minas Gerais, August 11-14, 1975 by Dr. Wenceslau Goedert and Mr. Wilson Soares. A similar presentation was made at Jataí, Goiás, to 80 farmers, researchers and extension agents of the Southwestern region of Goiás, February 24-26, 1976; Ing. Edson Lobato and Dr. Wenceslau Goedert gave recommendations and results on fertilizers and liming.

At the request of Ings. Gonçalo Evangelista de França and Antonio Bahia Filho, soil scientists from the National Center for Corn and Sorghum, Ing. José Salinas had a series of discussions with them and with Dr. R. B. Clark in early December 1975 covering the various aspects of his research program on simultaneous screening for high aluminum and low phosphorus tolerance in crop plants. These discussions constituted a concrete contribution to the initiation of this line of research at the National Center for Corn and Sorghum.

At the research planning conference for the Cerrado Region held in Brasilia, July 19-23, 1976, CPAC, which is responsible for coordinating and guiding agricultural research work on Cerrado soils, the results of the soils research were presented to the assembled 75 researchers representing 10 research entities.

Since the formation of CPAC about 200 extension agents and key farmers have participated with researchers in elaborating "technical packages of agricultural practices" for advanced production. The fertilizer and soil management recommendations are based, on a large part, on the research carried out in cooperation with the university contracts.

Cordero, A. and R. E. McCollum. 1977. Yield potential of interplanted annual food crops in North Carolina. Soil Science Society of North Carolina Proceedings. Vol. XX. p. 35-65.

Cox, F. R. and J. I. Wear. 1977. Diagnosis and corrections of zinc problems in corn and rice production. Southern Coop. Ser. Bull. 222, North Carolina State University, Raleigh. 73 pp.

Kamprath, E. J. 1977. Phosphorus fixation and availability in highly weathered soils. In Simpósio Sobre o Cerrado. São Paulo, Ed. da Universidade de São Paulo. p. 333-347.

Lepsch, I. F., S. W. Buol and R. B. Daniels. 1977. Soil-landscape relationships in the Occidental Plateau of São Paulo state, Brazil. I. Geomorphic surfaces and soil mapping units. Soil Science Soc. of Amer. Jour. 41: 104-109.

Lepsch, I. F., S. W. Buol and R. B. Daniels. 1977. Soil-landscape relationships in the Occidental Plateau of São Paulo state, Brazil. II. Soil morphology, genesis, and classification. Soil Sci. Soc. Amer. Jour. 41: 109-115.

Lopes, A. S. 1977. Available water, phosphorus fixation and zinc levels in Brazilian Cerrado soils in relation to their physical, chemical, and mineralogical properties. Ph.D. Thesis. North Carolina State University, Raleigh. 189 pp.

Yost, R. S. 1977. Effect of rate and placement on availability and residual value of P in an Oxisol of Central Brazil. Ph.D. Thesis. North Carolina State University, Raleigh. 160 pp.

Yost, R. S., E. J. Kamprath, G. C. Naderman and E. Lobato. 1977. Effeito de Níveis e Métodos de Aplicação de Fosforo na produção de milho em um solo de Cerrado do Brasil Central. Anais do XV Congresso Brasileiro de Ciência do Solo. Campinas, S. P., Brasil. p.303-307.

## 9.2 MAILING LIST

D. M. Silsbee

Requests for publications increased by 87%, raising the total listing of individuals and institutions on our mailing list to 1505 scientists, administrators, private companies, students and libraries which receive this service free of charge in 91 countries around the world. Thirty-one additional countries were placed on the mailing list for the 1976-1977 period. Almost half of the entries on the mailing list (742) go to 24 countries in Latin America. More than one-fourth (408) go to the United States and Canadian addresses, many of which serve as forwarding addresses to other countries; but most serve scientists, development institutions, libraries and foreign students. As result of closer working relationships with Africa, the listings for this region almost doubles to 114, which are distributed in 23 countries. Asia's listings increased to 133 entries spread in 17 countries and Europe's to 82, spread in 12 countries. Any individual or institution requesting this service is eligible to be placed on the tropical soils mailing list.

## 9.3 CONFERENCES AND SYMPOSIA

B. I. Monar

The communication process is facilitated by the participation of Program staff in scientific and policy-making meetings. Program staff members were invited to participate in key meetings in various countries during the report period of 1976 through mid-1977. A short description of the more formal meetings follows:

**1976**

World Food and Nutrition Study. National Academy of Sciences.

Dr. Pedro A. Sanchez formed part of the sub-group 4B (Resources for Agriculture: Land and Water) on this study. A five volume publication, with recommendations of actions to be taken, was released in early 1977.

Workshop on Soil and Water Management in Tropical Agriculture. International Institute of Tropical Agriculture, Ibadan, Nigeria, May 15-29, 1976.

Dr. Keith Cassel gave 11 formal lectures on field water balance techniques, current trends in U. S. erosion research, reclamation of eroded soil, soil physical measurements necessary for initiating erosion control research, field measurement of soil moisture potential, and the Purdue rainfall simulator. In addition, Dr. Cassel helped with several field and lab demonstrations dealing with water movement and water content studies. Mr. Hugo Villachica, upon invitation, also attended and participated in this workshop.

Cerrado Symposium. Brasília, Brazil, June 19-25, 1976.

A. Drs. Eugene J. Kamprath, Pedro A. Sanchez, K. Dale Ritchey, José Salinas and Walter Couto participated in this symposium sponsored by the National Academy of Sciences.

B. Mr. Edson Lobato and Mr. José Salinas prepared a paper on "Considerações Sobre o Manejo de Solos de Cerrados" which was presented by Edson Lobato at this symposium.

C. Mr. Alfredo Lopes presented the paper "A Survey of the Fertility Status of Soils Under "Cerrado" Vegetation in Brazil."

Reunião de Programação de Pesquisa na Região Dos Cerrados. Brasília, Brazil, July 19-23, 1976.

Dr. K. Dale Ritchey attended and participated in these meetings.

Fourth National Congress of the Venezuelan Society of Soil Science. Monagas, Venezuela, August 24 - September 3, 1976.

Dr. Pedro A. Sanchez presented results of the Tropical Soils Research Program at Yurimaguas and Brasilia and Dr. W. Couto presented the Fertility Capability Soil Classification System. Both papers were invited. Drs. Sanchez and Couto also advised the Universidad de Oriente on soil management in eastern plain savannas of Venezuela.

XI Reunião Brasileira de Ciência do Solo. Fortaleza, Brazil, October 24-30, 1975.

Dr. K. Dale Ritchey and Mr. Edson Lobato's paper "Efeito da Adubação com Potassio e Magnesio na Cultura do Milho num Oxisolo do Distrito Federal, nota previa" was presented by Wenceslau Goedert. Meeting was sponsored by the Sociedade Brasileira de Ciência do Solo.

Santo Domingo, Dominican Republic, November 1-10, 1976.

Dr. Robert B. Cate discussed with Dominican Republic government officials how the type of statistical economic analysis currently being used by NCSU in its Tropical Soils Research Program might be extended to the Dominican Republic in such a way as to complement both the LA/DR agricultural sector analysis activity and the USDA/PASA on identification of natural resources and appropriate technologies.

National Meeting on Science and Technology and Development. Washington, D. C., November 17, 1976.

Dr. Pedro A. Sanchez attended and participated in this meeting, held at the State Department upon invitation of Secretary of State Kissinger.

Adaptation of Plants to Mineral Stress in Problem Soils. Beltsville, Maryland, November 22-23, 1976.

Dr. Pedro A. Sanchez and Mr. José Salinas attended and participated in this workshop.

American Society of Agronomy Annual Meeting. Houston, Texas, November 28-December 2, 1976.

A. Bigham, J. M., D. C. Golden, L. H. Bowen, S. W. Buol and S. B. Weed. Mössbauer study of iron oxides in selected Ultisols and Oxisols.

B. Couto, W., S. W. Buol and P. A. Sanchez. The use of soil characterization information on soil fertility studies.

C. Golden, D. C., J. M. Bigham, L. H. Bowen, S. B. Weed and S. W. Buol. Mössbauer study of synthesized aluminum substituted goethites.

D. Weed, S. B., D. C. Golden and J. M. Bigham. Properties of aluminum substituted goethite.

**1977**

Symposium on Soil Management in the Humid Tropics. Manaus, Brazil, February 28 to March 1, 1977.

These meetings were organized by CNPq (Conselho Nacional de Desenvolvimento Cientifico e Tecnologico), at the Instituto Nacional de Pesquisas de Amazonia (INPA). Dr. Walter Couto gave an invited paper which contained an overview of NCSU's Tropical Soils Research Program.

IITA Third Annual Meeting to Review Collaborative Research on Soils of the Tropics. Reading, England, March 28 - April 2, 1977.

Dr. S. W. Buol presented a paper discussing the Fertility Capability Classification system and Dr. P. A. Sanchez discussed the Tropical Soils Research Program's fertility work in Peru and Brazil.

Lectures

A. A series of lectures on his thesis research work conducted at CPAC was given by Mr. Dale Bandy at the Faculdade de Medecina Veterinaria, Agronomia e Zootecnia Professor Antonio Ruete de Jaboticabal, São Paulo in January 1976.

B. Presenting lectures on their research work conducted at CPAC, Mr. R. S. Yost, Mr. Dale Bandy and Ing. José Salinas at the Centro de Pesquisas Agropecuarias dos Cerrados. These lectures were presented during 1976 and were attended by the research personnel of CPAC.