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ANNUAL REPORT FOR 1973

SOIL SCIENCE DEPARTMENT

NORTH CAROLINA STATE UNIVERSITY

RALEIGH, NORTH CAROLINA

under
Contract AID/csd 2806
with the
U. S. Agency for International Development

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INTRODUCTION

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INTRODUCTION

This is the third annual report of the Soil Science Department's tropical soils research program supported by Contract AID/csd 2806 with the United States Agency for International Development. The overall objective of this program is to provide new and relevant information to adequately characterize and manage extensive tropical soils for increased food production. The geographic emphasis is in Latin America, but the results are expected to be applicable to other tropical regions with similar environmental conditions.

During the first two years of operation, our activities were concentrated on a comprehensive review of the literature on soils research in Tropical America and extensive travel. Several critical research priorities were identified and arrangements were made with local institutions for cooperative activities. Three major field projects were identified: the fertility and management requirements of Oxisols of tropical savannas, the fertility and management requirements of Ultisols presently under shifting cultivation in tropical rainforests and how to intensify production in small farming units in Central America. Specific sites were selected for these three major ecological regions and cooperative agreements were made with local institutions.

In order to extrapolate and permit realistic economic interpretation of results gathered elsewhere, several region-wide projects were conducted. They include the development and testing of a fertility-capability soil classification system, the economic analysis of crop response data, and supporting laboratory and greenhouse studies on soil characterization, microbiology, chemistry, and fertility.

The activities during 1973 reflect the first full year of operation at the research stations in Brasilia, Brazil; Yurimaguas, Peru; and Turrialba, Costa Rica. The latter location serves as the headquarters for research activities in Central America. Figure 1 shows the principal research locations. Supporting research was conducted with soils or data in the countries shaded in the map.

HIGHLIGHTS OF THE YEAR

Campo Cerrado of Brazil

Studies in the Campo Cerrado of Brazil indicate that the management of these Oxisols is primarily a matter of fertility and subsoil moisture interactions. Liming to raise the pH

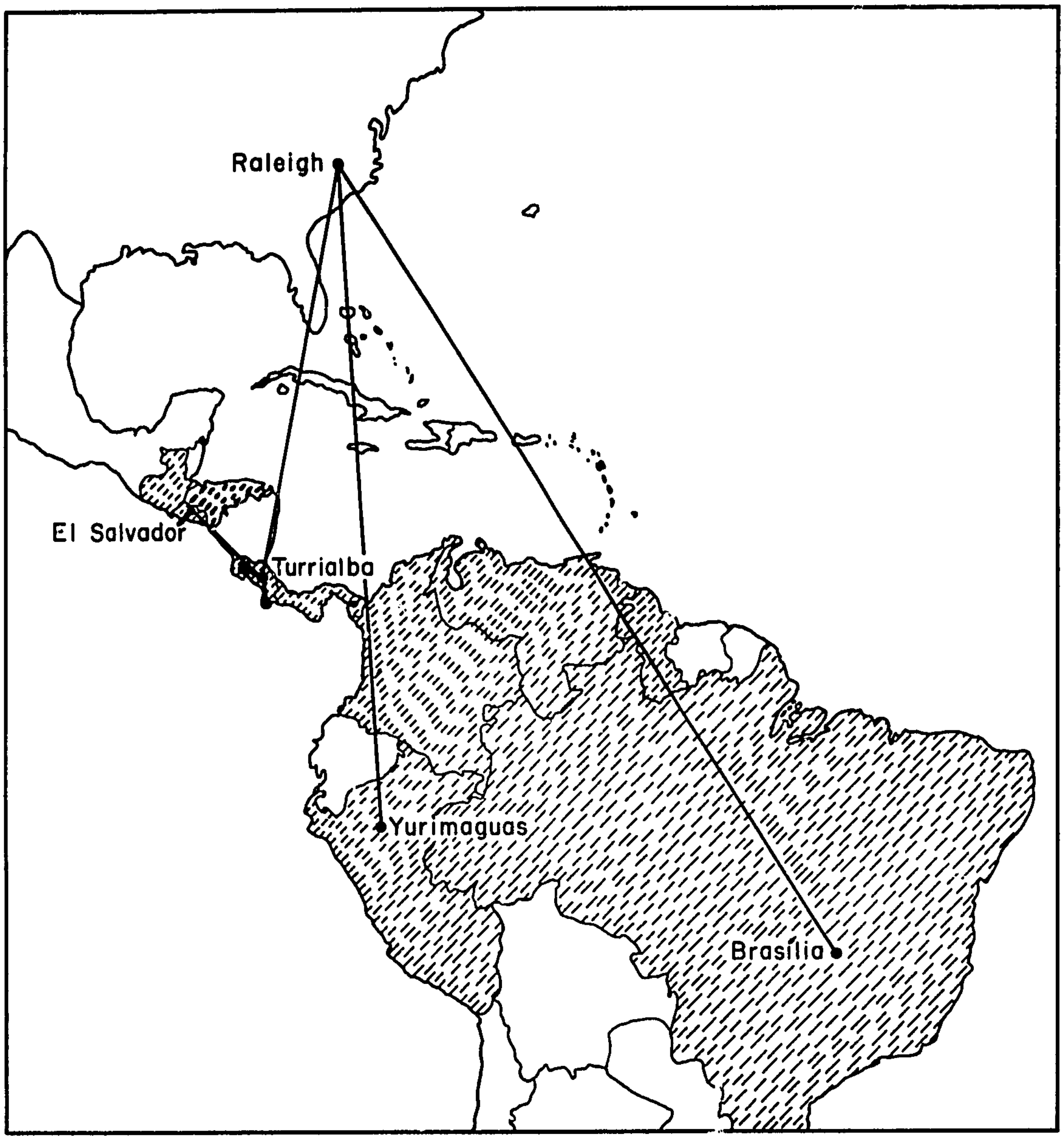


Figure 1. Map of tropical Latin America showing principal field research sites. Region-wide studies have been conducted in or with soils of the countries shaded.

to 5.5 in the top 30 cm of the soil increased corn yields and decreased moisture stress during critical short-term droughts that occur during the rainy season. Only a moderate rate of 2 tons/ha when incorporated in the top 30 cm was necessary to produce high corn yields in the first two crops. The estimated investment in lime, about US $ 20/ha is less than previously thought necessary to eliminate aluminum toxicity to corn in these very acid soils.

Although applications of nitrogen, potassium, and zinc are also necessary in these soils the amounts required are also within the economic range. The management of phosphorus, however, is the primary fertility problem due to the extremely high phosphorus fixation capacity of these Oxisols. The "Dark Red Latosol" on which the experiments were conducted requires the equivalent of about 2800 kg P_2O_5/ha to provide the desired amount of phosphorus in the soil solution. Broadcast applications were superior to banded applications during the first rainy season crop because they promoted more root development which in turn atenuated the effects of short-term droughts. In the subsequent irrigated dry season crop, banded applications were superior. These results suggest that a corrective level of broadcast phosphorus supplemented by banded applications with each crop may be the best management scheme. The high cost of such phosphorus applications using ordinary superphosphate raises serious economic questions. Other sources such as rock phosphates plus ammendments designed to decrease fixation such as silicates are being evaluated.

Outreach studies on the properties and distribution of Campo Cerrado soils indicate a remarkable uniformity in terms of low fertility and points out the areas where different results might be expected due to soil or climatic properties.

Amazon Jungle

Characterization studies of the Amazon Jungle soils indicate that Ultisols rather than Oxisols are the predominant well-drained soils of the Amazon Basin outside of the geological influence of the Guyana and Brazilian shields. These soils have management characteristics quite different from the Oxisols. Phosphorus fixation capacity is much lower than in the Brazilian Oxisols due to coarser topsoil texture and different mineralogy.

Experiments on land clearing methods in Ultisols in Yurimaguas showed that the traditional slash and burn practice was superior to mechanized clearing with a bulldozer. Yields of upland rice, cassava, pastures, corn, sorghum, and beans were consistently higher in the slash and burn system at several fertility levels. The fertilizer value of the ash, the severe compaction measured in the bulldozed plots and the movement of the topsoil by the bulldozer blade are the factors thought to be responsible for these differences. Continuous cropping in this jungle Ultisol is feasible with moderate applications of lime, nitrogen, phosphorus, potassium, and in some instances sulfur, boron, and molybdenum. High yields were obtained with upland rice, cassava, and *Panicum maximum* pastures. Corn and beans seem to be more sensitive to pests, aluminum toxicity and micronutrient deficiencies. The economics of continuous crop production in these shifting cultivation areas will depend largely on the transportation costs of fertilizers and lime.

Central America

A fertilization program for intensive forage sorghum production during the rainy season in northern El Salvador became a simple solution for counteracting the severe weight losses of dairy cattle during the dry season. Heavily fertilized forage sorghum is preserved in inexpensive trench silos and used as the principal source of feed during the dry season.

Experiments with upland rice fertilization in Costa Rica indicate that the inorganic nitrogen content in the profile at planting time was related to the type of nitrogen response observed. Under these conditions, sulfur coated urea was not superior to conventional sources.

Major effort was placed on the fertility-related aspects of multiple cropping systems for small farms on soils affected by volcanic ash. Several experiments are underway in identifying how to manage fertilizer applications when more than one crop is grown at the same time. Greenhouse experiments indicate that a large proportion of Costa Rican soils are deficient in sulfur. Initial studies are also under way aimed at eliminating copper toxicity to rice in lands formerly operated as banana plantations.

Region-wide Studies

Substantial progress was made in the development of a fertility-capability soil classification system which groups soils having similar fertility management limitations. The first formal version of this system was prepared for presentation at the Tropical Soils Seminar held in Colombia in February, 1974, and is included in this report. Initial assessment of the system in a world-wide, country-wide, and a county sample showed that large numbers of soil mapping units can be grouped in a small number of fertility-capability units. For example, most of the 678 soil profiles described in the soil survey reports of Brazil could be grouped into 23 fertility-capability units. All the 145 mapping units of the soil survey of Wake County, North Carolina, were grouped into 15 units.

Preliminary evaluation of this system was made using a series of potato fertilization experiments previously conducted in the Sierra of Peru. All 73 sites could be grouped into five fertility-capability units and each group produced a different response to phosphorus applications. When fertilizer recommendations were made by each group, the economic returns to fertilization increased dramatically. It was also found that this classification system supplements positively soil test criteria. Further evidence of its usefulness in other areas and possible modifications are being investigated.

The economists refined their concept of profit-prediction criterion and applied it to various models used in the analysis of corn and rice fertilizer responses in Costa Rica and corn in Minas Gerais, Brazil. The graphic linear response and plateau model proposed by Waugh, Cate, and Nelson gave the best recommendations without the use of a computer or complex calculations. Soil test information appeared to be of no value when incorporated as Cate-Nelson critical levels into the linear response and plateau or in the general quadratic model for the Minas Gerais corn data. The use of soil tests in both models was useful in increasing the profitability of corn response in the Costa Rica data.

Additional research projects were conducted throughout the region to supplement the data from priority areas and/or to investigate at depth some critical issues. Soil characterization studies in relation to landscape position were initiated in an Oxisol-Ultisol area in western São Paulo, Brazil, in an Andept area in central Costa Rica, in the Llanos Orientales of Colombia and in the Maracaibo Basin of Venezuela.

Laboratory and greenhouse studies have shown that the lime-phosphorus interactions in certain Oxisols of Panama reflect the field observations in Brasilia. Low soil phosphorus availability is believed to be the principal factor responsible for the low rates of organic matter mineralization in Andepts from Colombia. Diffusion was identified as a major factor accounting for the increased availability of phosphorus in flooded rice soils in India and Peru. The potassium release properties of certain Ultisols from Guyana confirm the existence of a strong release of non-exchangeable sources of potassium. More complicated soil testing methods than the dilute double acid extractant were not necessary for estimating available potassium in these soils and in their North Carolina counterparts.

Special emphasis has been made in disseminating these results as quickly as feasible to about 450 tropical soil scientists, institutions, and libraries throughout the world. The first edition of the "Review of Soils Research in Tropical Latin America" was quickly exhausted. A second English printing and a Spanish version were made in order to satisfy the demand.

PERSONNEL

The following North Carolina State University faculty and staff participated in the research reported during 1973.

Charles B. McCants, Head of the Department
Pedro A. Sanchez, Associate Professor and Project Leader
Donald D. Oelsligle, Assistant Professor and Central American Leader
Stanley W. Buol, Professor, Soil Genesis and Classification
Eugene J. Kamprath, Professor, Soil Fertility
Richard K. Perrin, Associate Professor, Economics
Fred R. Cox, Associate Professor, Soil Micronutrients
Robert E. McCollum, Associate Professor, Soil Fertility (Guatemala)
Arthur G. Wollum II, Associate Professor, Soil Microbiology
J. Wendell Gilliam, Associate Professor, Soil Chemistry
Sterling B. Weed, Professor, Soil Chemistry
Michael A. Granger, Research Associate, Fertility-Capability Soil Classification
Bhalla Batavia, Research Associate, Economics
Enrique Gonzalez E., Research Assistant, Soil Fertility (Brazil)
Russell S. Yost, Research Assistant, Soil Fertility (Brazil)
Alfredo S. Lopes, Research Assistant, Soil Fertility (Brazil)
Jose G. Salinas, Research Assistant, Soil Fertility (Brazil)
Edward J. Tyler, Research Assistant, Soil Genesis (Peru)
Christopher E. Seubert, Research Assistant, Soil Management (Peru)
Cesar E. Lopez, Research Assistant, Soil Fertility (Peru)
Michael K. Wade, Research Assistant, Soil Management (Peru)
Hugo Villachica L., Research Assistant, Soil Fertility (Peru)

S. J. Chang, Research Assistant, Economics

Fred T. Turner, Research Assistant, Soil Chemistry

Jose Mendez-Lay, Graduate Student, Soil Fertility (Panama)

Alfredo Alvarado, Graduate Student, Soil Genesis (Costa Rica)

Fernando Munevar, Graduate Student, Soil Microbiology (Colombia)

Leonidas Mejia, Graduate Student, Soil Genesis (Colombia)

Ramon Paredes, Graduate Student, Soil Survey (Venezuela)

Bertha Monar, Bilingual Secretary III

Kenneth O. Dickerson, Research Technician III

COOPERATING INSTITUTIONS AND INDIVIDUALS

A project of this nature involves a high degree of collaboration and participation of a host of other institutions. Each of the specific experiments is actually a cooperative effort with at least one other institution.

In the Campo Cerrado, the field work is conducted at the Brasilia Experiment Station as a joint project with Cornell University and the Empresa Brasileira do Pesquisas Agropecuarias (EMBRAPA), formerly DNPEA. The AID Mission in Brasilia has contributed substantially to this project by providing excellent logistical support.

In the Amazon Jungle, the field work is conducted in cooperation with the Dirección General de Investigaciones Agrarias of the Ministry of Agriculture at the Yurimaguas Experiment Station with supporting laboratory and greenhouse work at La Molina. The International Potato Center plays a major role in providing administrative and logistical support to this project.

In Central America, joint projects are conducted with the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) at Turrialba, Costa Rica; the Ministerio de Agricultura y Ganadería of Costa Rica; the Ministerio de Agricultura of El Salvador; the Instituto de Ciencias y Tecnología Agropecuaria of Guatemala and the U. S. Peace Corps throughout Central America. The logistical support is provided by CATIE including excellent faculty housing and laboratories.

Region-wide research is conducted in cooperation with several institutions, mostly on a scientist-to-scientist basis. Much of the research on the fertility-capability soil classification system was conducted in cooperation with the ISFEIP staff plus Peruvian and Brazilian scientists. The data needed for the economic analysis was provided by the Costa Rican Ministry of Agriculture and EMBRAPA. The soil characterization studies also involved the Instituto Agronômico de Campinas, the Universidad de Costa Rica, the Instituto Geografico Augustin Codazzi, CIAT, and the Ministerio de Obras Públicas of Venezuela. Soil samples for the microbiology, fertility, and chemistry studies were obtained in cooperation with the Instituto Colombiano Agropecuario, Ministerio de Agricultura y Ganadería of Panama, the Ford Foundation in India, North Carolina Agricultural Mission to Peru, and Ministry of Agriculture of Guyana.

Throughout Latin America as well as on campus, close working relationships exist with the NCSU staff assigned to the International Soil Fertility Evaluation and Improvement Program.

The following staff from other cooperating institutions have actively participated in the research reported during this year:

Brazil

George C. Naderman, Jr., Research Associate, Cornell University, and Joint Cornell-NCSU Project Leader
James M. Wolf, Research Assistant, Cornell University
Robert B. Cate, Jr., Regional Director, ISFEIP
Wilson V. Soares, Head, Brasilia Experiment Station
Eneas Z. Galrão, Soils Specialist, Brasilia Experiment Station
Elcius Martins, Research Technician, Cornell-NCSU Project

Peru

Carlos Valverde S., Project Leader for the Ministry of Agriculture
Marco A. Nureña, Head, Yurimaguas Experiment Station
Carmen Torres, Soils Department, La Molina Experiment Station
Mario Cano, Soils Department, La Molina Experiment Station

Costa Rica

Alvaro Cordero V., Head, Soils Section, MAG, San José
Arnoldo Romero, Rice Specialist, MAG, Palmar Sur

Gordon S. Miner, Regional Director, ISFEIP, San Jose

Antonio M. Pinchinat, Plant Breeder, CATIE, Turrialba

Rufo Bazan, Soil Scientist, CATIE, Turrialba

Edgardo Ramirez, Graduate Student, CATIE, Turrialba

Aridio Perez, Graduate Student, CATIE, Turrialba

El Salvador

Jorge Alfaro, Head, Soils Department, CENTA, Santa Tecla

Emilia de la Peña, Soils Department, CENTA, Santa Tecla

Julia de Menendez, Soil Testing Laboratory, CENTA, Santa Tecla

George Greibel, U. S. Peace Corps, San Salvador

Guatemala

Anibal Palencia, Head, Plant Nutrition Program, ICTA, Guatemala

James L. Walker, Regional Director, ISFEIP

The following administrative staff from cooperating institutions have provided various kinds of support for the program:

Brazil

Jose Ireneu Cabral, Presidente, EMBRAPA, Brasilia

Roberto Meirelles de Miranda, Director, EMBRAPA, Brasilia

Nathaniel Bloomfield, Head of Pedology Group, EMBRAPA, Brasilia

Wenceslau Goedert, Soils Specialist, EMBRAPA, Brasilia

Edson Lobato, Coordinator of Cerrado Research, EMBRAPA, Brasilia

William Rogers, Agriculture and Rural Development Officer, USAID/Brasilia

Alphonse Chable, Deputy ARDO, USAID/Brasilia

Lawrence J. Able, USAID/Brasilia

Peru

Mariano Segura B., Director General de Investigaciones Agrarias, Lima

Manuel Llavería, Director del Centro Regional de Investigaciones Agrarias III, Tarapoto

Jose del Carmen Muro, Supervisor, DGIA, Lima

Richard L. Sawyer, Director General, International Potato Center

Carlos Bohl, P., Executive Director, International Potato Center

Oscar Gil, Controller, International Potato Center

Curry C. Brookshier, Food and Agricultural Officer, USAID, Lima

Costa Rica

Manuel Elgueta, Director, CATIE, Turrialba

Alberto Vargas, Subdirector de Investigaciones, MAG, San Jose

Jorge Soria, Jefe, Departmento de Suelos, Cultivos,Tropicales, CATIE

Milton Lau, Agricultural Officer, USAID/San José

El Salvador

Armando Alas, Director de Investigaciones, CENTA

Jose Perez Guerra, Director de Extensión, CENTA

Mauricio Salazar, Escuela Nacional de Agricultura

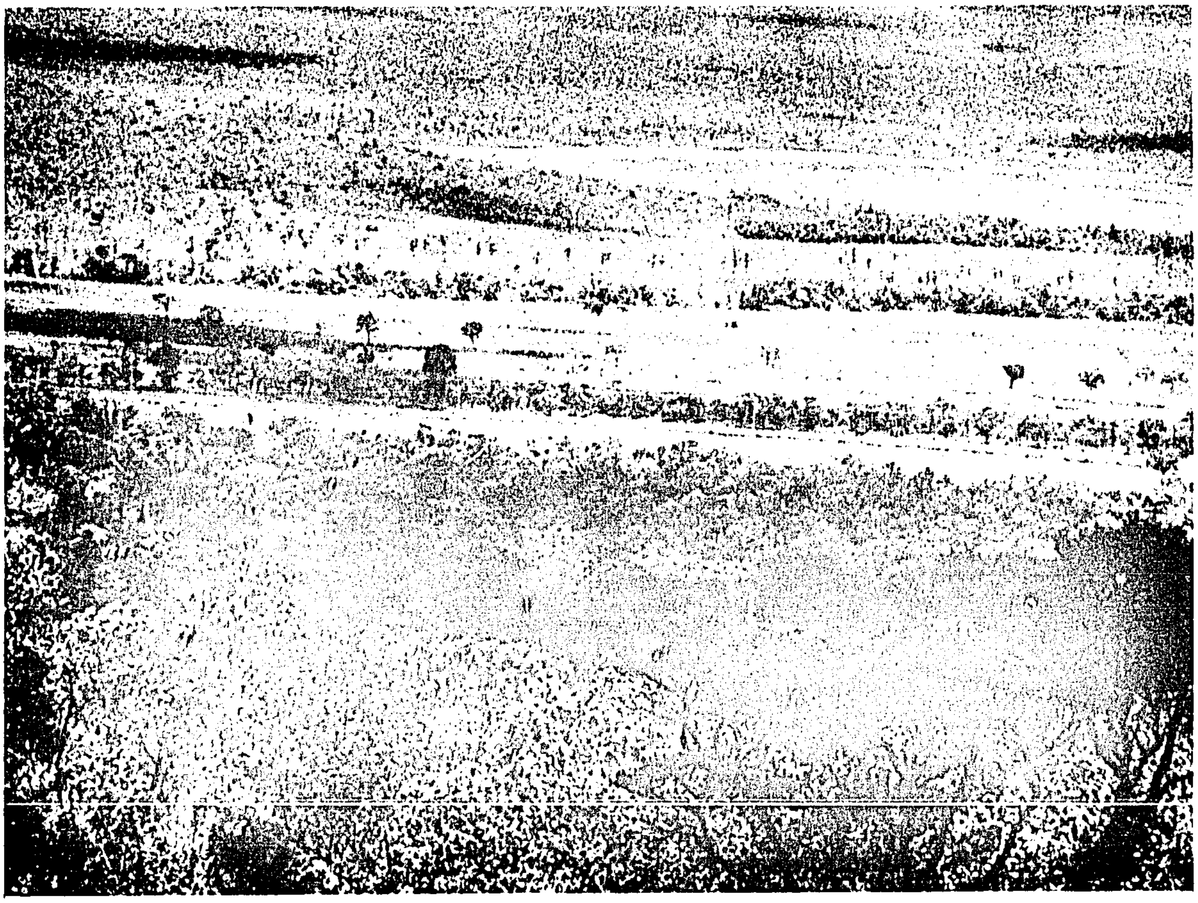
Jorge Dimas, Escuela Nacional de Agricultura

Gordon Bremer, U. S. Peace Corps

Colombia

Luis A. León, Director del Programa de Suelos, ICA Palmira

RESEARCH IN THE CAMPO CERRADO OF BRAZIL



View of the Brasilia Experiment Station.

The field research project initiated in Brasilia in 1972, continued during this year with the overall objective of determining how to manage Oxisols in tropical savannas. This operation is a joint project of Cornell and North Carolina State Universities in cooperation with the Empresa Brasileira do Pesquisas Agropecuarias (EMBRAPA). The Estacão Experimental de Brasília serves as project headquarters.

Four soil scientists were stationed at Brasilia during this year. Dr. George C. Naderman, Jr. (Cornell), Project Leader, Mr. Enrique Gonzalez (NCSU), Mr. Russell S. Yost (NCSU), and Mr. James M. Wolf (Cornell). In addition, Mr. Alfredo S. Lopes (NCSU) spent three months conducting a study of soil properties throughout the Cerrado. Drs. Marlin G. Cline (Cornell) and Stanley W. Buol (NCSU) worked with a group of Brazilian soil scientists for two weeks to determine the degree of extrapolation of research results to other areas of the Cerrado. Dr. F. R. Cox (NCSU) spent one month planting the micronutrient field experiment in Brasilia. Drs. E. J. Kamprath, P. A. Sanchez, C. B. McCants, and M. Drosdoff travelled to Brasilia to provide various kinds of assistance to the on-site personnel. Project expenses were shared by both Universities.

Two soil specialists of the experiment station have been involved in the research activities. They are Mr. Wilson V. Soares, Station Director, and Mr. Eneas Z. Galrão. The station has also provided field equipment, fertilizers, seeds, office, laboratory and greenhouse space as well as the majority of the routine labor needs.

The first series of field experiments were planted during the rainy season which started in November, 1972. The experiments were designed to provide relevant information about the requirements for and effectiveness of fertilizer applications in Typic Haplustox soil (Latosol Vermelho Escuro, distrófico, textura, argilosa, fase cerradão). This soil is considered representative of huge areas of savanna Oxisols. Experiments were conducted to determine the optimum depths and rates of liming, rates and placement of phosphorus, rates and timing of nitrogen, rates of zinc and zinc-pH interactions. Corn was used as the test crop.

After the first crop was harvested in May, 1973, dry season corn crops were planted on the phosphorus and lime experiments with the use of irrigation. The first irrigation experiment was also conducted during the dry season. This second crop of these experiments

Table 1. Characteristics of the soil used in the Brasilia experiments. Typic Haplustox, fine, kaolnitic, isothyperthermic. Fert. capability unit: Cdaik.

			Water-dispersible clay	pH		Org	Total	Exchangeable			CEC	Base
Horizon	Sand	Clay		H_2O	KCl	C	N	Al	Ca & Mg	K	(sum)	Saturation
cm	%	%	%			%	%	meq/100g				%
0- 10	36	45	14	4.9	4.2	1.8	0.21	1.9	0.4	.10	2.4	21
10- 35	33	48	6	4.8	4.3	1.2	0.08	2.0	0.2	.05	2.2	11
35- 70	35	47	1	4.9	4.2	0.9	0.05	1.6	0.2	.03	1.8	12
70- 50	35	47	0	5.0	4.2	0.7	0.05	1.5	0.2	.01	1.7	12
150-260	39	42	0	4.6	4.4	0.3	0.03	0.7	0.2	.02	0.9	24

Mechanical analysis courtesy of Mr. Marcelo Camargo, Centro de Pesquisas edológicas, EMBRAPA.

was harvested in December, 1973, and the experiments were replanted at that time.

Besides continued corn production on the original experiments, new experiments have been initiated to compare the fertilizer-moisture relationships of the two most important Oxisols of the Cerrado, the Dark Red and the Red Yellow Latosols. Two experiments of similar design have also been planted to study the long-term effectiveness of several phosphosus fertilizers including Brazilian rock phosphates for forage production with *Brachiaria decumbens* and *Stylosanthes humilis*.

SOILS AND CLIMATE

The properties of the soil where the experiments are conducted appear in Table 1. This deep, extremely well-structured Oxisol is very low in bases, high in aluminum and relatively well supplied with organic matter. Available phosphorus determined by various methods provide only traces. The P adsorption curve for the two Oxisols are given in Figure 2. Approximately 530 ppm P were required to give 0.05 ppm P in the soil solution of the Dark Red Latosol and 360 ppm P in the Red Yellow Latosol. These values are equivalent to 2340 kg P_2O_5/ha and 1660 kg P_2O_5/ha respectively. Consequently, these Oxisols are more infertile than the Ultisols used in the Yurimaguas experiments but they have superior physical properties.

The average rainfall pattern in Brasilia is shown in Fig. 3 along with that of the 1972-73 season. Brasilia has a typical Ustic soil moisture regime with a five month dry season. On the average, potential evapotranspiration exceeds precipitation during half of the year. The 1972-1973 rainy season started with higher than average monthly rainfall. These average figures, however, can be very misleading. Short-term droughts locally referred to as "veranicos" commonly occur during the rainy season and cause marked detrimental effect on crop growth. Fig. 4 shows the effect of these veranicos on soil water storage during the first four months of the 1972-1973 rainy season.

DEPTH OF LIMING EXPERIMENT

Objectives and Design

Although most Oxisols are quite acid and often aluminum-toxic to crop species, liming has seldom proved to be a successful practice in the tropics. Our previous review of the

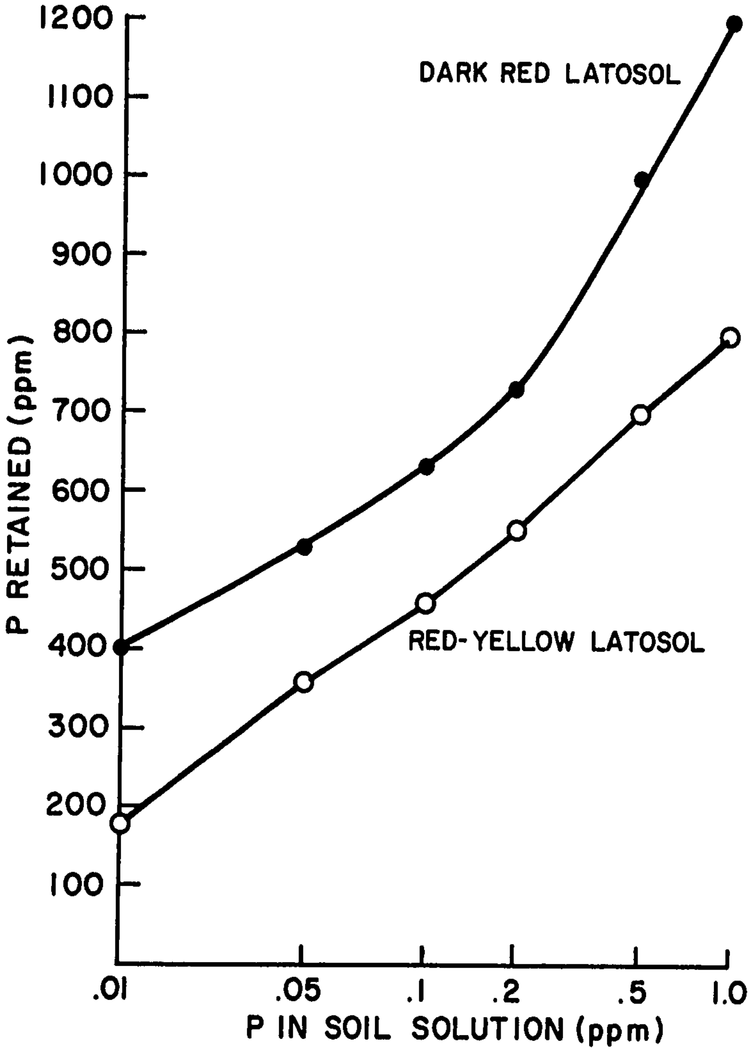


Figure 2. Phosphorus fixation patterns of two Oxisols at the Brasilia Experiment Station. The Dark Red Latosol was the soil used in the field experiments.

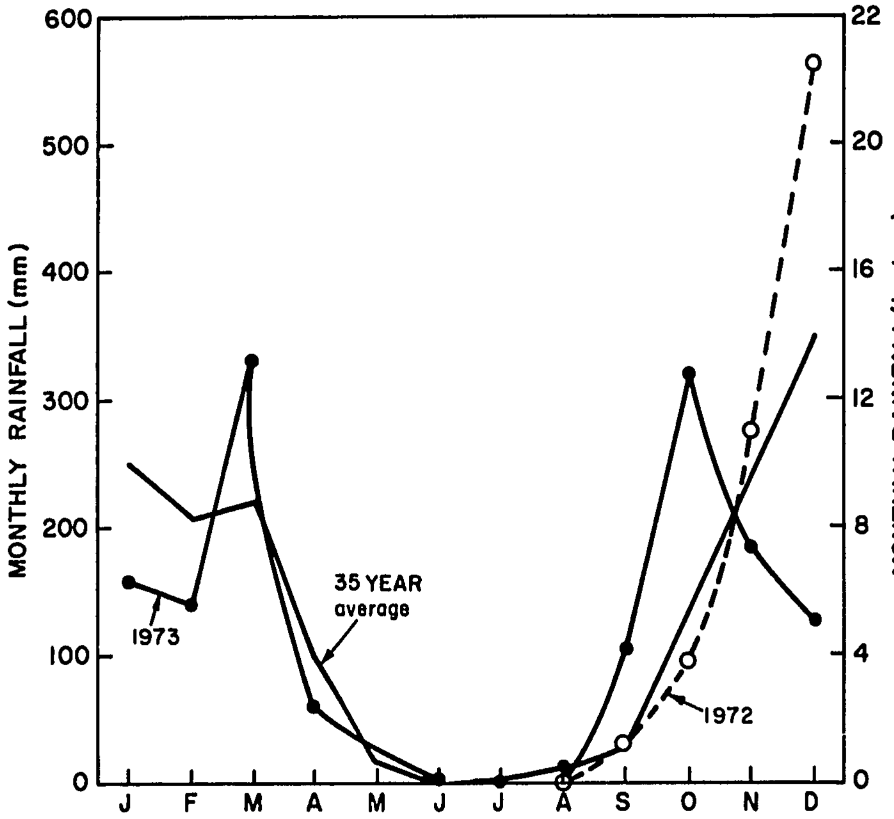


Figure 3. Rainfall pattern in Brasilia showing the long term average, and the 1972-1973 period.

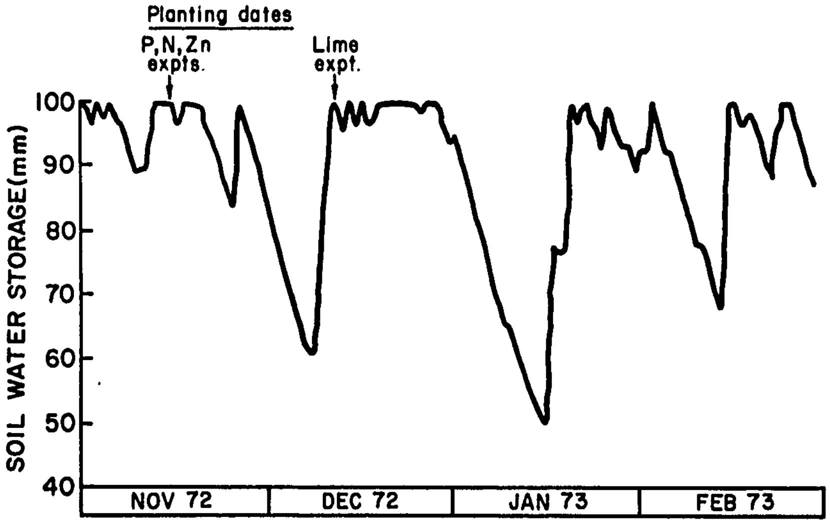


Figure 4. Computed soil moisture storage during the first four months of the rainy season in relation to planting dates of the field experiment.

Table 2. Effect of rates and depth of liming in soil pH and aluminum saturation. Brasilia 1973.

Depth of Incorporation	Lime Rate	Soil Depth	pH	Al Saturation
cm	ton/ha	cm	1:1H_2O	%
No lime	0	0-15	4.7	63
		15-30	4.7	71
Shallow (0-15)	1	0-15	5.0	45
		15-30	4.8	59
	2	0-15	5.1	25
		15-30	4.8	59
	4	0-15	5.6	6
		15-30	4.8	53
	8	0-15	6.3	2
		15-30	4.9	52
Deep (0-30)	1	0-15	5.1	36
		15-30	5.0	54
	2	0-15	5.4	11
		15-30	5.2	34
	4	0-15	5.9	8
		15-30	5.4	21
	8	0-15	6.5	2
		15-30	5.9	7

literature identified two main reasons: 1) field researchers often apply excessively high rates of lime aimed at increasing the pH to neutrality. 2) liming the topsoil does not correct aluminum toxicity in the subsoil. A field experiment was designed to determine the optimum lime rates and whether deeper placement of lime could be beneficial to corn. A factorial design was used with five lime rates (0, 1, 2, 4, and 8 ton $CaCO_3$ - equivalent/ha) incorporated at 15 and 30 cm depths. The locally-produced variety Cargill 111 was planted in 80 cm rows at an approximate population of 62,500 plants/ha. The 58 m^2 plots were arranged in a randomized complete block design with five replications. The experiment was planted on December 11, 1972, and harvested on May 10, 1973. The crop received 100 kg N/ha of urea in three applications, 300 kg P_2O_5/ha, as ordinary superpaspate, 100 kg K_2O/ha as KCl, 11 kg Zn/ha, and 10 kg borax/ha at planting. A residual experiment was planted on June 11, 1973. It received an additional 375 kg P_2O_5/ha, 200 kg N/ha and frequent irrigation.

The lime source was locally available calcitic limestone. The material was finely ground with more than 60% finer than 60 mesh and more than 40% finer than a 100 mesh. Its magnesium content was very low.

By plowing as deeply as possible with ordinary equipment, followed by rotovating, it was possible to achieve fairly uniform lime incorporation to nearly 30 cm depth. In the "shallow" treatments, lime was applied after rotovation, incorporated to about 15 cm depth by disking. Two additional treatments were added in which two lime rates were incorporated to about 12 cm depth by disking, in an area which was neither plowed nor rotovated previously. An additional treatment received an application of 100 kg Mg/ha as magnesium sulfate with no lime.

Results

The effect of the lime treatments on pH and percent aluminum saturation at two soil depths is shown in Table 2. Aluminum saturation in the unlimed soil was about 60 to 70%. The shallow lime treatments did not greatly change the aluminum saturation below 15 cm. For this soil, the incorporation to 30 cm of at least 4 ton/ha reduced aluminum saturation within that depth to levels which are considered adequate for most crops. The resulting pH ranged from 5.4 to 5.9.

The grain yields from the first and second crops are shown in Fig. 5. Yields for the first crop were considerably lower than the better yields in other experiments because of

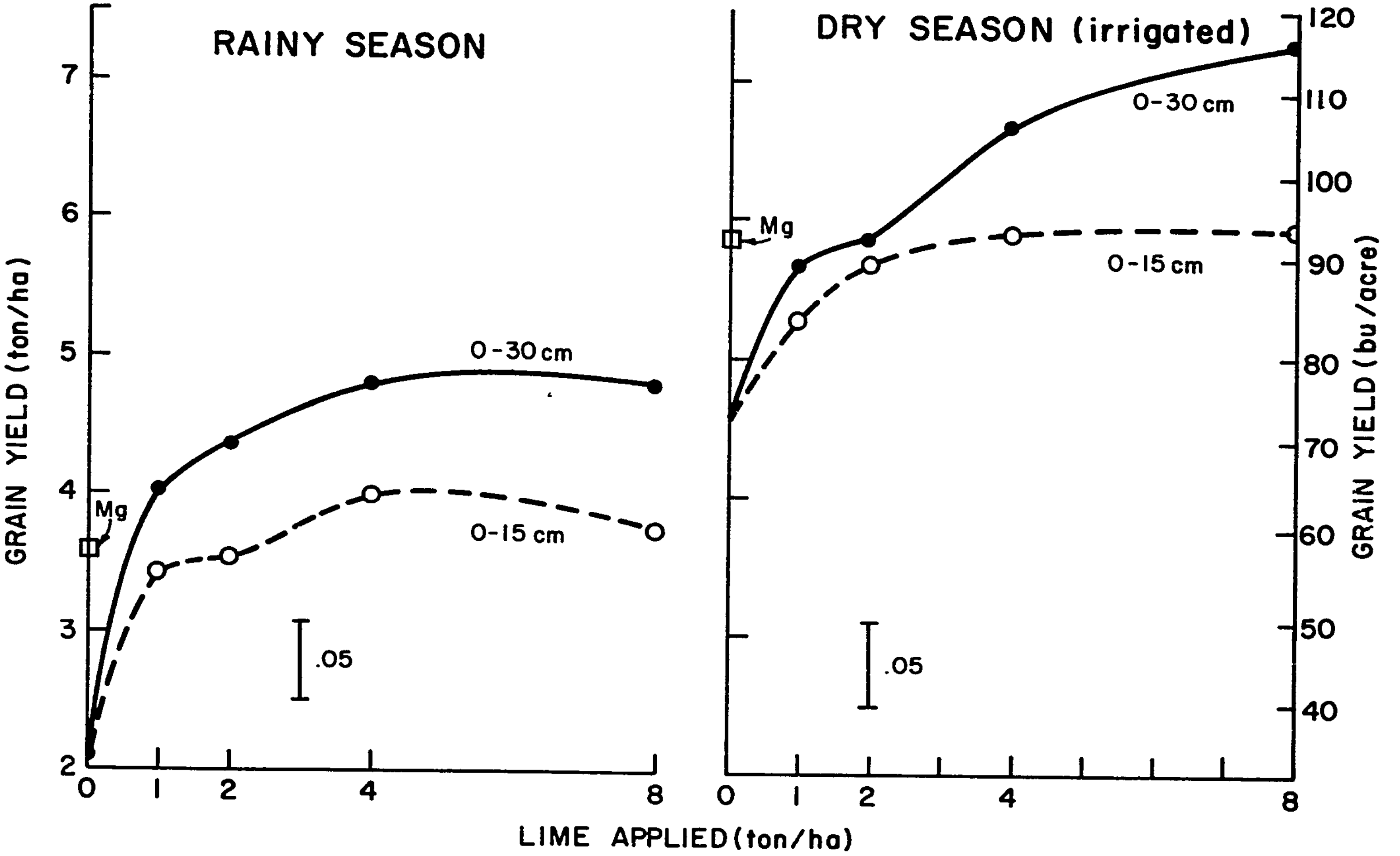


Figure 5. Effect of depth and rate of liming on the first two corn crops.
Brasilia, 1973.

the relatively low phosphorus rate applied. The higher yields obtained in the second crop were due in part to the higher phosphorus level and probably higher solar radiation in this irrigated dry season crop.

For both crops, the deeper application of 4 or 8 ton/ha yielded significantly more than the same quantities incorporated to 15 cm depth. For the first crop this was also true for the rate of 2 ton/ha. These yield increases due to deeper incorporation were in the approximate range of 0.8 to 1.3 ton of grain/ha. In the first crop there were no significant yield differences among the 2, 4, or 8 ton/ha rates incorporated at either depth. This was also the case in the shallow treatments of the second crop. However, the 8 ton/ha rate yielded significantly more than the 2 ton/ha rate when deeply incorporated in the dry season crop.

The yields of the magnesium treatment (without lime) were at least 1.3 tons/ha higher than the check treatment in both the first and second crops. Nearly half of the yield increase of the best lime treatment was achieved just by this magnesium application. Analytical data from the ear leaves, as well as plant deficiency symptoms, also suggested the existence of magnesium deficiency. The application of magnesium through the use of dolomitic lime appears to be important. Fortunately, dolomitic limestone deposits exist near Brasilia and in other areas of Central Brazil.

In certain treatments root samples were taken at three depths and estimates were made of the root length per unit of soil volume. Data from these measurements in the first crop are presented in Table 3. For all three of the treatments shown, the root length per 100 cm^3 of soil was much greater in the 0 to 15 cm depth increments than in the deeper areas. The application of 2 or 4 ton/ha incorporated to 15 cm did not greatly change the length of roots per unit of soil volume at the 15 to 30 cm depth. A comparison of root lengths in the 15 to 30 cm depth for the latter two treatments shows that the deeper incorporation of 4 ton/ha nearly doubled the root length per unit of soil volume. Roots found in the regions of high aluminum saturation were thickened and distorted and undoubtedly were fairly ineffective in the uptake of water and nutrients.

These results indicate that deeper incorporation of lime will permit more extensive and deeper root development. The initial lime application provided significantly higher yields in two consecutive crops when the material was deeply incorporated. A large part of this

Table 3. The effects of rate and depth of incorporation of lime on Al saturation and development of roots of the rainy season first corn crop. Brasilia 1972-73.

Lime rate	Depth of incorporation	Depth increment of sample	Al satn	Dry wt. of roots	Root length/ soil volume
ton/ha	cm	cm	%	g	cm/100 cm^3
2	0-15	0-15	24	13.9	1,007
		15-30	60	9.4	236
		30-45	69	1.8	56
4	0-15	0-15	6	12.5	912
		15-30	55	9.3	342
		30-45	65	3.0	108
4	0-30	0-15	8	14.1	930
		15-30	20	8.2	650
		30-45	65	3.5	137

Mr. Enrique Gonzalez observes the differences in growth between shallow (left) and deep (right) incorporation of lime.

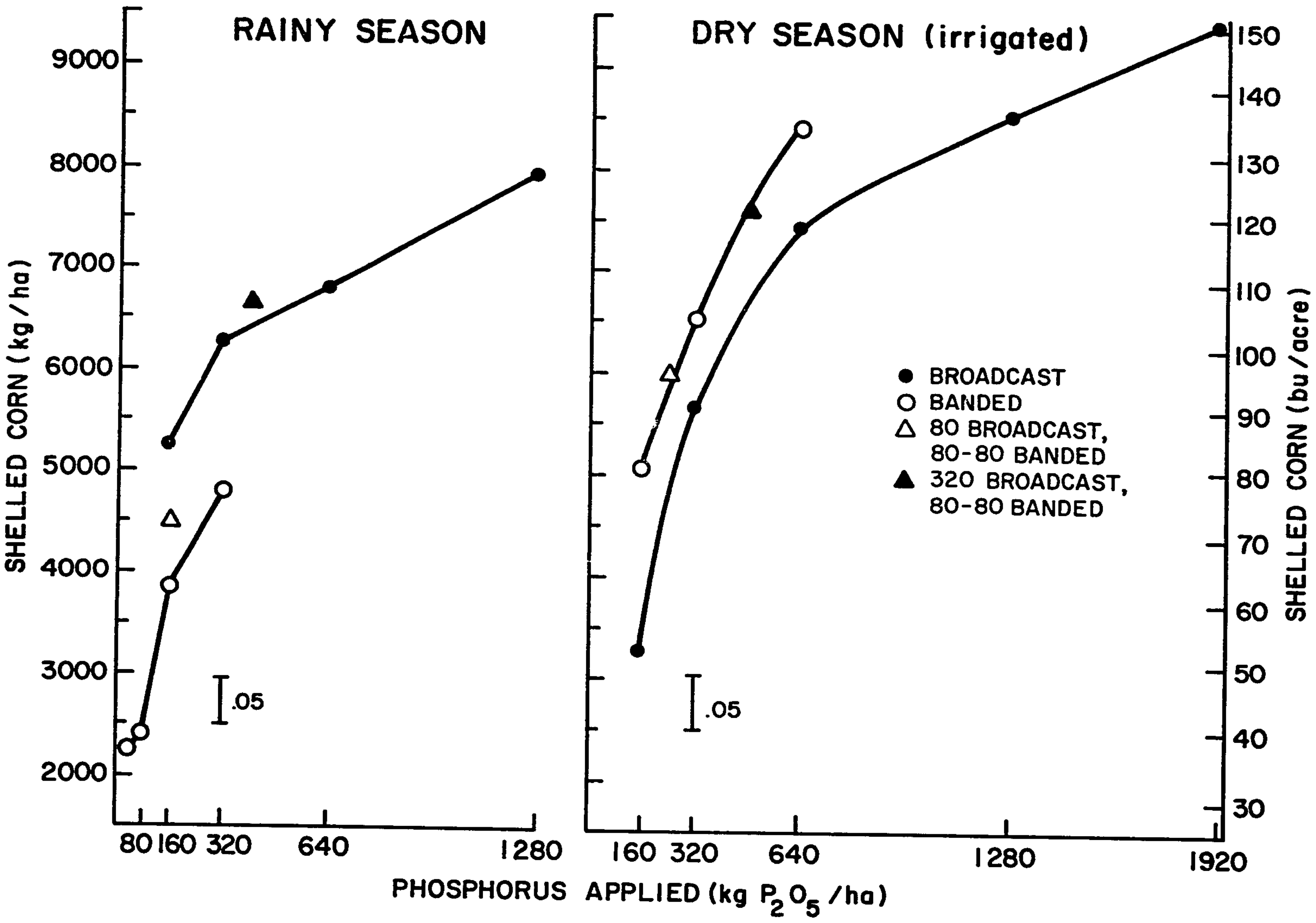


Figure 6. Yield response to phosphorus applications in the first two crops. Brasilia, 1973.

yield response to deep incorporation is undoubtedly due to the ability of these plants to extract moisture from greater soil depth during periods of dry weather which normally occur within the rainy season. The interpretation of the dry season results must wait for further analytical data.

It is too early to ascertain which rates are most desirable. More data on the residual effect is needed. Nevertheless, rates as low as 2 ton/ha of lime seem appropriate. This rate coincides with the present recommendation of applying an amount of lime which is equal to 1.5 times the exchangeable aluminum content of the soil.

PHOSPHORUS FERTILIZATION

Objectives and Design

Phosphorus deficiency is one of the most serious limitations to crop productivity in Oxisols; without added phosphorus, corn simply dies in this soil. A long-term experiment was planted in October, 1972, in order to evaluate different phosphorus fertilization strategies. The results of this experiment over a period of several years will provide much of the information necessary to maximize the effectiveness of phosphorus fertilization in Oxisols.

The experiment consisted of four phosphorus rates broadcast and incorporated to about 20 cm depth prior to the first planting. Another four phosphorus rates were banded with each crop. Two other treatments received both an initial broadcast application followed by banded applications with each crop. The same variety, blanket fertility treatments and other details of the lime experiment were used. Lime was added at the rate of 4 ton/ha. The rainy season crop was irrigated once during a severe "veranico" just prior to the tasseling stage. The dry season crop was irrigated at an average of every 4 days according to tensiometer readings.

Results

The results for the first and second crops are shown in Fig. 6 and Table 4. In the first crop, broadcast applications were overwhelmingly superior to banded applications. This observation is contrary to commonly held views on how to apply phosphorus in soils of extremely high fixation capacity. At early stages of growth, the banded treatments were superior to the broadcast ones. Because of differences in patterns of root development, we found the banded treatments were more severely affected by the two short-term droughts or

Table 4. Effects of phosphorus application methods on percent maximum yield and total corn production during the rainy and dry seasons. Brasilia 1973.

Treatment	Broadcast first crop	Banded first crop	Banded second crop	Relative yield first crop	Relative yield second crop	Annual corn grain yields
	kg P_2O_5/ha	kg P_2O_5/ha	kg P_2O_5/ha	%	%	ton/ha
1	160	-	-	66	38	8.54
2	320	-	-	79	67	11.96
3	640	-	-	85	87	14.29
4	1280	-	-	100	100	16.50
5	-	40	1920[1]	28	112	11.81
6	-	80	80	30	60	7.49
7	-	160	160	48	77	10.43
8	-	320	320	60	99	13.22
9	320	80	80	84	86	13.98
10	80	80	80	57	70	10.57

[1] Broadcast before planting second crop.

Without phosphorus applications (left) no corn crop is possible in this Oxisol. Adequate growth (right) is obtained with relatively high rates of phosphorus fertilization.

veranicos. Corn roots were concentrated along the phosphorus band while in the broadcast treatments, root development was more uniformly distributed through a larger volume of soil. When the droughts took place, the broadcast treatments were better prepared to withstand it. A maximum yield of almost 8 ton/ha (127 bu/acre) was obtained with the highest broadcast rate. Phosphorus contents of the ear-leaves reflect the relatively poor utilization of banded applications (Table 5).

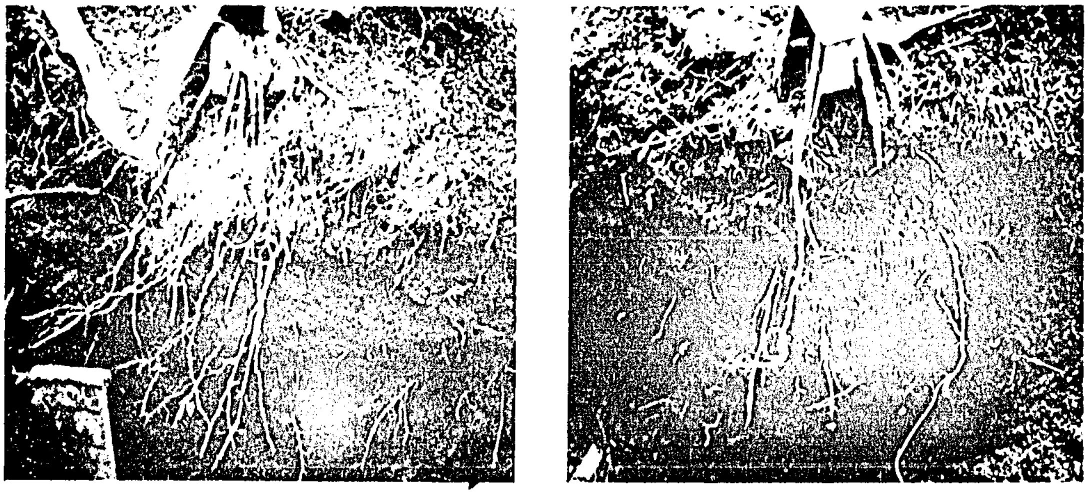
The dry season irrigated crop produced the opposite results. The residual effect of the original broadcast treatments at the rates of 640 and 1280 kg P_2O_5/ha provided slightly higher yields than in the original crops. A new broadcast application of 1920 kg P_2O_5/ha reached the highest yield of 9.5 tons/ha (152 bu/acre). In spite of these high yields, the banded treatments were definitely superior to the broadcast ones. A treatment which received a banded application of 320 kg P_2O_5/ha prior to each planting yielded 8.4 ton/ha. The superior behavior of the banded treatments may be associated with the absence of severe water stress due to the frequent irrigation intervals. A comparison of treatments in which similar amounts of phosphorus were applied, broadcast vs. two banded applications, shows that the banded treatments produced higher yields. However, the total yield for the two crops was higher in the broadcast treatments (Table 4). Data from subsequent crops are needed to determine the relative efficiency of these methods over several seasons, which would represent the situation faced by farmers.

These results suggest that a "corrective" level of broadcast phosphorus followed by banded applications to each crop may be the most efficient application method. Future crops from this experiment should show the relative advantage of utilizing the residual effect of heavy broadcast applications versus applying lower rates at periodic intervals.

Table 5. Ear-leaf phosphorus contents as affected by phosphorus management. Brasilia 1973.

Treatment	Broadcast	Banded first crop	Banded second crop	P content, ear leaf first crop	P content, ear leaf second crop
	kg P_2O_5/ha			%	
1	160	-	-	0.19	0.11
2	320	-	-	0.24	0.16
3	640	-	-	0.23	0.19
4	1280	-	-	0.30	0.25
5	-	40	1920*/	0.12	0.27
6	-	80	80	0.12	0.13
7	-	160	160	0.14	0.15
8	-	320	320	0.15	0.20
9	320	80	80	0.23	0.16
10	80	80	80	0.17	0.13

*/ Broadcast before planting second crop.



More extensive root development in the topsoil of broadcast treatments (left) in comparison with the more localized root pattern in the banded treatments. Rainy season crop

Soil test values shown in Table 6 and the previous phosphorus adsorption isotherms studies indicate some loss of phosphorus availability from the broadcast treatments 1 and 2 during the first two crops. These losses are being evaluated but require additional corn crops for good estimates. At the higher broadcast levels (treatments 3 and 4), the dry season crop yields were higher than those of the first crop, suggesting that in spite of some loss of phosphorus availability, there were more influential factors which permitted yield increases. The yield decreases observed in the second crop in treatments 1 and 2 appeared to

Table 6. Effect of phosphorus broadcast rates on soil test phosphorus values estimated by two extractants at various dates. Planting dates: Nov. 15, 1972 and May 8, 1973.

Treatment	Broadcast P rates	Date of Sampling (1973)		
		Feb. 18	May 26	Oct. 25
No.	kg P_2O_5/ha		ppm	
North Carolina Extraction:				
1	160	5	4	3
2	320	7	9	7
3	640	34	18	20
4	1280	53	69	56
5	1920*	-	120	103
Olsen Extraction:				
1	160	1.5	0.8	0.8
2	320	2.7	3.2	1.4
3	640	9.6	5.0	3.0
4	1280	15.9	19.2	11.0
5	1920*	--	33.9	22.8

*/Broadcast before planting second crop.

be associated with reduced phosphorus availability which could presumably be described as fixation. Again, more data are needed to explain these differences.

These results are necessarily tentative, especially because of the influence of differences in daylength, solar radiation, temperature, moisture stress, and numerous other factors between the first and second crops. Measurements have been made of growth, dates of tasseling, nutrient concentration, and uptake to document the differences between the two crops.

Corn yields in this experiment as well as those from the second crop in the lime experiment confirm a high production potential of corn during the dry season if adequate irrigation systems are used.

Yields of the second crop confirmed the results of the first crop that extremely large amounts of phosphorus fertilizer are required to approach near-maximum corn yields. Data from a third and subsequent crop are essential to provide an indication of the relative effectiveness of various application methods and the residual effects.

The above results strongly suggest we evaluate other sources of phosphorus which may be more efficient than ordinary superphosphate. Two experiments of similar design have been planted to *Brachiaria decumbens* and *Stylosanthes humilis* late in 1973 to evaluate different rock phosphate sources, partially acidulated rock phosphates and the role of calcium silicate in decreasing phosphorus fixation.

NITROGEN FERTILIZATION

Objectives and Design

There is considerable doubt that non-legume crops grown on Oxisols require large quantities of nitrogen for maximum yields. Optimum rates of applications, efficiency of utilization by crops, and the relative effectiveness of various nitrogen sources fertilizers are factors which are not well established. Results of the Cornell contract in Puerto Rico suggest that highly weathered soils of the tropics often have relatively good nitrogen supplying power. Indeed, general observations from the first two corn crops suggest that nitrogen was less critical than phosphorus, magnesium, or zinc on soils which have not previously been fertilized or cropped.

A nitrogen experiment, consisting of 10 treatments, with different rates and times of application of urea was planted during the rainy season. One treatment received calcium nitrate as a source of nitrogen and calcium, and two treatments received sulfur-coated urea, an experimental slow-release fertilizer supplied by the Tennessee Valley Authority. This experiment was not planted during the dry season, but was replanted in the second rainy season with some treatment modifications based upon the first crop's results. The details of experimental design, plot size, variety, and the basic applications of lime, potassium, magnesium sulfate, boron, zinc, and molybdenum were the same as for the phosphorus experiemnt.

The phosphorus application for the first crop was 200 kg P_2O_5/ha broadcast and 200 kg P_2O_5/ha banded. From the results of the phosphorus experiment, this level proved to be inadequate for maximum yields. Therefore, the yield response and effectiveness of nitrogen uptake in the first crop at the higher nitrogen rates were probably restricted by an inadequate phosphorus level. This experiment was irrigated once during a severe dry period just prior to the tasseling stage.

Results

A description of the treatments and the results of the first crop are given in Table 7. In spite of apparently uniform growth during the early stages, the yield data had a high coefficient of variability (43%). Inspection of the data suggested that this may have been caused by variation in the supply of native soil nitrogen.

As indicated in Table 7, there was a yield response to the addition of 120 kg N/ha at 28 days after planting as compared with the application of 80 kg N/ha at the same date. A 80 kg N/ha rate yielded more than 40 kg N/ha applied at the same time. There was some evidence that the split applications of 40 kg N/ha at 20 days and 52 days gave better utilization than the same rate applied at 28 days. The same comparison of two 60 kg N/ha applications versus one application of 120 kg N/ha gave no yield difference. This suggests fertilizer nitrogen losses probably by leaching, which reduced yields when limited nitrogen was applied. At the rate of 140 kg N/ha, no benefit was gained by splitting applications. This suggests the possibility of substituting labor cost for nitrogen fertilizer.

The two sulfur-coated urea sources and calcium nitrate gave similar yields to that of ordinary urea at the same rate. The fact that the sulfur-coated urea was no more effective than ordinary urea may have been related to the previous observation that under these conditions, the loss of nitrogen by leaching was not excessive, and hence a slow-release source

Table 7. Effects of sources, rates, and timing of sidedress nitrogen applications on corn yields during the rainy season. (Urea was the nitrogen source unless otherwise indicated). Brasilia 1973.

Time of application				Shelled corn yields
0	20	28	52	
	Days after seeding			tons/ha
20	0	0	0	3.25
0	0	40	0	3.58
20	0	40	0	4.03
20	0	80	0	5.29
20	40	0	40	6.18
20	0	120	0	6.26
20	60	0	60	6.31
20	0	80[1]	0	5.10
20	0	80[2]	0	5.68
20	0	80[3]	0	5.42

[1] SCU-1, [2] SCU-2, [3] $Ca(NO_3)$, $LSD_{.05}$ = 1.10

was unnecessary. Furthermore, this source may be more appropriately used at planting time. It is also possible that the release characteristics of the materials used were not completely appropriate for nitrogen uptake by corn plants.

Besides the yield data, a major purpose of this experiment is to evaluate the effectiveness of fertilizer nitrogen through estimates of the total uptake of nitrogen by the crop. Samples for this purpose have been taken but analysis of some of them is not yet complete. The interpretation of this data, particularly from the second and subsequent crops, will also provide a useful estimate of the quantity of non-fertilizer nitrogen available in this soil and the number of crops which can utilize it.

ZINC FERTILIZATION

Objectives and Design

Symptoms of zinc deficiency, responses to zinc fertilization by corn and other crops, and preliminary soil test data obtained by F. R. Cox have indicated the need for research to develop adequate methods for diagnosing and correcting zinc deficiency on soil of this type. An experiment was established to evaluate the response of three corn varieties to levels of 0, 1, 3, 9, and 27 kg Zn/ha applied as $ZnSO_4$ incorporated in the soil to a depth of 25 to 30 cm by rotovation. Boron was applied as 10 kg borax/ha as a general treatment, but an additional treatment which received no boron was also included. The varieties Cargill 111, Funks G 795-W-1, and Silver Queen sweet corn were included as subplots in a randomized, complete block design with five replications. A second experiment was established at the same time to study the interaction between zinc rates and high soil pH levels induced by overliming on corn growth. A factorial experiment was established with three lime rates (7.5, 15, and 22.5 ton $CaCO_3$ - equivalent/ha) and three zinc rates (0, 3, and 9 kg Zn/ha applied as in the previous experiment).

The phosphorus application for these experiments consisted of 325 kg P_2O_5/ha broadcast and 100 kg P_2O_5 banded. For the first experiment, the lime rate was about 12 ton/ha. The potassium, nitrogen, molybdenum applications were similar to those of the phosphorus experiment. Ear leaf samples and soil samples were collected at two growth stages.

Results

The grain yields are given in Figs. 7 and 8. Zinc deficiency in the check plots prevented any production. Very severe and typical Zn deficiency symptoms were noted and photographed, particularly during the first half of the growing season. Yields increased significantly up to 3 kg Zn/ha, with no significant decrease due to the lack of added boron nor to the highest level of 27 kg Zn/ha (Fig. 7).

The second experiment shows a detrimental effect of the higher lime rates on yields at either both zinc rates. The addition of up to 9 kg Zn/ha did not overcome the tendency of the higher lime rates to reduce yields presumably due to a reduction in zinc availability.

Plant samples from the Cargill variety were collected twice during the season. An emission spectrograph analysis of the sample taken at 17 days after emergence is presented in Table 8. This indicates that the only limiting micronutrient was zinc. Ear leaf samples were also collected from all varieties at tasseling. Zinc deficiency appeared on the plants receiving no zinc by the time of the first sampling. The minimum Zn content in these plants was 22.4 and 24 ppm when analyzed by atomic absorption and emission analysis, respectively. This is considerably above the 15 ppm considered critical at later stages of growth.

The soil zinc data estimated by three extraction methods is presented in Table 9. The 0.1 N HCl extracted the most zinc and the DTPA the least. A first approximation of the critical zinc level under these conditions may be viewed as that achieved by the 3 kg/ha rate. In this case, 1.36, 0.92, and 0.56 ppm were extracted by the 0.1 N HCl, double acid (0.05 N HCl + 0.025 N H_2SO_4), and DTPA.

There was no evidence of an interaction between the effects of soil zinc level and soil pH in the second experiment. At lower pH levels in the liming study, which received 10 kg Zn/ha, the zinc content of Cargill 111 at thinning was 41, 33, and 29 ppm when 2, 4, and 8 ton of lime/ha were applied. In the first experiment reported here, the pH was raised to pH 6.4 and at the 9 kg Zn/ha rate, the plant zinc content at thinning was 24 ppm. Some of these apparent differences may be due to dilution by improved growth, but this aspect should be investigated in more detail. Since these soils are quite low in magnesium, the relation between zinc and magnesium should be assessed carefully.

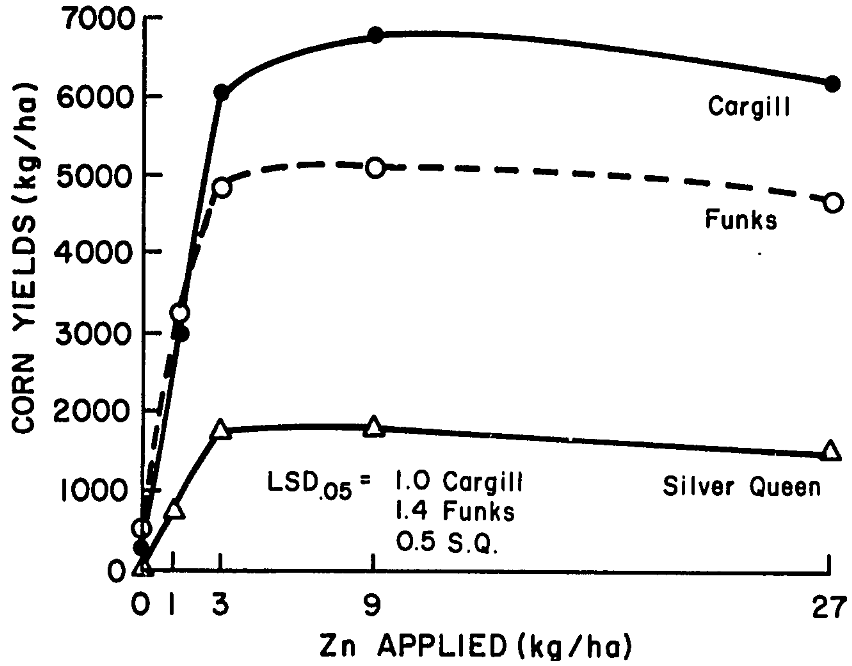


Figure 7. Varietal response to zinc rates in an Oxisol limed to pH 6.4.

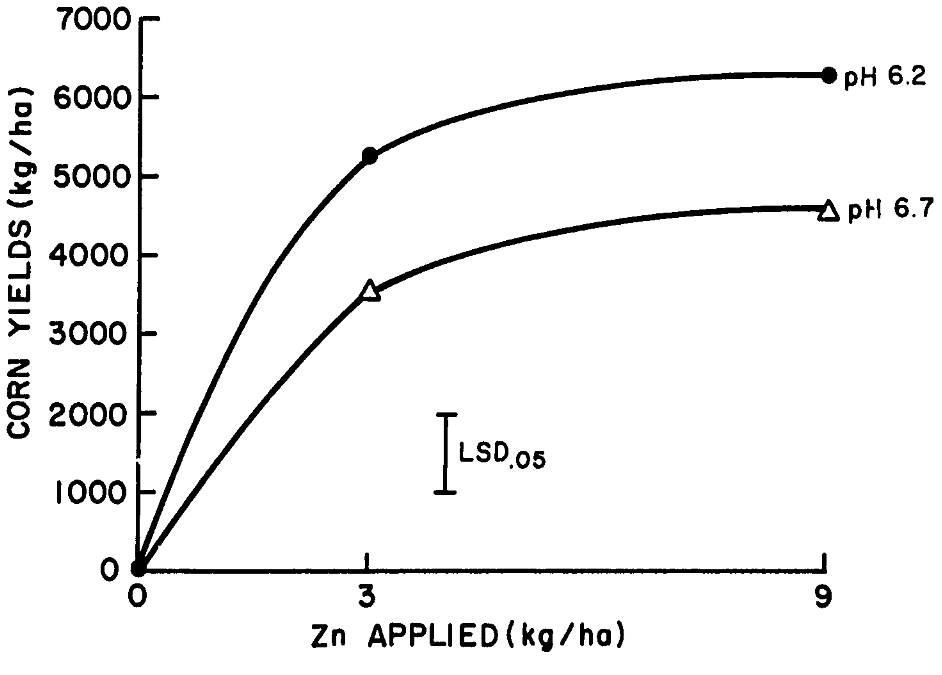


Figure 8. Zinc-soil pH interactions on Cargill 111 corn.

Table 8. Phosphorus and micronutrient composition of 17 day-old Cargill 111 plants as affected by zinc fertilization. Brasilia 1973.

Zinc rates	P	Zn	B	Mn	Cu	Mo	Fe
kg/ha	%	ppm					
0	0.48	23	30	89	13	7.6	1000
1	0.47	24	31	84	10	7.2	1000
3	0.42	22	25	64	8	7.1	1000
9	0.28	25	22	46	6	8.5	1000
27	0.25	33	21	37	4	6.6	1000

Table 9. Effect of zinc fertilization on zinc soil test values by different extractant in the first zinc experiment. Soil pH of 6.4. Brasilia.

	Soil test Zn values		
Zinc rates	0.1N HCl	Double acid	DTPA
kg/ha	ppm		
0	0.86	0.52	0.28
1	1.16	0.64	0.36
3	1.36	0.92	0.56
9	2.17	1.58	0.90
27	5.26	4.18	2.40

It is important that these studies be continued. By this means the residual effect of a zinc application can be determined. One application should suffice for several years. Also, the zinc applied will equilibrate better with the soil in time allowing for a more realistic estimate of soil zinc level. The first experiment was replanted during the second rainy season.

OUTREACH STUDY OF PROPERTIES OF CERRADO SOILS

During the period of May 8 to September 3, 1973, 495 topsoil samples were taken in 57 selected points from the Central Plateau of Brazil by Mr. Alfredo S. Lopes. The area covered is a triangle with sides at Belo Horizonte, Minas Gerais, Porto Nacional, Goias, and Mineiros in the border between Goias and Mato Grosso (Figure 9).

The soil samples were dried, screened, and divided at the Brasilia Station and were sent to Raleigh. At the present time, they are being evaluated for their chemical and physical properties. The chemical analyses include pH in H_2O and in KCl, organic matter, phosphorus, potassium, calcium, magnesium, exchangeable acidity, zinc, manganese, iron, copper, and phosphorus fixation. Zinc will be extracted with three different solutions. Mechanical analyses are also being run on these samples. Other data concerning the sample site, soil color, etc. have also been recorded.

The main goal of this survey is to determine the nutritional status of these soils. The data will be evaluated statistically to determine any relations between zinc level and locations within the area, or slope position, or any of the other soil properties measured. These samples will be utilized for studies concerning P fixation, Mg levels, and lime requirements. This collection is probably the most comprehensive set of soil samples obtained from the potential outreach area of this project.

OUTREACH STUDY OF THE DISTRIBUTION CERRADO SOILS

Objectives and Design

An exploratory study was conducted from May 28 to June 9, 1973, by Dr. Marlin G. Cline of Cornell, Dr. Stanley W. Buol of NCSU, and Messrs. Marcelo N. Camargo, Clotario O. da Silveria, Jorge O. I. Larach, and Paulo T. K. Jacomine of the Brazilian Ministry of Agriculture.

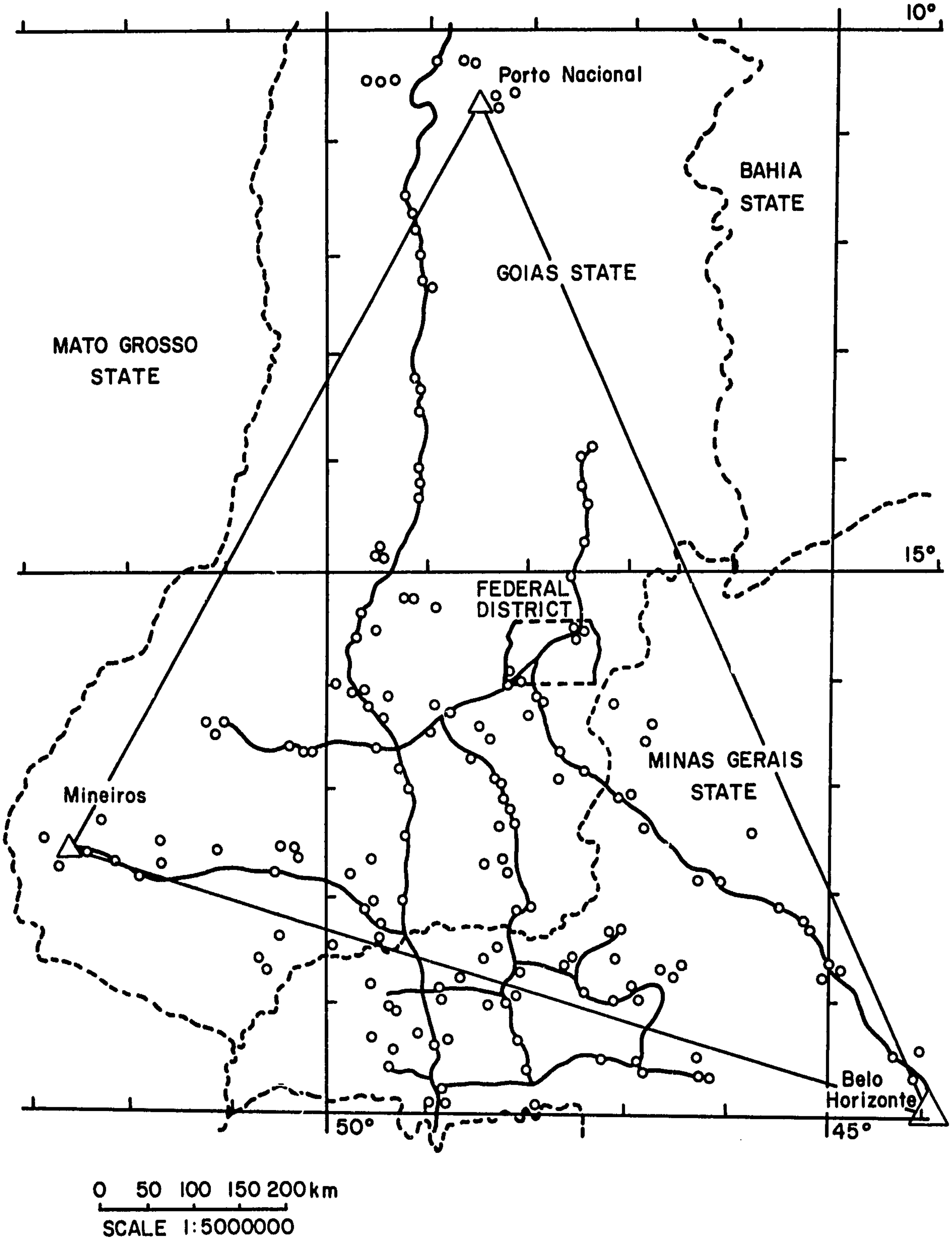


Figure 9. Route map and sample sites of the survey of the zinc status of soils under Cerrado vegetation in Brazil.

The purpose of this study was to determine the possible kinds and degrees of extrapolation of the field research conducted at the Brasilia Station to other areas of the Cerrado. The group covered approximately 2700 km. through the States of Goiás, Minas Gerais, Mato Grosso and the Federal District. The exploration included areas of the São Francisco, Paraná, Araguaia, and Tocantins drainage basins. The four Brazilian soil scientists served as guides and provided a running commentary on soil conditions, geomorphology, geology, vegetation, and land use while travelling and at study stops.

The experimental site at the Brasilia Station was selected to represent the highly weathered and leached soils of good structure but very low fertility known to be extensive in Central Brazil and other tropical savannas. The soil is classified by Brazilian pedologists as _Latosol Vermelho Escuro distrófico, textura argilosa, fase cerradão_ (Dark Red Latosol, dystrophic, clayey texture, cerradão phase). The soil would probably be classified as a Typic Haplustox, fine, kaolinitic isohyperthermic by the U. S. Soil Taxonomy. The site is on a gently sloping geomorphic surface at an elevation of about 1000 m. It is about 850 or 900 m. northeast of the base of a sharp escarpment that rises to an older erosion surface about 150 meters higher than the experimental site. The vegetation of the site before clearing is believed to have been moderately tall and thick stand of twisted trees and shrubs with a grass which is known as "Cerradão." This is considered by Brazilian authorities to indicate somewhat better soil fertility than the lower and thinner stands of the same species known as "Cerrado," which is more extensive on the plateau.

Although soil analytical data and crop performance under experiment confirm favorable physical soil conditions and very low fertility at the experimental site, questions could be raised about how representative the site may be of extensive areas of the Central Plateau. The position of the site relative to the escarpment to higher land could suggest moisture relationships typical of the plateau. The vegetation could suggest soil fertility somewhat better than normal for soils of the plateau.

Soil maps of the region indicate that the "Dark Red Clayey Latosols" mapped at the experimental site are extensive on the plateau. The degree of similarity in various properties that affect management needs, however, was not certain. The map also indicates that other extensive areas in central Brazil are Latosols but are "Yellowish Red," "Medium textured," or both. The degree to which these differences in color or texture might be associated with differences in requirements for cropping was in doubt. These and other uncertainties suggested a need to investigate the soils of reasonably extensive areas some distance from the experimental site and appraise the probability that the experimental results could be extended to them.

Results

The group made detailed descriptions of the soils and landscapes of the different areas travelled and interpretated available data. The details have been published in a paper by Cline and Buol (1973). The following conclusions were reached.

1. The results of the cooperative soil research at the site currently used on the Brasilia Experiment Station should apply in principle to an immense area on the Central Plateau of Brazil.
2. Applications of the results may vary in detail on different kinds of soils of the plateau.
   a. The evidence indicates that the experimental results may be transferred directly to the dystrophic clayey Dark Red Latosols, with only such special adaptations of farming practice as may be needed to accommodate the effects of past land use, local environmental and topographic conditions, resources and skills of farm operators, and the like for specific sites. The aggregate area of these soils is very large. The topographic position of the experimental site is similar to that which farmers now cultivating soil in the valleys first encounter as they extend their operations to the less fertile soils of higher-lying land.
   b. The evidence indicates that the experimental results may be transferred similarly to most, but not necessarily all, areas of dystrophic clayey, Red-Yellow Latosols. (See Conclusion No. 4, also.) The exceptions would appear to be mainly in some areas that have evidence of excessive wetness at times, presumably during or following periods of high rainfall. These exceptions are mainly at places where seepage occurs, such as areas at the base of escarpments and on the lower-lying parts of very long slopes. Some nearly level areas do not receive water from adjacent higher lying land but have little runoff or lateral seepage may also have similar problems. The aggregate area to which results should apply directly is very large. The principal fertility problems should be similar on the periodically wet areas to those of

better-drained sites, but water control should present special problems during the rainy season.

c. The loamy (medium textured) dystrophic varieties of both Dark Red and Red-Yellow Latosols have lower organic matter, lower exchange capacity, and possibly different moisture relations than their clayey equivalents. Some differences of needs in practice when the research results are applied should be expected, although the principles established should apply generally. Rates and timing of nitrogen applications, for example, may need to be different than on the clayey varieties, especially during the first few years of cropping. Large differences in requirements for phosphorus and zinc, however, would not be anticipated. Liming practices may need to be modified slightly. The data show significantly lower moisture equivalents for the loamy varieties, but it is by no means certain that their capacities to supply moisture for plants is less than that of the clayey soils. There was some feeling on the part of Brazilian authorities that water supplying potential might be even better. (See Conclusion No. 4 also.)

d. Eutrophic varieties of both Dark Red and Red-Yellowish Latosols not only have higher base status than their dystrophic equivalents but should have lower exchangeable aluminum and less restricted rooting in the subsoil. This implies that not only liming needs may be different but also soil moisture problems may not be so great. It is possible that phosphorus management may differ as well. Nevertheless, the <u>principles</u> that apply to the dystrophic varieties should apply to the eutrophic soils also.

e. The requirements of eutrophic "Red Yellow Podzolic Equivalents" (Alfisols) may be significantly different in detail from those of the Latosols. The information available is inadequate to do more than speculate about most of these potential differences. It is likely, for example, that the nitrogen fertilizer practice needs may be similar to that at the experimental site, but the needs for lime and phosphorus could be different.

3. Whether or not the different vegetation types (cerrado, cerradão, campo limpo, semi-deciduous forest) are reliable indicators of inherent differences in fertility needs for

farming remains unresolved. Experience of Brazilian authorities would indicate that soils under cerradão, for example, may have enough higher native fertility to be significant for a few years cropping in primitive systems that lack fertility inputs from outside sources. This is not likely to be evident for more than a few years. In systems that employ fertilization, the difference is not likely to be measureable in crop response, if it exists. Soils under semideciduous forest may have greater advantages for primitive systems. They are not likely to differ enough from those under cerrado vegetation to materially affect fertilizer practice in modern systems unless the forest is associated with eutrophic soils, as it commonly is.

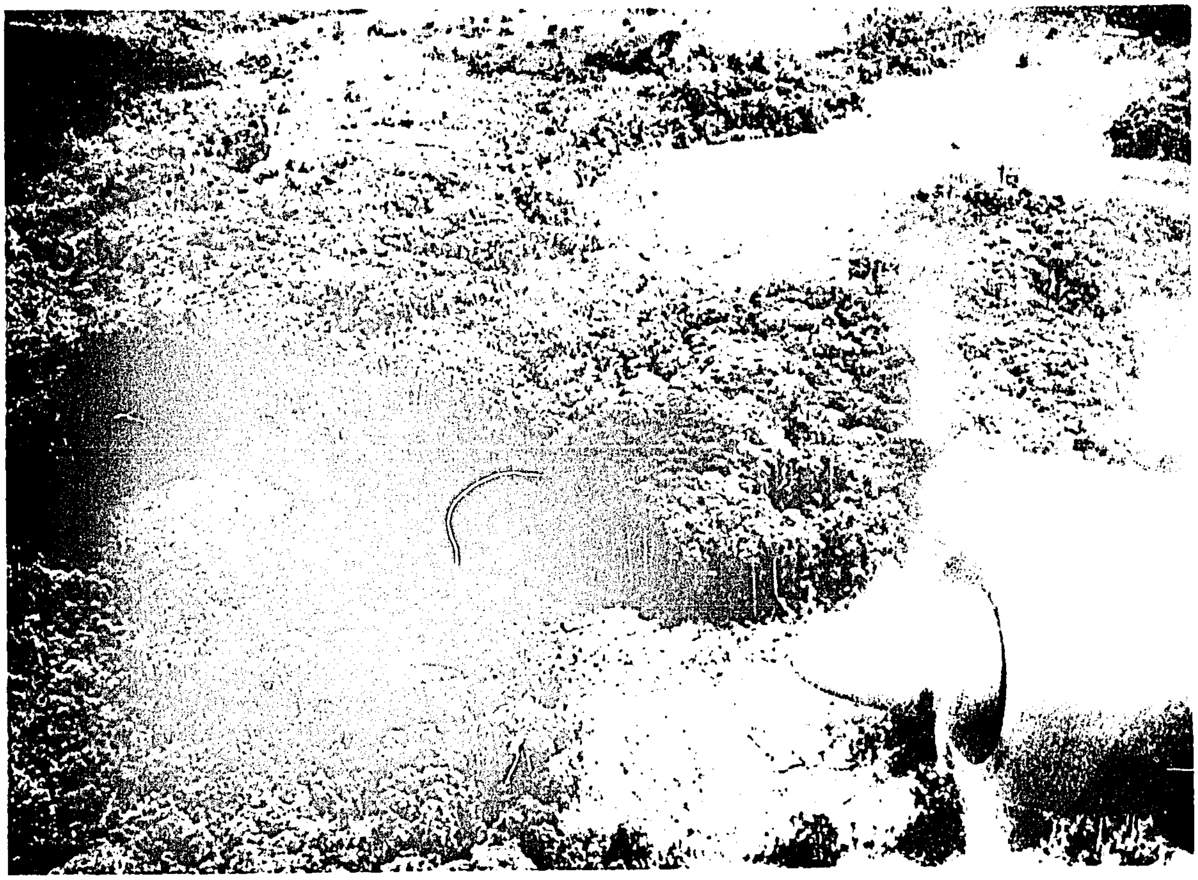
4. Enough uncertainty exists about the relationships between the clayey soil at the experimental site and loamy varieties, Red-Yellow Latosols, and soils that do not lie near an escarpment to a higher surface to justify a satellite experiment to test potential differences. A site for a satellite experiment was located on the highest erosion surface on the Experimental Station. Local scientists indicated that similar sites are receiving considerable attention from persons seeking to establish large-scale farming operations in the region. The soil is a loamy Red-Yellow Latosol. It has been suggested that a simple experiment be established on it to test crop behavior with selected phosphorus-lime treatments used at the main site, and that soil moisture relations be followed during the cropping season. Water for irrigation is not available at the site. Any differences found would be potentially the result of confounded effects of soil differences related to soil color and soil texture, of topographic position, and of lack of irrigation. If significant differences were found and could not be explained by observations and data, it may be important to locate other sites through which the effects of confounded factors can be resolved.
5. An attempt should be made to assemble the information available about the response of crops to fertilization, liming, and water control on the eutrophic varieties of Dark Red and Red-Yellow Latosols. Data may be available from experiment stations at other places such as Anápolis, and may indicate what differences in needs for farming practice, if any, exist between these soils and dystrophic varieties.
6. The capacity of the Dark Red and Red-Yellow Latosols to supply water for plants during relatively short dry periods in the rainy season appears to be one of the very critical

factors in crop production. It is suggested that Brazilian authorities may wish to investigate the feasibility of constructing small ponds or reservoirs on suitable land forms of these soils to supply water for supplemental irrigation during the rainy season. The climatic data seen suggests that small ponds should be full at most times during the rainy season and that if enough water can be impounded for even one irrigation it might make the difference between a reasonable yield and crop failure.

7. The feasibility of developing a viable agriculture on the dominant soils of the region will, in our judgement, depend on the skill and resources of farm operators for applying intensive inputs of fertility, lime, and water control and on the economics of returns form intensive systems. It would, in our judgement, be a disservice to people who lack such skills and resources to encourage them to undertake farming on these soils. For these reasons, we believe that the experimental program should be oriented to systems that employ intensive inputs, but without prejudice as to whether those inputs are applied to small or large farming operations.

Members of the exploratory team in a typical Cerrado field.
From left to right: Camargo, Olmos, Klinger, da Silveira,
and Cline. Photographed by S. W. Buol.

RESEARCH IN THE AMAZON JUNGLE OF PERU



Aerial view of the Yurimaguas Experiment Station.

The field research program initiated in 1972, continued during this year with the overall objective of determining how to manage jungle Ultisols presently under shifting cultivation for sustained crop production. This operation is a joint project with the Direcion General de Investigaciones Agrarias - (CRIANO) of the Peruvian Ministry of Agriculture. The Yurimaguas Experiment Station serves as project headquarters.

Three soil scientists were stationed in Yurimaguas during this year. Mr. Edward J. Tyler continued his detailed soil survey of the Station and returned to Raleigh in May, 1973. Mr. Christopher E. Seubert conducted the continuous cropping experiment with emphasis on comparing land clearing systems. He completed his assignment in August, 1972 and returned to Raleigh. Mr. Cesar E. Lopez arrived in July, 1973 to take the leadership in the continuous cropping experiments and initiate a program on pasture fertilization. These on-site personnel were backstopped by Drs. P. A. Sanchez, S. W. Buol, and C. B. McCants of NCSU and by Dr. Carlos Valverde and Ing. Jose del Carmen Muro of the Peruvian Ministry of Agriculture. The analysis of the soil, plant, and water samples were conducted at La Molina and at Raleigh.

The research program is aimed at providing a viable alternative to shifting cultivation for areas in the Amazon Jungle which are being rapidly populated as a result of new road construction, oil explorations and drilling operations. This project's literature review proved that no systematic research on this problem has been conducted in tropical Latin America.

Our research efforts have concentrated on 1) characterizing and classifying the most extensive soils of the Upper Amazon Basin, 2) evaluating the effect of land clearing methods on soil properties and crop yields, 3) monitoring the soil changes as a function of time after clearing, and 4) selecting the most practical cropping sequences and in determining the fertilizer requirements for sustained cropping in this area.

SOIL CHARACTERIZATION STUDIES

Regional Studies

The rationale for selecting Yurimaguas as a representative site in terms of soils, climate and agricultural practices was described in the 1972 Annual Report. Studies conducted by project staff throughout the Colombian and Peruvian Amazon Basin showed that the most

Table 10. Properties of representative well and imperfectly drained soils from the IVITA station, Pucallpa, Peru.

Horizon	Clay	Sand	pH	Organic Matter	Olsen P	Exchangeable Cations Al	Ca	Mg	K	CEC (sum)	CEC of clay	Base satn
cm	%	%	1:1 H_2O	%	ppm	meq/100g						%
Profile P-1. Typic Paleudult, clayey, kaolinitic, isohyperthermic. Fertility-capability: LCa.												
0- 4	25	43	4.2	3.7	2	1.9	8.0	1.1	0.36	11.6	46	84
4- 26	29	39	4.1	1.6	1	6.6	3.2	0.6	0.24	10.8	37	39
26- 85	41	33	4.1	0.9	1	9.1	1.2	0.5	0.20	11.1	27	18
85-160	25	55	4.2	0.4	1	5.9	1.4	0.5	0.20	8.1	32	17
160- +	41	29	4.2	0.3	1	10.7	1.2	0.5	0.20	12.7	31	16
Profile P-2. Aquic Paleudult, clayey, mixed, isohyperthermic. Fertility-capability: LCga.												
0- 3	27	35	5.2	6.3	2	0.2	4.2	2.1	0.52	7.1	26	97
3- 21	45	17	4.3	1.9	1	4.0	2.2	1.2	0.40	7.9	17	49
21- 62	59	15	4.2	1.0	1	8.7	0.8	0.9	0.32	10.8	18	19
62- +	57	21	4.1	0.5	1	11.6	0.4	0.7	0.24	13.1	23	11

extensive soils of the area are Ultisols (Red Yellow Podzolic soils) and not Oxisols (Latosols) as they presently appear in large scale soil maps of the area. Substantial information was gathered during this year which confirms further these observations. In addition to the 16 profiles previously characterized from the Yurimaguas and Iquitos areas, observations were made around Pucallpa where very little soils information is available. Table 10 shows the properties of two representative profiles collected at the IVITA cattle station near Pucallpa. The well-drained member classifies as a Typic Paleudult just like those found in similar positions in Yurimaguas, Iquitos, or the southern Colombian Amazon. The poorly drained member is classified as an Aquic Paleudult and has similar properties to other poorly drained soils found in Yurimaguas, Iquitos, and Leticia. The gleyed mottled subsoil is extremely high in aluminum; it has also been described in other parts of the Upper Amazon. As mentioned in the previous reports, these layers have been previously considered to be soft laterite (plinthite.) The CEC of the clay suggest the presence of a mixed 1:1 and 2:1 mineralogy. These layers do not dry irreversibly and therefore are not plinthite. If they were, the quality of the local roads would be far superior to what they are.

Soil Properties-Landscape Relationships at the Yurimaguas Station

The experiment station property selected by Drs. Buol, Sanchez, and Ing. Nureña in 1971 was mapped at the detailed level by Mr. Tyler during the year. The study includes geomorphic relationships, soil profile characterization and genetic implications. Data from several intensive study areas were also collected. These consist of water table measurements and chemical analysis of soil water extracts at several depths. A total of 18 soil profiles were sampled in detail. Laboratory characterization is in progress at Raleigh.

Four major geomorphic surfaces were identified at the Station and the soils within them delineated. Figure 10 shows the distribution of these surfaces and the location of key profiles. The first geomorphic surface comprises the flood plains of recent origin and the terraces not higher than 2 meters above the Shanusi River level. The soils are variable in composition because of recent river activity. Textures range from sands to clays and drainage from excessive to poor. In some instances major lithologic breaks are noted. The soils immediately adjacent to the river are subject to frequent flooding. Flooding also occurs in depressional areas further from the river in clayey soils. This water is probably perched

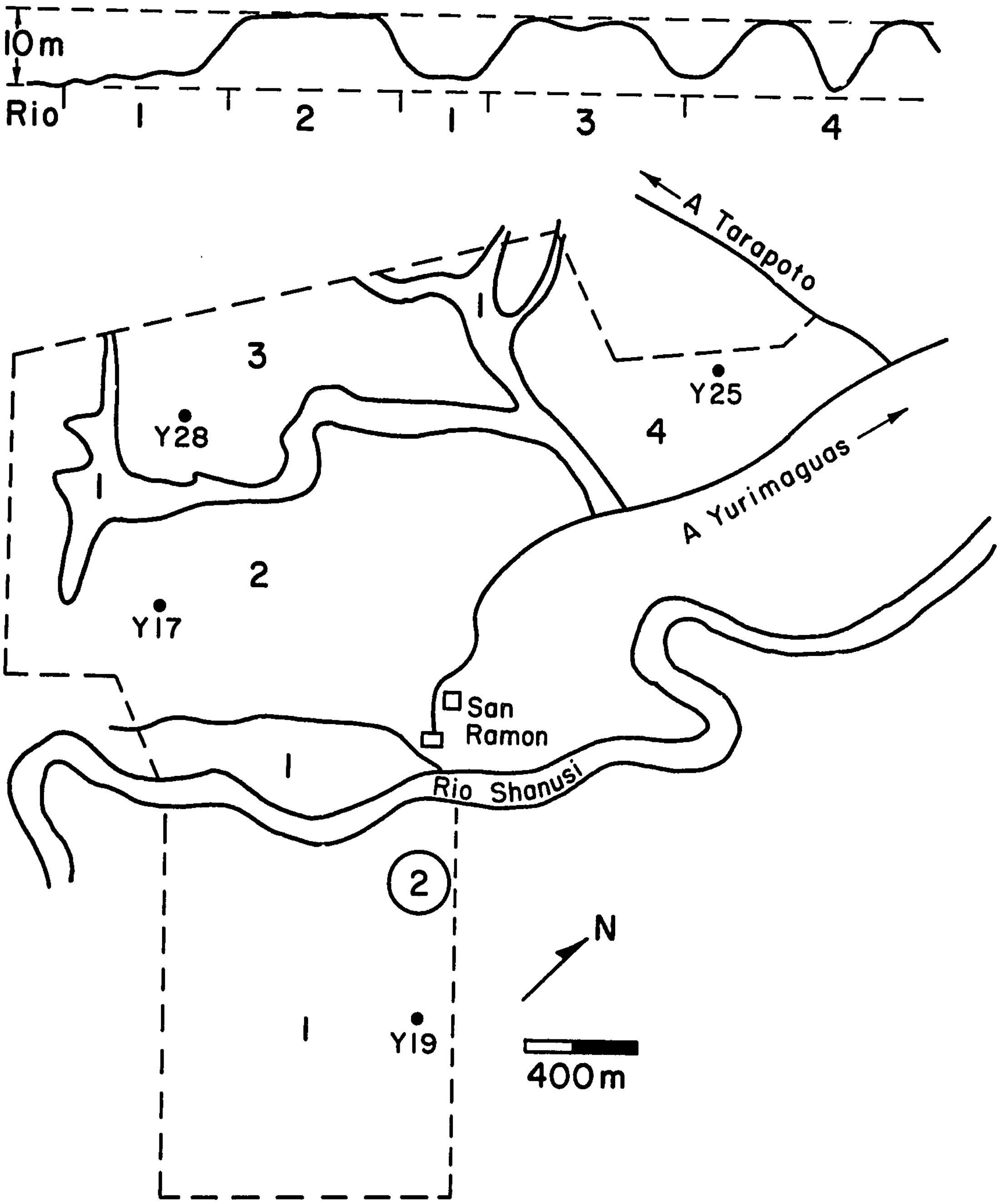


Figure 10. Map of the Yurimaguas Experiment Station showing the four main geomorphic surfaces and the location of key soil profiles.

rain water. All the soils of this surface are influenced by high water tables as evidenced by mottling, concretions, and other signs of wetness which are found in all but the coarsest textures. Profile Y-19 in Table 11 is an example of the soils in this surface. This sandy loam soil has a perched water table at 62 cms. These soils are generally less acid than those of the upland position and most of the annual crop agriculture is concentrated in this surface. Periodic flooding is one of the main limitations of this area. These soils are also found in the deeply incised drainage ways of the upland positions as shown in Figure 10.

The other three geomorphic surfaces form the upland positions which have very uniform elevation of about 10 m above the river. The second surface consists of large and flat areas in which are incised very lightly by the drainage pattern. The soils are deep, well drained and extremely acid. The water table is generally below 2 m except in the drainage ways. Profile Y-17 in Table 11 is representative of this area. It belongs to the Yurimaguas series according to the ONERN soil survey. It is a Typic Paleudult with low cation exchange capacity, high aluminum saturation and very low available phosphorus. The field trials were conducted on this surface and in an area adjacent to Profile Y-17. The small drainage ways are often of coarse texture and show mottled colors. The present land use pattern consists of upland rice, cassava, and some permanent pastures.

The third geomorphic surface is strongly undulating with continuous slope changes throughout. It is moderately incised by the drainage ways. The main soils are morphologically not very different from the second surface. Profile Y-28, tentatively classified as a Typic Tropudult, is representative of this third surface. Land use is essentially the same as in the second surface.

The fourth geomorphic surface is deeply incised with the drainageways at nearly the level of the Shanusi River. The sideslopes are steep and change abruptly to relatively small flat tops. In the sideslopes slumping of the slopes is often evident. The soils of these sideslopes are imperfectly drained with a gleyed impermeable mottled horizon that can perch water. Profile Y-25 in Table 11 is representative of these sideslopes. It belongs to the Pucullpa series according to the ONERN soil survey. In the flat tops, the soils are sandier and may belong to the arenic subgroups of the Paleudults. Very little cropping is evident in this surface. Pastures are the only agricultural activity encountered.

Table 11. Properties of typical profiles found in the four main geomorphologic surfaces described at the Yurimaguas Experiment Station.

Horizon	Clay	Sand	pH	Al + H	Ca	Mg	K	Na	CEC (sum)	Base Satn.
cm	%	%	1:1H_2O			meq/100g				%
First surface: Profile Y-19: Aquic Dystropept. Fertility-capability: Lgak.										
0- 10	21	62	5.0	0.7	3.7	0.7	.05	0.08	5.2	86
10- 25	23	65	4.9	5.9	0.6	0.2	.13	0.06	6.9	14
25- 62	23	66	5.4	7.6	0.4	0.3	.14	0.19	8.6	12
62-100	32	43	5.3	8.5	2.2	2.5	.18	1.23	14.6	42
100-130	33	27	5.3	4.8	5.7	5.0	.20	2.19	17.9	73
130-160	31	33	5.4	2.0	7.0	4.9	.18	0.18	14.1	86
Second surface: Profil Y-17: Typic Paleudult. Fertility-capability: Leak.										
0- 4	19	58	4.2	3.0	.24	.20	.12	.04	3.6	17
4- 16	24	46	4.3	3.7	.18	.11	.06	.03	4.1	9
16- 25	28	40	4.3	4.6	.09	.06	.04	.04	4.9	5
25- 50	30	41	4.4	4.9	.05	.03	.04	.03	5.1	3
50-100	32	39	4.4	5.4	.09	.03	.04	.03	5.6	3
100-200	39	31	4.6	7.4	.05	.03	.06	.03	7.6	2
Third surface: Profile Y-28: Typic Tropudult. Fertility-capability: Leak.										
0- 5	5	80	4.3	1.8	.65	.23	.04	.02	2.7	34
5- 40	16	58	4.2	3.9	.17	.05	.04	.02	4.2	7
40- 80	29	50	4.2	5.1	.06	.42	.03	.06	5.7	10
80-115	20	57	4.2	4.3	.07	.04	.02	.02	4.4	2
115-160	30	49	3.5	5.0	.05	.03	.04	.03	5.1	3
160-200	10	50	4.1	5.4	.04	.03	.04	.02	5.5	2
Fourth surface: Profile Y-25: Aquic Paleudult. Fertility-capability: LCgak.										
0- 5	10	50	3.6	4.0	.31	.21	.12	.02	4.6	13
5- 16	13	57	3.9	4.6	.11	.08	.06	.02	4.9	20
16- 34	20	50	4.1	6.2	.03	.03	.06	.11	6.4	4
34- 89	35	39	4.1	8.9	.05	.04	.09	.03	9.1	2
89-170	48	34	4.3	11.9	.04	.06	.20	.04	12.2	2
170-200	50	11	4.3	15.2	.06	.36	.31	.06	16.0	5

Phosphorus Fixation

The characterization studies indicated that these soils may have serious fertility limitations. Additional data was needed to estimate the degree of phosphorus fixation and the lime requirements. Samples of the Yurimaguas series (Profile Y-13) located in the experimental plots on the second geomorphic surface and the Pucallpa series (Profile Y-25) of the fourth surface were brought to Raleigh.

Phosphorus sorption isotherms were developed from the top 15 cm of these two soils. Fig. 11 shows that a rate of about 25 ppm of P is needed to produce the desired level of 0.2 ppm P in the soil solution. This indicates that a moderate amount of phosphorus (50 kg P/ha or 116 kg P_2O_5/ha) is needed to satisfy the fixing capacity of this soil and provide adequate amounts to plants. The Yurimaguas series has a relatively low phosphorus fixation capacity which is quite similar to that of the Norfolk series, a Paleudult of the Coastal Plain of North Carolina. The low clay content is thought to be the main reason for the low fixing capacity. The more clayey Pucallpa series required 100 ppm P to reach the 0.2 ppm level in the soil solution. This is four times higher than the Yurimaguas series and approaches the fixing capacity of some Ultisols of the North Carolina Piedmont.

An additional trial was conducted with the top 30 cm of the Yurimaguas series. Due to the clay increase, the phosphorus fixing capacity doubled. This indicates a higher phosphorus requirement if deep plowing to that depth is considered desirable.

In comparison with the Brazilian Oxisols, the phosphorus fixation capacity of these jungle Ultisols is much lower. This is probably due to the lower clay content and different clay mineralogy. While a major portion of the efforts in Brasilia are logically geared toward making phosphorus applications economically, this issue is of lower priority in Yurimaguas.

Lime Requirements

The top 15 cm of the two soils were incubated with increasing rates of $Ca(OH)_2$ in the laboratory. $Ca(OH)_2$ was used instead of carbonate because it is the only source of lime presently available in the area. The neutralization curves are shown in Fig. 12. The Yurimaguas soil has an initial pH of 4.1 with 1 meq of exchangeable aluminum which amounts to 64% aluminum saturation. Approximately 2 meq of Ca were needed to neutralize the exchangeable

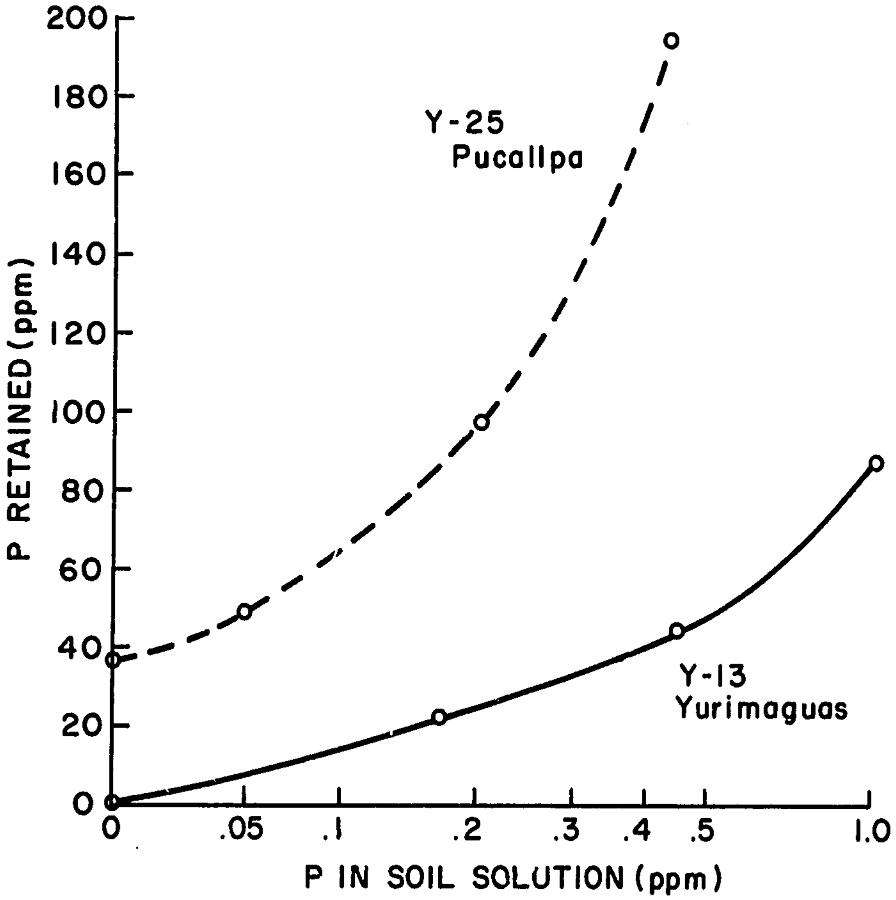


Figure 11. Phosphorus retention curves of two Ultisols from the Yurimaguas Experiment Station. Field experiments were conducted on profile Y-13.

aluminum and raise the pH to 5.5. This quantity corresponds to about 4 ton/ha of $Ca(OH)_2$. However, only 2 ton/ha of $Ca(OH)_2$ were needed to reduce aluminum saturation to 20%. At this level it is probable that aluminum is no longer a limiting factor.

The Pucallpa soil had the same initial pH but 3.9 meq of aluminum which amounted to 87% aluminum saturation. About 5.5 ton/ha of $Ca(OH)_2$ were needed to neutralize the aluminum and raise the pH to 5.5. About 4 ton/ha of $Ca(OH)_2$ were needed to decrease the aluminum saturation to 20%. When the top 30 cms of the Yurimaguas series was used, it was necessary to apply 3.5 ton/ha of $Ca(OH)_2$ to raise the pH from 4.1 to 5.4.

CONTINUOUS CROPPING EXPERIMENT .

Objectives and Design

The goal of the field research is to determine what are the soil and crop management practices required for continuous production in jungle Ultisols. The approach chosen consisted of a main long-term experiment called "continuous cropping" supported by several supplementary experiments aimed at answering more specific questions such as optimum rates of individual nutrients.

The continuous cropping experiment consists of opening a new clearing every year in order to evaluate the time factor (years after clearing) within the same climatic conditions. The specific objectives of this experiment were: 1) To compare the traditional slash and burn hand clearing system with mechanized clearing in terms of yields and soil properties, 2) To compare the productivity and profitability of different cropping systems at different fertility levels and 3) To determine the changes in soil properties with time associated with fertility declines and ways to correct it.

The first clearing was carried on a two hectare tract on a Typic Paleudult soil (Yurimaguas Series, Profile Y-13) located in the second geomorphic surface under a 17-year old secondary forest. A factorial experiment was installed, consisting of two clearing systems (slash and burn vs. bulldozing) as the main plots, six cropping systems as the subplots and seven fertility levels as the subsubplots. The 280 m^2 subplots were arranged in a randomized complete block design with four replications.

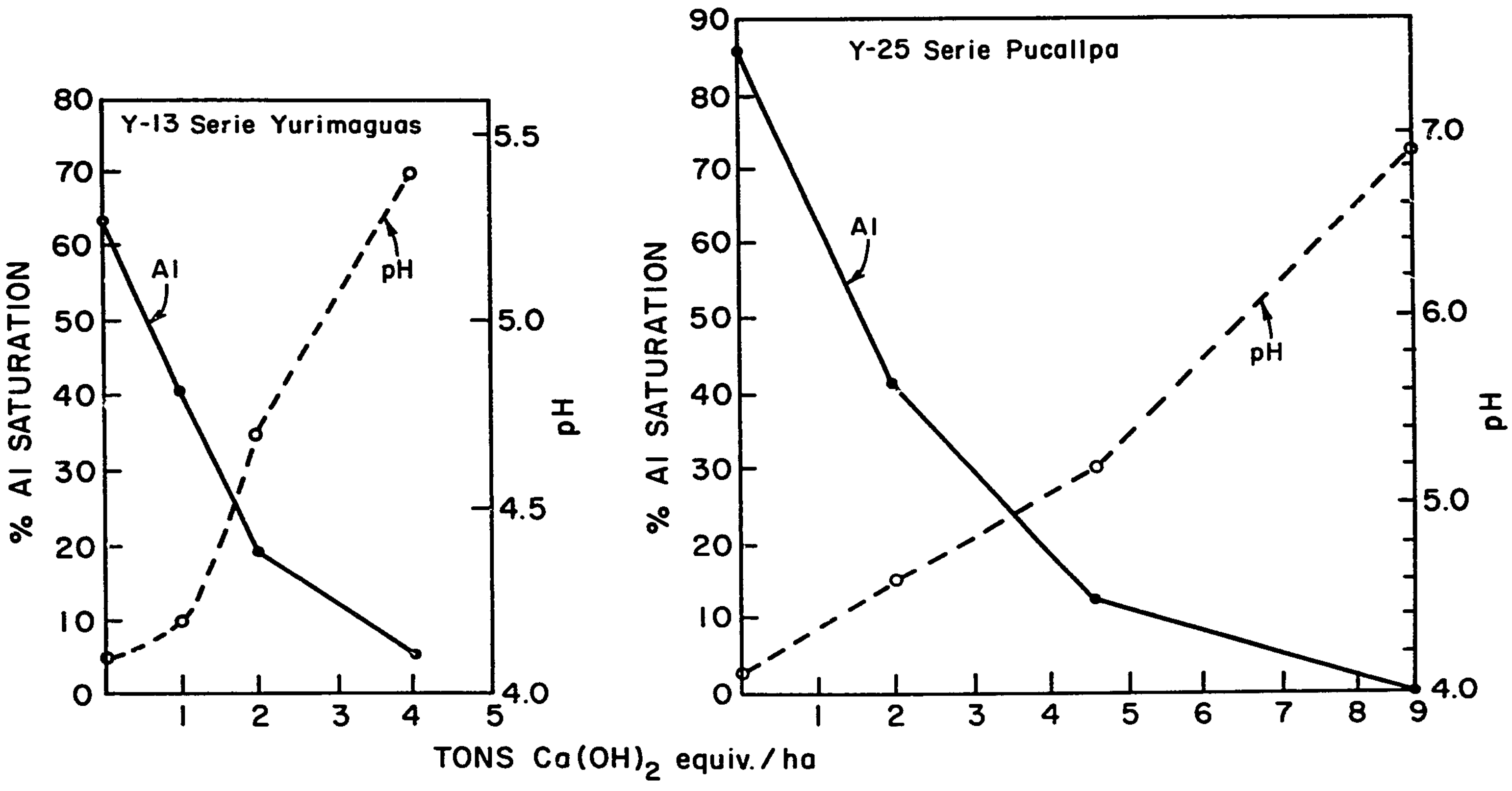


Figure 12. Neutralization curves of the topsoils of the Yurimaguas and Pucallpa series at the Yurimaguas Station.

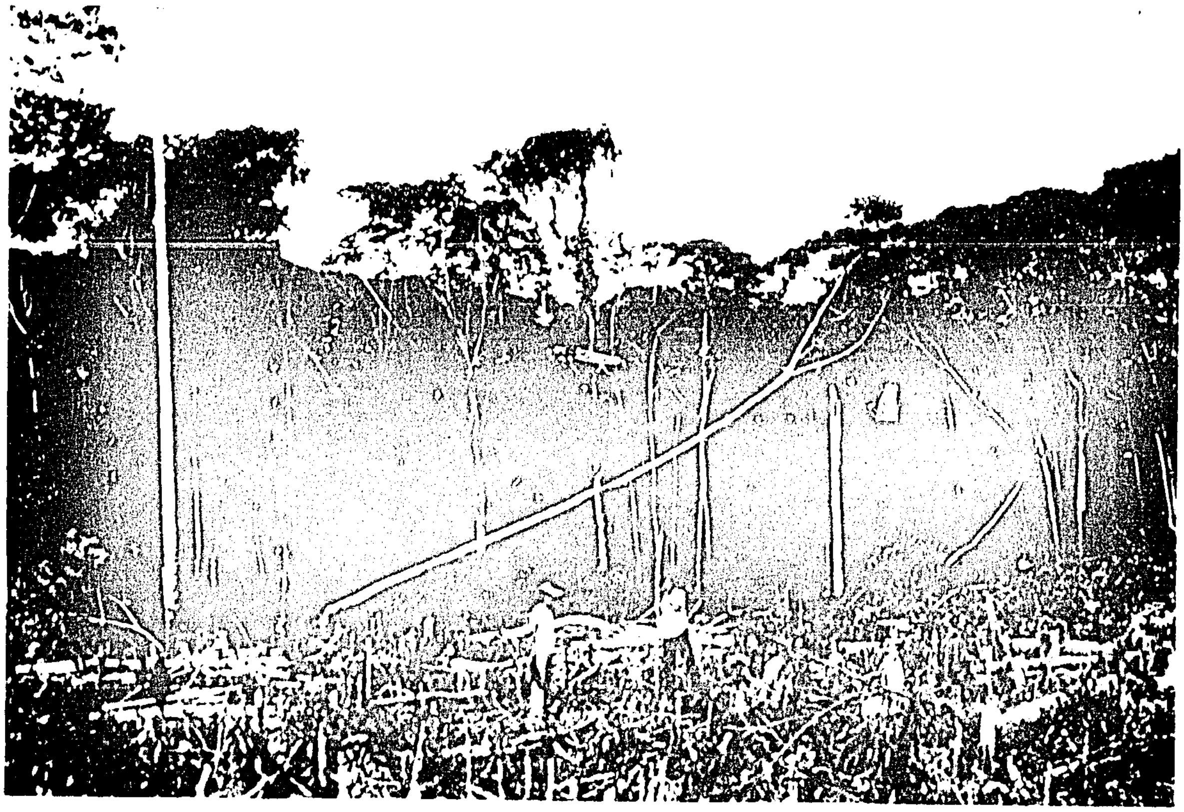
The "rozo" (cutting underbrush and vines with machetes) the "tumba" (felling trees with axes) and the "picacheo" (separating branches from trunks) were accomplished during the week of September 8, 1972. Three weeks later, the appropriate areas were burned. In the bulldozed plots a D-6 Caterpillar tractor equipped with a conventional blade removed the felled vegetation and piled it away from the plots. In this treatment, the land was totally free of vegetation or tree stumps.

Seven different cropping sequences were planted in the first clearing. They are described in Table 12. The continuous upland rice system will evaluate fairly intensive exploitation by the cereal crop best adapted to the area. The second cropping system involves a succession of taller and later-maturing crops actually used by some farmers in the area. Following the plantain harvest, these plots will be abandoned to forest regrowth. The third system involves intensive cropping of two cereal and two grain legumes. The fourth is a rice-pasture succession used by some farmers as an alternative to shifting cultivation. Guinea grass (Panicum maximum), the pasture grass species best adapted to the area was used. The fifth sequence involves grain sorghum, a climbing bean and two soybean varieties. The sixth and seventh systems consists of immediate pasture establishment after clearing. They will permit evaluating the influence of tropical Kudzu (Pueraria phaseoloides), the pasture legume best adapted to the Yurimaguas area, on yields and nitrogen supply.

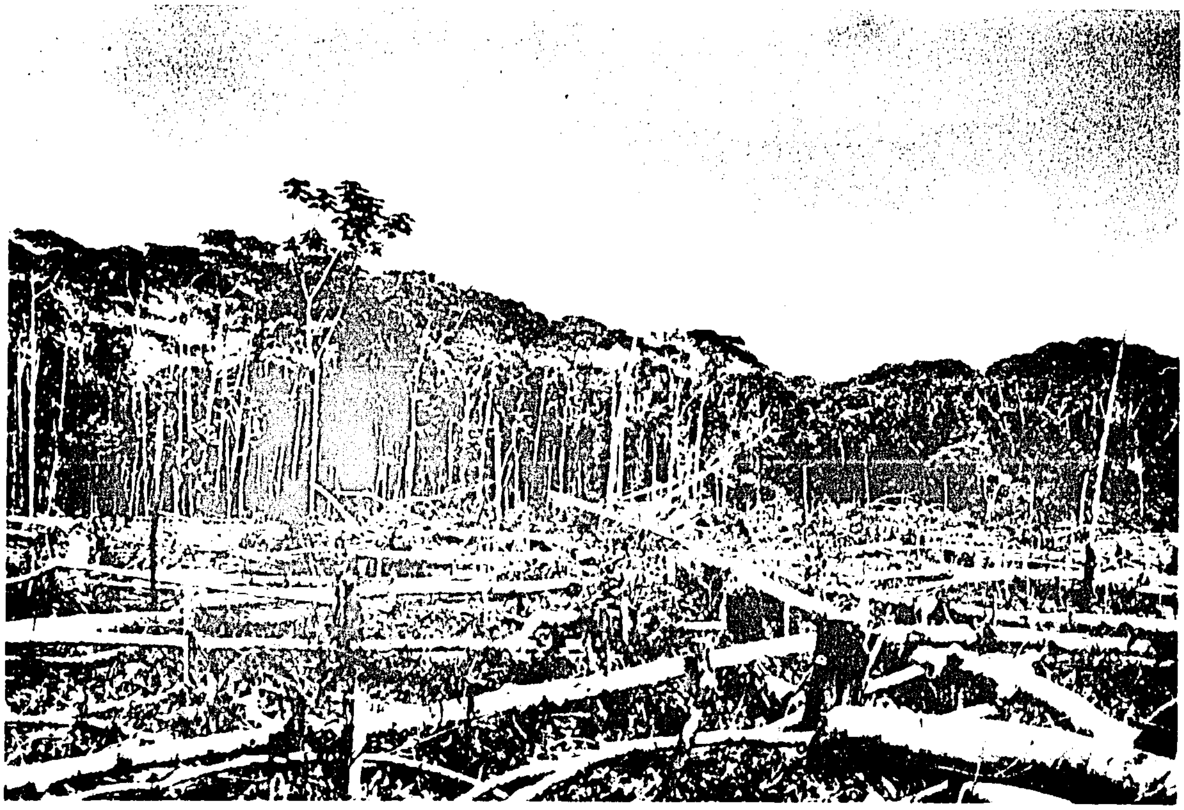
The October, 1972 plantings did not receive a fertility differential because of delays in obtaining the required fertilizers. After the rice harvest of February, 1973, the following fertility and tillage differentials were established in croppings systems 1 to 5.

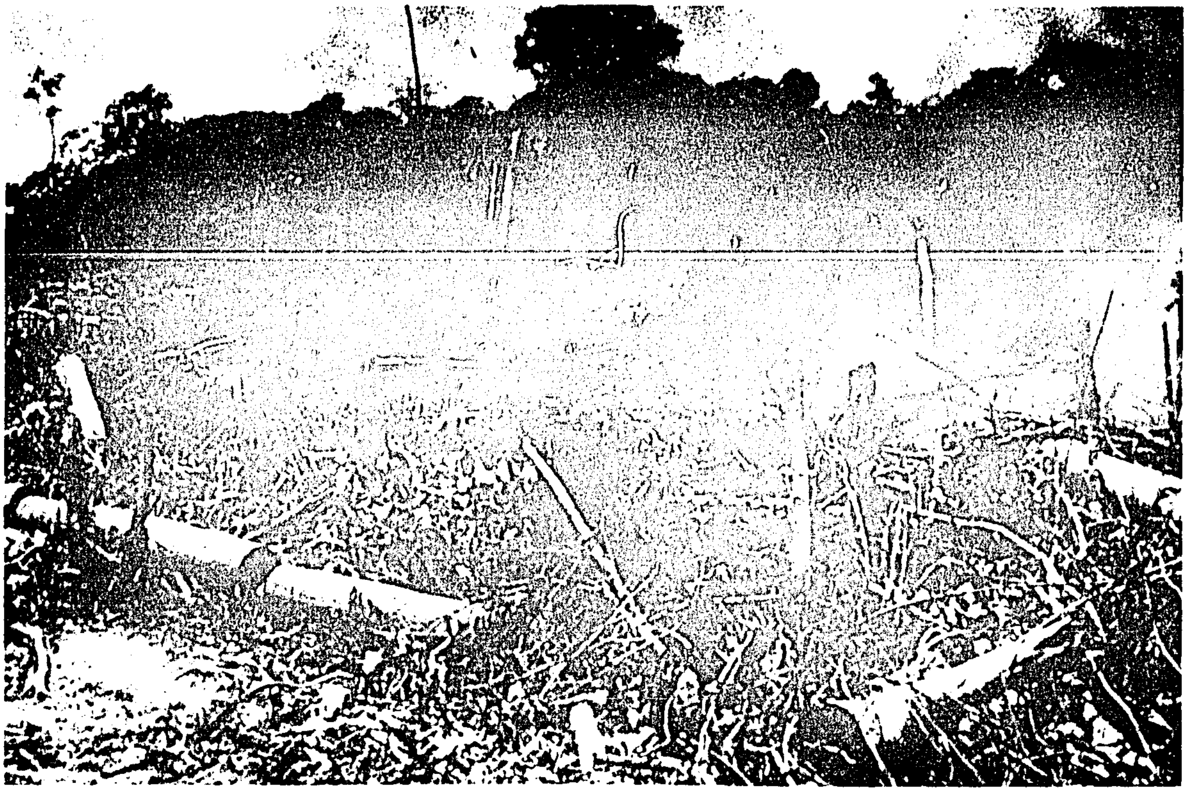
1. No fertility, no tillage
2. No fertility - rototilled
3. 50-0-40 kg/ha of N, P, and K
4. 50-176-40 kg/ha of N, P, and K
5. 50-176-40 plus 4 ton lime (2.6 ton/ha of $Ca(OH)_2$ equivalent)

Treatments 2 to 5 were rototilled with a 6 hp Kubota hand tractor. In the burned plots it was possible to rototill around the stumps without difficulty. Urea, ordinary superphosphate and KCl were the sources used. Fertilizers and lime were incorporated with the rototiller up to 10 cm depth, instead of at 15 cm as planned. The pH of the top 10 cm increased from 4.1 to 6.0 in the limed plots.



Aspect of 1972 clearing operations: "tumba" (above) and field drying after "picacheo" (below).





The land clearing differentials: slash and burn (above) and bulldozer clearing (below).

Table 12. Description of cropping systems used in the continuous cropping experiment.

Cropping System	Variety	Date Planted	Date Harvested	Spacing cm.
1. Continuous Rice				
Rice	IR 578-8	Oct. 5, 1972	Feb. 28, 1973	25 x 25
Rice	IR 4-2	Apr. 3, 1973	Aug. 28, 1973	25 x 25
Rice	IR 4-2	Oct. 1, 1973	-	25 x 25
2. Rice - Cassava - Plantains - Fallow				
Rice	IR 578-8	Oct. 5, 1972	Feb. 28, 1973	25 x 25
Cassava	Huallaga	Mar. 17, 1973	Feb. 9, 1974	100 x 100
Plantains	Local	Feb. 22, 1974	-	200 x 300
3. Rice - Corn - Soybean - Soybeans				
Rice	IR 578-8	Oct. 5, 1972	Feb. 28, 1973	25 x 25
Corn	Cuban Yellow	Mar. 29, 1973	July 21, 1973	60 x 80 (42,000 Plants/ha)
Soybean	Improved Pelikan	July 24, 1973	Oct. 1, 1973	30 x 80
Soybean	Improved Pelikan	Nov. 23, 1973	-	30 x 80
4. Rice - Guinea Grass Pasture				
Rice	IR 578-8	Oct. 5, 1972	Feb. 28, 1973	25 x 25
Guinea Grass	Local	Mar. 10, 1973	-	50 x 50
	Cuts: July 20, Sept. 29, Dec. 6, and Feb. 6			
5. Grain Sorghum - Beans - Soybeans - Soybeans				
Sorghum	NK-222	Oct. 6, 1972	Feb. 15, 1973	25 x 25
Beans	Hualláguina	Mar. 28, 1973	July 10, 1973	60 x 80
Soybeans	Improved Pelikan	July 24, 1973	Oct. 1, 1973	30 x 80
Soybeans	Improved Pelikan	Nov. 23, 1973	-	30 x 80
6. Guinea Grass Pasture				
Guinea Grass	Local	Oct. 15, 1972	-	50 x 50
	Cuts: Dec. 1, Jan. 18, Mar. 18, May 6, July 18, Sept. 24			
7. Guinea Grass - Kudzu Pasture				
Guinea Grass	Local	Oct. 15, 1972	-	50 x 50
	Cuts: Dec. 1, Jan. 18, Mar. 18, May 6, July 18, Sept. 24			

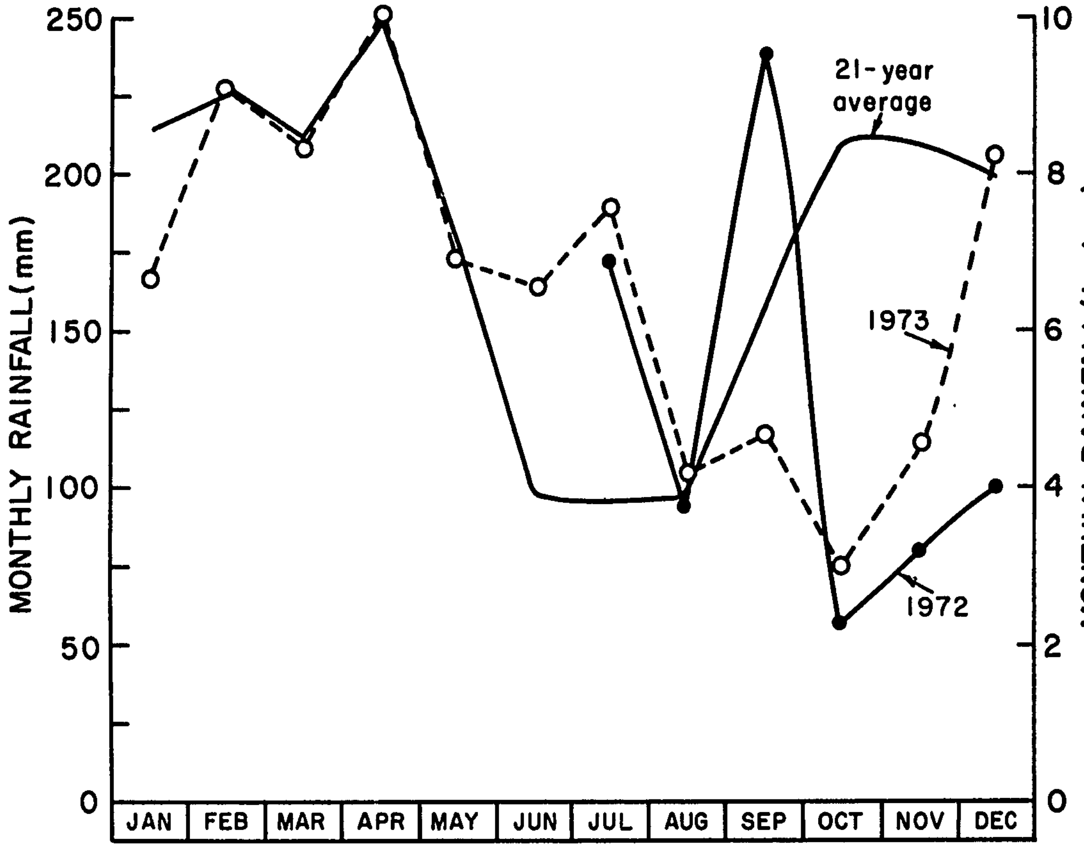


Figure 13. Monthly rainfall pattern in Yurimaguas during the experimental period in comparison with the 21-year average.

Table 13. Effects of land clearing methods on the nutrient status of the first upland rice crop at two growth stages. Yurimaguas, 1973.

	30 day old seedlings		Grain at Harvest	
Nutrient	Slash & burn	Bulldozed	Slash & burn	Bulldozed
N %	4.03	3.97	1.54	1.52
P %	0.17	0.13	0.19	0.12
K %	3.02	1.94	0.29	0.26
Ca %	0.30	0.33	0.68	0.65
Mg %	0.17	0.16	0.09	0.07
Mn ppm	41	97	57	77
Cu ppm	15	15	7	9
Fe ppm	132	159	42	51
Zn ppm	65	80	35	37

Table 14. Effects of land clearing methods on grain yields and dry matter production in the first five months. Yurimaguas, 1973.

	Grain Yields*		Total Dry Matter*	
Cropping System	Slash & burn	Bulldozed	Slash & burn	Bulldozed
	kg/ha			
1 to 4. Rice	1210	1047	3146	2452
5. Sorghum	394	163	2601	520
6. Guinea Grass (3 cuts)	-	-	4883	2040
7. Guinea/Kudzu (3 cuts)	-	-	4366	2165

*All treatment differences were significant at the 1% probability level.

Soil samples were obtained at three depths at the following times: before clearing, three weeks after burning, and every three months afterwards. They are presently being analyzed at Raleigh and in Lima. Ash samples and samples of unburned vegetation were also taken. Plant samples were taken at harvest and at other intervals to identify nutrient deficiencies. Infiltration rates were measured with locally made double ring infiltrometers at 1 and 11 months after clearing in selected plots. Soils were also sampled for bulk density determinations.

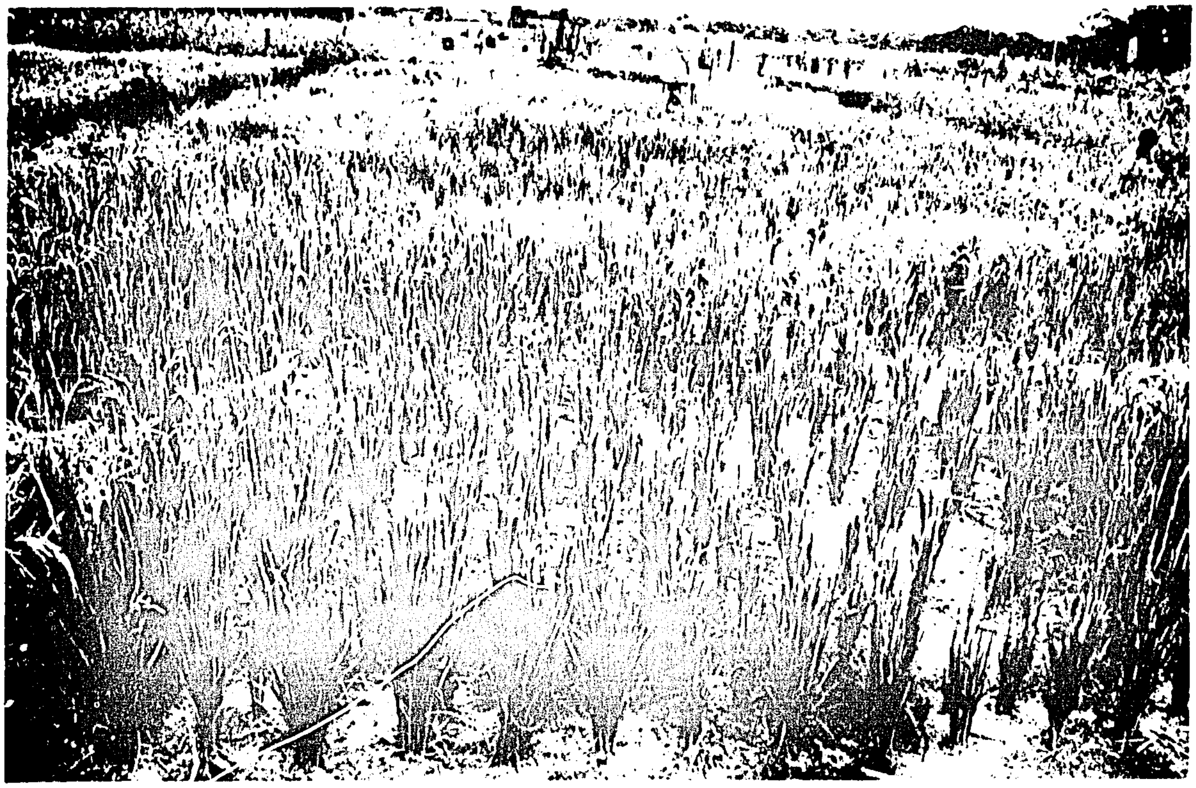
Effects of Land Clearing Methods

Within the first month after seeding, all crops were greener and more vigorous in the burned than in the bulldozed plots. A foliar analysis of 30-day-old rice plants showed a much higher phosphorus and potassium content in the burned plots (Table 13). These differences continued with growth but a severe drought during the months of October and November reduced drastically the rice and sorghum grain yields. This can be observed in Fig. 13 where the 1972-73 rainfall is plotted against the 21-year average.

The yields of rice, sorghum, and pastures during the first five month period appear in Table 14. The severe drought period is the main reason why the rice yields were so low. The yields and dry matter in the burned plots were significantly superior to the bulldozed plots. The nutrient composition of the rice grains at harvest (Table 13) shows that this difference is primarily associated with phosphorus contents. The grain sorghum yields were even lower due to the drought and a severe bird attack. Nevertheless, the yield and dry matter differences between clearing treatments were remarkable. Pasture production in the burned treatments more than doubled the production in the bulldozed treatments.

These results indicate that the bulldozed clearing was definitely detrimental to crop growth. In the entire experiment, total dry matter production in the bulldozed treatments was less than half of that obtained by the traditional slash and burn method. The detrimental effect of the mechanized clearing could be due to three factors: 1) The absence of ashes as a nutrient source, 2) Soil compaction by the bulldozer, and 3) Topsoil movement from the higher parts and accumulation in the lower parts by the bulldozer blade.

The superior appearance of the first rice crop in the slash and burn treatments (above) contrasts sharply with the growth in the bulldozed clearings (below). Yurimaguas, February, 1973.



Influence of the Ash

Table 15 shows the chemical composition of ashes, green leaves, and dry forest leaves prior to burning. Ashes were collected in 100 cm^2 areas at random as soon as was possible after burning. The material analyzed included true ash as well as partially burned vegetation on the soil surface. The data reported in this table is the mean of 62 samples. The average dry weight of the ashes was about 4 ton/ha. This figure was used to estimate the amounts of nutrients added in the process of burning.

Table 15 shows that a considerable amount of nitrogen probably in the form of partially burned material was added to the soil in the process of burning. Moderate additions of phosphorus, potassium, calcium, magnesium, manganese, and iron are also evident in this table. These quantities are considerably lower than the values in the literature from wood ashes. We observed that only part of the forest is actually burned: the leaves, litter, twigs, small branches and the bark of tree trunks and large branches. According to our literature review, these parts account for less than 10% of the total forest biomass. The unburned parts, such as trunks, large branches, stumps, and roots decompose gradually. The nutrient contents of the fresh and dry forest leaves indicates rapid mineralization and possible addition to the soil of considerable quantities of N, P, K, Ca, and Mg prior to burning. Discounting the possible rapid mineralization of these nutrients, the process of burning *per se* added nutrients in the equivalent amounts of approximately 70 kg N/ha, 20 kg P_2O_5/ha, 47 kg K_2O/ha, and 240 kg/ha of dolomitic lime.

Soil Compaction

Clearing with a bulldozer caused severe soil compaction. Fig. 14 shows the infiltration rates taken in the burned and the bulldozed plots at 1 and 11 months after clearing. Each figure is the average of four constant head, double ring infiltrometers. The slash and burned plots had an average infiltration rate of 10 cm/hr and the bulldozed plots 0.5 cm/hr. No measureable changes were observed between 1 and 11 months. All measurements were taken in untilled plots.

The third factor, transfer of topsoil from the higher to the lower areas was observed visually. These three factors gave the soil surface completely different appearance. After one year of cultivation, the burned plots had a darker color and good tilth while the bulldozed plots had a lighter colored soil surface and a packed appearance.

Table 15. Elemental composition of fresh and dry forest leaves prior to burning, and ashes collected after the first burning. Yurimaguas, 1973.

Nutrient	Fresh leaves	Dry leaves	Ash and partially burned material	
	Concentration			kg/ha
N %	6.12	0.84	1.72	69
P %	0.38	0.19	0.14	6
K %	6.12	0.84	0.97	39
Ca %	2.42	1.98	1.92	77
Mg %	1.62	0.98	0.41	16
Na ppm	370	550	180	0.7
Mn ppm	2972	3110	1867	7.4
Cu ppm	100	106	79	0.3
Fe ppm	644	1026	1900	7.6
Zn ppm	482	372	137	0.5

Aspect of the ash sampling operation.

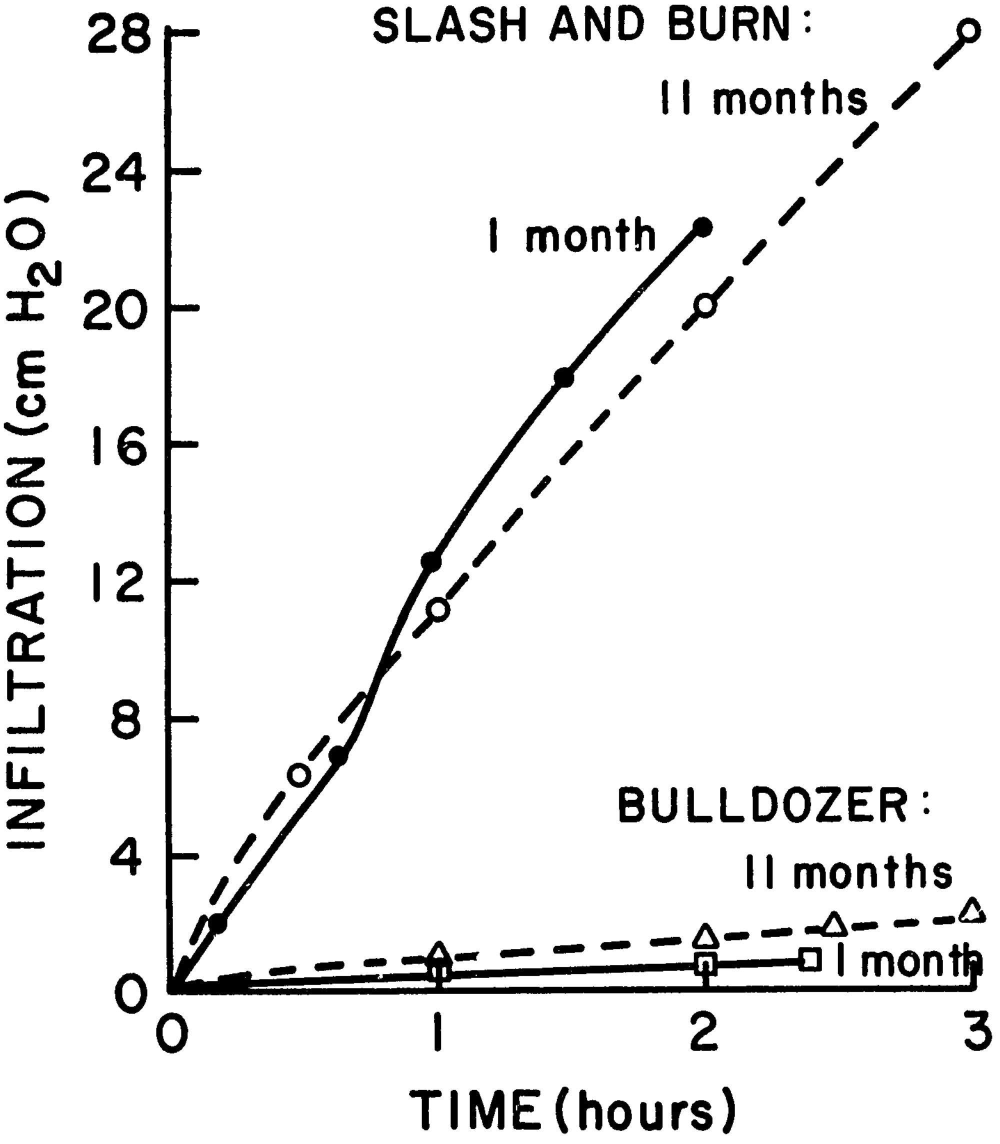


Figure 14. Effects of land clearing systems on the infiltration rates of untilled soils at 1 and 11 months after clearing.

Land Clearing - Fertility Interactions

The results of the second continuous upland rice crop appear in Table 16. The yields without added fertility were superior to those of the first crop, because of a better rainfall distribution pattern. No response to tillage *per se* was observed. Without added fertility, the average rice yield of the burned treatments was 1.8 ton/ha, while in the bulldozed treatment, it was 1.0. A strong response to nitrogen, potassium, and lime was observed in both land clearing systems. The highest yield obtained (3.2 ton/ha) is excellent for upland rice. The overall effect of mechanized clearing was to produce 66% as much yield as the slash and burn system.

The cassava yields following rice appear in Table 17. Again no differences due to tillage were observed in the plots without added fertility. In both land clearing treatments a strong response to phosphorus and lime was observed. The maximum yields obtained with bulldozing (32 ton/ha) were not significantly different to those obtained with the traditional slash and burn (34 ton/ha). It is relevant to note that the yields of the burned treatment without fertility (22 ton/ha) more than doubled those of the bulldozed treatments (10 ton/ha). The overall effect of bulldozing was to decrease the yields to 67% of that obtained in the slash and burn system.

The yields of corn following rice in the third cropping system were extremely low. This is due to severe disease attack and the presence of sulfur, boron, and molybdenum deficiencies. These deficiencies were visually diagnosed by Dr. Valverde and later confirmed by the foliar analysis shown in Table 18. The grain yields shown in Table 19 are too low to permit a realistic appraisal of fertilizer response. Nevertheless, it can be observed that the yields of the bulldozed treatment were about a fifth of those obtained with the slash and burn treatment. The results of the soybean crops which followed corn in this system are not available at the time of this writing.

The dry matter production of Guinea grass during the first nine months in the fourth system after the rice harvest is shown in Table 20. Unlike rice and cassava, there was a noticeable response to tillage alone, particularly in the bulldozed clearing. Guinea grass responded positively to the nitrogen, phosphorus, potassium and lime rates applied. The maximum yields obtained (24 ton/ha in 300 days) compare favorably with the best Guinea grass

Table 16. Effects of land clearing methods and fertilizer application of the second planting of upland rice cropping system 1. Yurimaguas, 1973.

Treatment	Slash and Burn	Bulldozed clearing
	kg/ha	
1) Untilled check	1632	1013
2) 0 - 0 - 0	1938	1088
3) 50 - 0 - 40	2351	1254
4) 50 - 172 - 40	2562	1660
5) 50 - 172 - 40-4 tons lime/ha	3210	2527
Mean	2244	1481

$LSD_{.05} = 439$

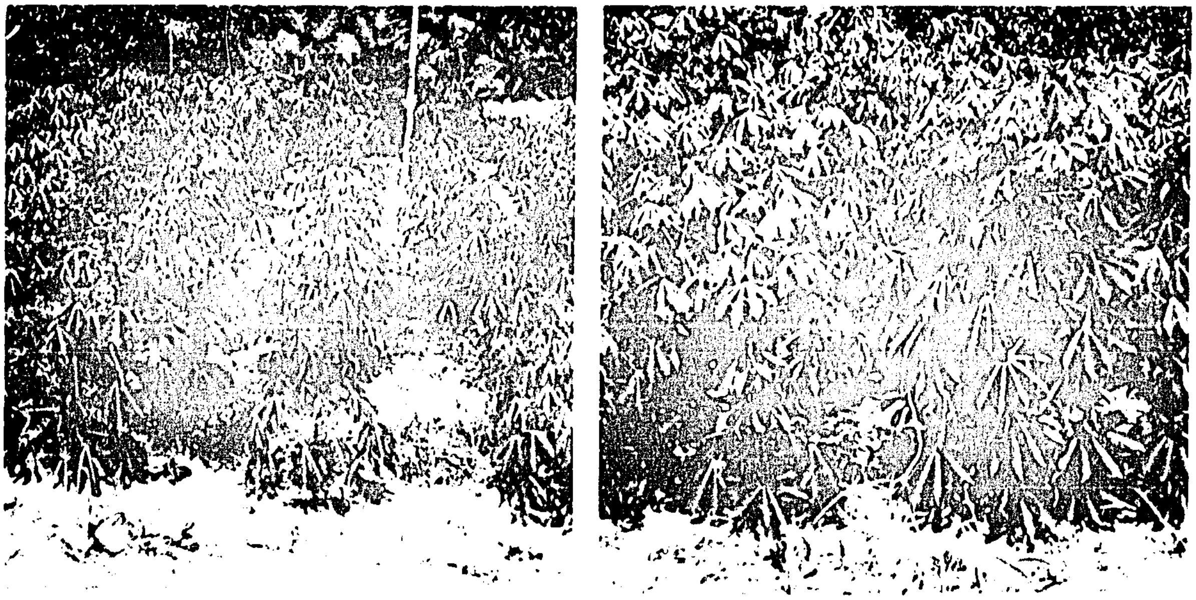
Appearance of the slash and burn treatments in second rice crop: Treatment 1 (left) and Treatment 5 (right). July, 1973.

Aspects of the bulldozed treatments in the second rice crop: Treatment 1 (left) and Treatment 5 (right). July, 1973.

Table 17. Effects of land clearing methods and fertilizer applications on cassava yields in cropping system 2. Yurimaguas, 1973.

Treatment	Slash and Burn	Bulldozed clearing
	ton/ha roots	
1) Untilled check	22.0	10.1
2) 0 - 0 - 0	22.5	9.4
3) 50 - 0 - 40	21.9	12.5
4) 50 - 172 - 40	29.1	23.0
5) 50 - 172 - 40-4 tons lime	34.2	32.0
Mean	25.9	17.4

$LSD_{.05} = 4.3$



Cassava responds sharply to fertilizers and lime applications. Left: Treatment 1, Right: Treatment 5 of the bulldozed clearings.

Table 18. Nutrient content of ear-leaves of corn taken at harvest. Yurimaguas, 1973.

	Fertility level	
Element	0-0-0	50-172-40-4 ton lime
N %	2.38	1.82
P %	0.16	0.26
K %	0.68	0.99
Ca %	2.60	4.60
Mg %	0.36	0.12
S %	0.12	0.07
B ppm	12	17
Mo ppm	0.5	0.6
Mn ppm	116	88
Cu ppm	16	6
Fe ppm	141	78
Zn ppm	14	13

Table 19. Effects of land clearing methods and fertilizer applications on corn grain yields in cropping system 3. Yurimaguas, 1973.

Treatment	Slash and Burn	Bulldozed Clearing
	kg/ha	
Untilled check	536	38
0 - 0 - 0	567	13
50 - 0 - 40	739	7
50 - 172 - 40	196	85
50 - 172 - 40-4 ton lime	701	370
Mean	537	102

LSD$_{.05}$ = 120

Table 20. Effects of land clearing systems and fertilizer applications on *Panicum maximum* dry matter production in cropping system 4. Sum of first four cuts. Yurimaguas, 1973

Treatment	Slash and Burn	Bulldozed Clearing
	ton/ha	
Untilled check	7.24	4.45
0 - 0 - 0	9.87	8.31
50 - 0 - 40	14.97	6.19
50 - 172 - 40	18.98	12.86
50 - 172 - 40-4 ton lime	24.10	18.38
Mean	15.03	10.04

Pasture production was also severely reduced with the bulldozed clearing. Pictures show unfertilized Panicum maximum stands in the slash and burn plots (top) and the bulldozed plots (bottom). Photograph taken February, 1973.

Table 21. Effects of land clearing systems and the presence of Kudzu on annual dry matter production of forage in cropping systems 6 and 7. Sum of six cuts. Yurimaguas, 1973.

Cropping Systems	Slash and Burn	Bulldozer Clearing
	ton/ha	
6. Guinea grass	10.4	4.7
7. Guinea/Kudzu mixture	9.7	5.7
Mean	10.1	5.2

Table 22. Nutrient composition of kudzu leaves with or without deficiency symptoms in cropping systems of Yurimaguas, 1973.

Element	Healthy leaves	Leaves with symptoms
N %	4.76	3.50
P %	0.18	0.12
K %	0.76	0.37
Ca %	4.60	0.80
Mg %	0.42	0.54
S %	0.07	0.03
B ppm	24	41
Mo ppm	0.6	0.06
Mn ppm	76	179
Cu ppm	12	17
Fe ppm	514	119
Zn ppm	24	24

yields obtained in other tropical areas. On the average, the pasture production in the bulldozed system was 67% of that produced by the traditional slash and burn.

Bean production in the fifth cropping system was extremely low. The plants had normal vigorous early growth and strong visual responses to lime, but succumbed to the attack of a fungus disease. The yields in the bulldozed plots were less than 70 kg/ha while the yield in the burned plots were in the order of 361 kg/ha. Lime increased yields tenfold but the yield levels were too low for meaningful comparisons.

Pasture production during the first 340 days in cropping systems 6 and 7 are shown in Table 21. These plots were not fertilized and only reflect the land clearing differentials. The slash and burn treatments produced about twice as much dry matter as the bulldozed treatments. No effect of Kudzu on total production was observed, because of its slow start. Measureable quantities of Kudzu began to be harvested within six months. At this time nutrient deficiency symptoms were observed in this legume. Foliar analysis from La Molina indicate severe phosphorus, potassium, calcium, sulfur and molybdenum deficiencies (Table 22).

After identifying the problem, a blanket application of 20 kg S/ha, 5 kg B/ha, and 0.2 kg Mo/ha were applied to all plots since September, 1973. The overall appearance of the experiments has improved significantly.

The second clearing was planted to upland rice in October, 1973 according to the cropping schemes. Unlike the first clearing, the fertilizer and lime differentials were applied from the start. Although the harvest data is not yet available, the visual appearance of the first crop is superior to the third continuous rice crop of the first clearing. Little visual fertilizer response has been observed in this new clearing.

The data on soil dynamics and nutrient uptake of the different cropping systems will be presented in the next annual report.

Preliminary Conclusions

The first 18 months of this experiment produced the following preliminary conclusions.

1) Mechanized land clearing -- in the way it was done -- is definitely inferior to the traditional slash and burn practice. In cases where good yields were obtained, (such as with upland rice, cassava, and pastures,) the bulldozed clearings attained approximately two-thirds of the yields of the slash and burn system. In cases where poor yields were

obtained, (such as sorghum, corn, and beans) the differences were in the order of 2 to 5 times in favor of the slash and burn treatment.

2) The detrimental effect of bulldozing is associated with severe soil compaction which reduced infiltration rates to 1/20th of the original. The absence of the ash as a fertilizer and topsoil movement from high to low spots have also contributed to these differences.

3) The ash and partially burned material added approximately 70 kg N/ha, 20 kg P_2O_5/ha, 47 kg K_2O/ha, the equivalent of 240 kg/ha of dolomitic lime and considerable quantities of micronutrients to the burned plots. This was reflected in a higher nutrient content in the crops and in higher yields at the same level of fertilization.

4) The Typic Paleudult soil on which experiment was conducted is deficient in nitrogen, phosphorus, potassium, calcium, sulfur, boron, and molybdenum. Yield responses varied with crop species. Upland rice responded to nitrogen, potassium, and lime. Unlike previous reports from other tropical areas, cassava responded strongly to phosphorus and lime. Guinea grass responded positively to nitrogen, phosphorus, potassium, and lime.

5) The yields obtained with these three crops compare favorably with other locations. Upland rice produced up to 3.2 tons/ha. The use of a short-statured variety adapted to the environment is no doubt a contributing factor. A local, unimproved cassava variety yielded 34 ton/ha or over four times the world's average. The positive response to phosphorus and lime is no doubt associated with the high yield levels of this experiment. Reports from the Llanos Orientales of Colombia on negative responses of cassava to lime refer to maximum yields in the order of 8 tons/ha. Perhaps other limiting factors were present in that area which prevented high yields. The highest dry matter production of Guinea grass (24 ton/ha in 10 months) underscores the area's potential of pasture production.

6) The economic evaluation of this data must wait the results of a second and third year in order to evaluate the residual effect of phosphorus and lime. It seems, however, that the fertility requirements are not as high as originally expected. Nevertheless, it is obvious that the traditional clearing system is more economical than the

mechanized one. The cost of slash and burning are about S/2500/ha (US$53) in commercial operations in the area. Mechanized land clearing costs from S/5000 to 10,000/ha according to the type of machinery used.

7) It must be remembered that the mechanized clearing method utilized was the most rudimentary. It is possible that if KG-type floating blades are used, the effect of carrying topsoil could be minimized. Nevertheless, these results suggest extreme caution before clearing jungle soils of this type with similar machinery. Experience in other parts of the Peruvian Jungle indicate that clearing huge tracts of land with machinery is relatively simple and fast. Unfortunately, as one flies over such areas, one observes secondary forests regrowth in 100 ha square blocks! This suggests that the problem is not only one of land clearing, but how to manage the soil after clearing it.

PASTURE FERTILIZATION

The first series of supplemental experiments aimed at obtaining more precise fertility information was planted in October, 1973 with the purpose of determining the minimum rates of nitrogen, phosphorus, and lime required for optimum Guinea grass production. Pastures were studied first since beef production is considered the first priority in the Jungle agricultural development plans.

Objectives and Design

The literature review indicated that the research strategies on tropical pasture fertilization are polarized in two extremes. The extensive approach consists of utilizing forage legumes as the source of nitrogen and applying minimum quantities of phosphorus, lime, and other nutrients in order to achieve moderate production levels. The best example of this is in tropical Australia. The intensive approach consists of heavily fertilization of pure grass species with optimum levels of inorganic nitrogen, other nutrients and lime. Although the investiment in fertility is high, the production levels are also very high. This is the basis of highly successful cattle industry in Puerto Rico. Researchers usually decide on which approach to use beforehand. This usually prevents a meaningful comparison of approaches and the possibility of arriving at some middle ground. Our experiments in Yurimaguas were designed to provide a wide range of alternatives in pasture fertilization.

Two experiments were planted in September and October, 1973, in a field adjacent to the continuous cropping experiment with similar soil, topography and original vegetation. The fields were cleared a year before by Ing. Nureña and grown to rice followed by beans without any fertilization. Pastures were then planted, following the general concept of having food crops produced first before putting the land into pastures. Guinea grass (Panicum maximum) was selected as the grass species because it is the improved species most widely used in the area. Stylosanthes guyanensis was selected as the legume species based on IVITA's experience in Pucallpa.

Nitrogen Experiment

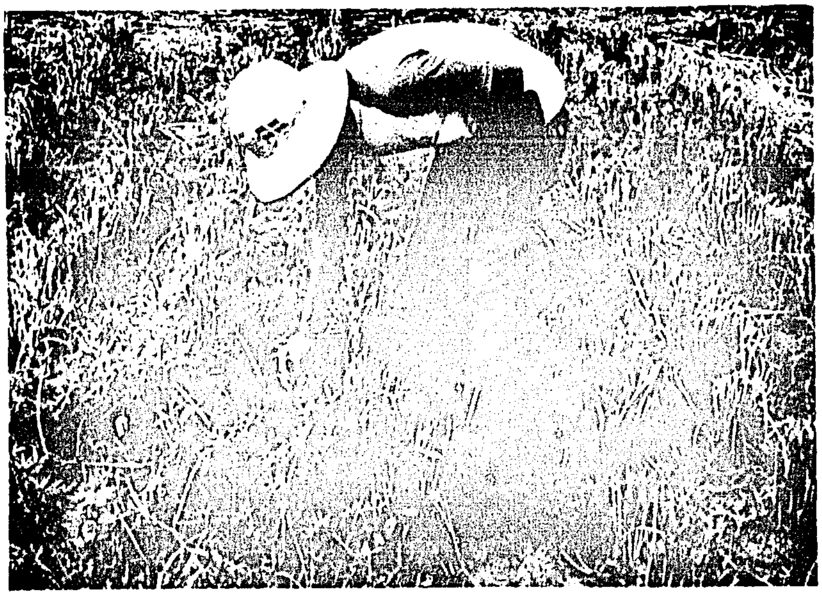
The first experiment consisted of 12 treatments arranged in a completely randomized design with three replications with 24 m^2 plots. The treatments shown in Table 23 compare Stylosanthes as a source of nitrogen to a wide range of annual urea rates and sulfur-coated urea (SCU), an experimental slow-release source supplied by the Tennessee Valley Authority. The design also includes the effects of lime and phosphorus on stylo establishment. A starter rate of 20 kg N/ha was applied to the stylo plots as recommended in the literature. The annual urea rates were divided in six equal amounts and applied after every cut. Cutting frequency was every eight weeks. The SCU rates were divided in two parts applied every six months. A basal application of 50 kg P/ha as ordinary superphosphate and 3.5 ton lime/ha was broadcast and incorporated with the rototiller at 15 cm depth in the appropriate treatments. Potassium was applied at seeding and after every cut at the rate of 35 kg K_2O/ha as KCl. The entire experiment received a blanket application of 30 kg S/ha as sulfur flower, 0.5 kg B/ha as borax (Boroperu) and 0.2 kg Mo/ha as ammonium molybdate.

Table 23 shows the results of the first cut of Guinea grass. A marked response to lime is evident without major differences due to nitrogen levels. The establishment of stylo was very much affected by lime and phosphorus. In the treatments which did not receive these ammendments, there were very few stylo seedings in spite of repeated reseedings. Stylo establishment was very good in plots which received phosphorus and lime. The plants had abundant red nodules in spite of not having received innoculants.

The most important aspect of these preliminary results is the high dry matter production obtained in the limed plots with 20 kg N/ha. The 5.5 ton/ha level produced in eight weeks is equivalent to the annual Guinea grass production in the burned but not fertilized plots of

Table 23. Dry matter production of first cut of Guinea grass in the nitrogen experiment. Yurimaguas, 1973.

Nitrogen source	Annual N rate	Applications of PK Lime	Dry matter produced in two months	Dry matter in green material
	kg N/ha		ton/ha	%
0	0	0	3.62	22.2
0	0	Lime	5.52	19.9
Stylo	20	0	2.40	19.4
Stylo	20	Lime	5.25	19.2
Stylo	20	PK	2.95	18.1
Stylo	20	PK Lime	5.43	19.7
Urea	100	PK Lime	5.14	19.2
Urea	200	PK Lime	5.24	18.9
Urea	400	PK Lime	6.26	22.3
Urea	800	PK Lime	5.60	18.6
SCU	100	PK Lime	4.90	17.5
SCU	200	PK Lime	5.93	20.6



Ing. Cesar Lopez examining the good growth of Stylosanthes guyanensis in the Guinea grass plots which received phosphorus and lime.

cropping system 4 (Table 19) or the annual production of the bulldozed plots in cropping system 6 (Table 20 of the previous experiment).

Lime-Phosphorus Experiment

A factorial experiment consisting of five rates of phosphorus and three rates of lime was installed in an adjacent plot. Four rock phosphate sources were included as additional plots at the rate of 200 kg P/ha without liming. The "Fosbayovar" rock from northern Peru is being compared with TVA's three standard rock phosphate sources. The treatments are shown in Table 24. Lime, phosphorus, plus the same basal rate of sulfur, boron, and molybdenum were broadcast and incorporated with a rototiller. The forage will be cut every eight weeks. A total of 50 kg N/ha and 30 kg K/ha is to be applied after every cut.

The results of the first cut are also shown in Table 24. A response to added phosphorus was only observed at the 25 kg P/ha level. The behavior of rock phosphates, particularly the Florida and Morocco sources was good. As in the previous experiment, these results are too preliminary to permit clear conclusions.

UPLAND RICE FERTILIZATION

Ing. Nureña planted a management experiment involving nitrogen rates, plant spacing, varieties and dates of seeding in order to determine the variety-nitrogen relationships in terms of differences in precipitation and solar radiation. Two plantings were established on September 24 and November 23, 1973. This experiment is part of an international network on this subject. No data is available at the time of this writing.

GERMPLASM INTRODUCTION

With the exception of rice, the germplasm collection at Yurimaguas is very limited. Cognizant of the importance of working with improved varieties in soil management experiments the project staff has obtained small quantities of germplasm for national and international sources. This material is being evaluated by the Ministry plant breeder. During this year the most important introductions were as follows:

Pastures

Several varieties of Stylosanthes guyanensis from IVITA (Pucallpa), IRI (Matão, Brazil), and from CIAT. The Ministry staff obtained and planted a collection of important

Table 24. Dry matter production of the first cut of Guinea grass in the phosphorus-lime experiment. Yurimaguas, 1973.

Phosphorus Rate Source	Lime rate (ton/ha) 0	2	3.5	Mean
kg P/ha	ton/ha			
0	3.43	3.98	3.65	3.69
25 ord. superphosphate	4.45	5.15	5.18	4.93
50 ord. superphosphate	4.74	3.75	4.55	4.35
100 ord. superphosphate	4.35	4.68	3.70	4.24
200 ord. superphosphate	4.99	5.03	4.07	4.69
Mean Lime Rates	4.39	4.51	4.25	
200 Fosfayovar Rock	3.80			
200 North Carolina Rock	3.67			
200 Florida Rock	4.92			
200 Morocco Rock	4.91			

Excellent pasture production is possible in the Amazon Jungle Ultisols with moderate fertilizer inputs.

pasture grasses which are being evaluated with only nitrogen applied to test for their tolerance to aluminum.

Corn

Several varieties from the National Corn Program of Peru were obtained from Ing. Federico Scheuch of the Universidad Agraria at La Molina. Two varieties from Carimagua, Colombia, reported to be aluminum tolerant were also introduced.

Grain Legumes

A series of bean and cowpea varieties tolerant to aluminum from Carimagua, Colombia, were introduced. Other lines were also obtained from IITA in Nigeria and CATIE in Turrialba, Costa Rica.

Ing. Nureña continues to evaluate large numbers of rice selections from the National Rice Program in Lambayeque and has established local collections of cassava and sweet potato cultivars.

RESEARCH IN CENTRAL AMERICA

Intensive multiple cropping systems in Turrialba.

The research activities in Central America are aimed at intensifying crop production in small farming units. Unlike the other two areas in which this program operates, the Central American Highlands are densely populated areas with adequate infrastructure where the bulk of the food is produced on small farms. Five research areas were identified as high priority subjects in this area: the fertility requirements of multiple cropping systems, forage sorghum production during the rainy season for feed for the dry season, upland rice fertilization, sulfur, and certain micronutrient studies.

The field work was conducted by Dr. Donald D. Oelsligle in cooperation with the Centro Agronómico Tropical de Investigación y Enseñanza in Turrialba, Costa Rica, the Ministeries of Agriculture of Costa Rica and El Salvador, the International Soil Fertility Evaluation and Improvement Project, and the U. S. Peace Corps in this area. Drs. P. A. Sanchez, F. R. Cox, S. W. Buol, and Ing. Alfredo Alvarado conducted on-site studies in Costa Rica and El Salvador through various short-term assignments. Activities in Guatemala were conducted by Dr. R. E. McCollum in collaboration with the ISFEIP and ICTA staff. Most of the laboratory work was carried out at the Costa Rica and El Salvador soil testing laboratories and in Raleigh.

INTENSIVE MULTIPLE CROPPING - COSTA RICA

Objectives and Design

The vast majority of small farming operations in the Central American Highlands on soils affected by volcanic ash involve intercropping. The most common form is a relay planting of beans into corn. Many of these practices date back for centuries and are undoubtedly quite sophisticated in terms of the resources available to farmers. Soil scientists have ignored such practices and have aimed their research at how to fertilize monocultures. According to a recent survey conducted by the CATIE staff, approximately 70 percent of the bean production in Central America comes from intercropped fields. A series of experiments were planted in January, 1973 in Turrialba in order to obtain information which could be used to design intensive cropping systems for small farmers in the udic climates characterized by the absence of a marked dry season (Fig. 15).

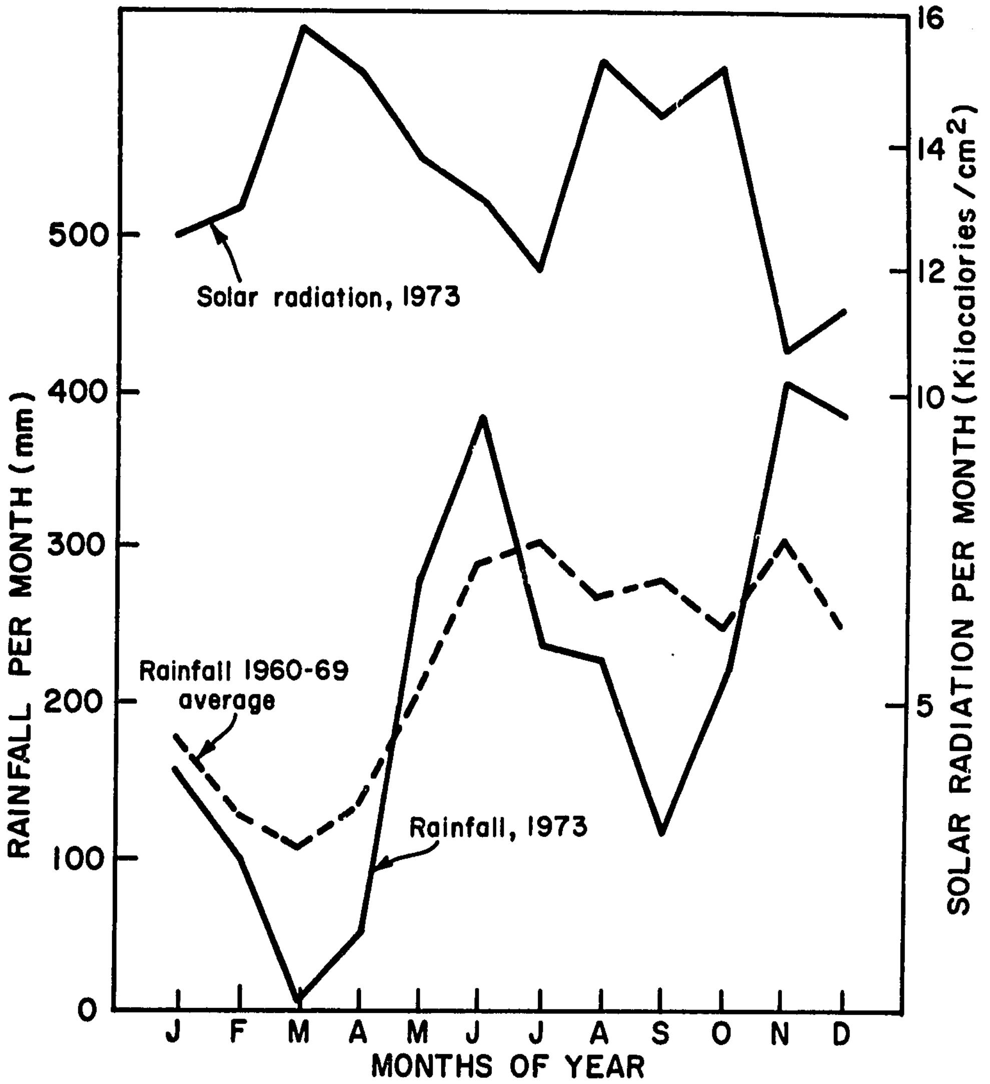


Figure 15. Rainfall and solar radiation pattern at Turrialba, Costa Rica.

Five experimental cropping systems were tested at three soil fertility levels on a Colorado soil derived from volcanic ash. This soil is classified as a Typic Dystrandept. Its properties are shown in Table 25. According to other analysis this soil has a loamy texture, about 8% organic matter in the topsoil. The dominant clay minerals are allophane, halloysite, and kaolinite.

From this analysis, phosphorus appeared to be the only nutrient which would seriously limit crop production. To determine the level of phosphorus application, fixation curves were determined for these two nutrients. These data for phosphorus are shown in Figure 16. The graph shows that approximately 250 kg P_2O_5/ha should bring the soil level up to 12 ppm. Later analyses show that in reality the 250 kg rate raised the soil test phosphorus level to approximately 6 ppm.

Rainfall and solar radiation data show that 1973 was not a typical year (Fig. 15). The pronounced dry period in March and April severely affected all crops growing during this period. Normally this period is optimum for bean production as beans are very susceptible to excess water.

The five cropping systems were grown at low, medium and high soil fertility levels in a factorial experiment arranged in a randomized complete block design with three replications. The subplot size was 90 m^2. The first treatment consisted of the common corn/bean intercropping system practiced throughout Central America followed by two additional corn crops. The second system is a straight succession of beans, rice and corn. In the third system, cassava and beans were intercropped. After the beans were harvested, rice was interplanted within the cassava. The fourth system consisted of a continuous sorghum cut for forage every two months. The fifth system consisted of Elephant grass (<u>Pennisetum purpureum</u>) for the same purpose. These last two systems were included since we believe that animal production should be an integral part of small farm cropping systems.

The annual nitrogen, phosphorus, and potassium rates applied to each system are shown in Table 26. Ammonium nitrate, ordinary superphosphate and KCl were the sources used.

Food Crop Production

Table 27 s[illegible] planting dates, harvest dates, and yields of the five cropping systems. When comparing the yields of beans grown alone (B) to beans with cassava (C) and to beans with corn (A), it can be seen that the cassava crop had no effect on bean yields, while corn

Table 25. Soil analysis for Colorado series (Typic Distrandept, fine, isohyperthermic) used in the multiple cropping experiments at Turrialba. Fertility-capability:Lx.

Rep.	Depth	pH	P	Al	Ca	Mg	K	CEC (sum)	Base Saturation	Fe	Cu	Zn	Mn
	cm		ppm	meq/100g					%	ppm			
I	0-20	5.4	3	0.15	9.5	2.3	0.64	12.6	99	100	17	3.6	71
I	20-40	5.6	1	0.10	6.5	1.6	0.26	8.5	99	58	13	1.4	33
II	0-20	5.4	4	0.10	7.5	2.0	0.46	10.1	95	98	18	2.0	50
II	20-40	5.5	3	0.20	6.5	1.8	0.26	8.8	98	60	13	1.8	30
III	0-20	5.4	3	0.10	7.0	1.8	0.36	9.3	99	84	16	3.2	64
III	20-40	5.3	3	0.10	5.5	1.7	0.18	7.5	99	72	16	2.0	45

P, K, Ca, Mg and micronutrients extracted by the modified Olson procedures.

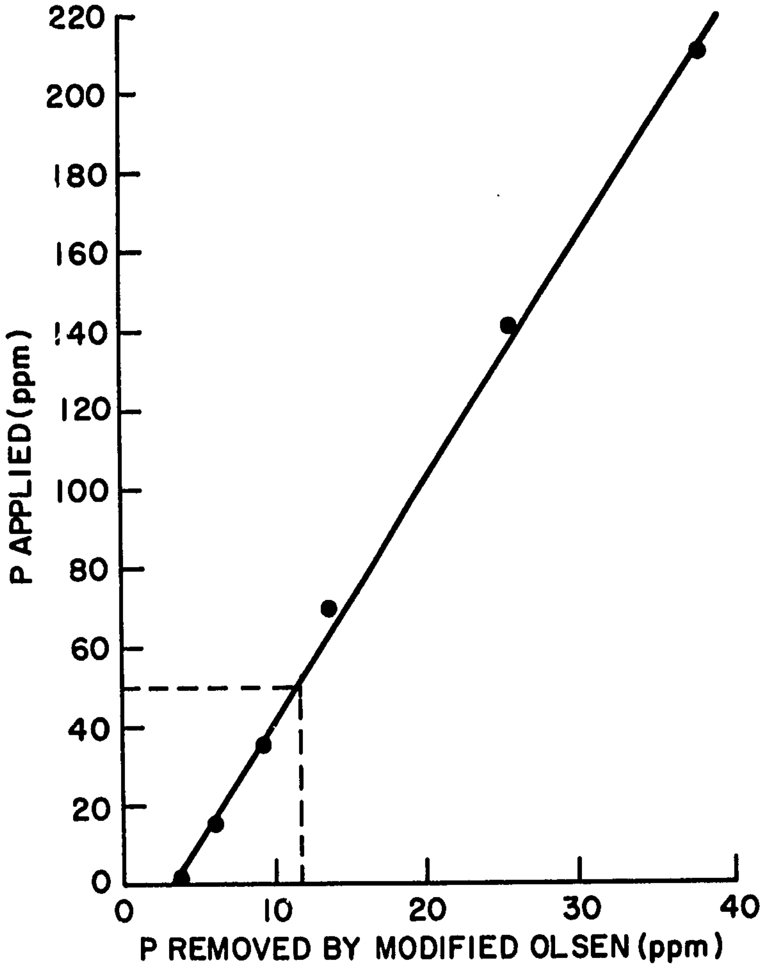


Figure 16. Phosphorus retention curve for the Colorado soil in relation to soil test values. Turrialba, 1973.

held the beans to about 1/3 of the yield obtained in the bean monoculture plot. Consequently the bean-cassava combination is promising.

The rice which was to follow the beans in the cassava was severely attacked by the rice blast fungus (Pyricularia oryzae) and did not produce grain. Corn yields were much better in the second planting due to better rainfall distribution.

Based on observations on the crops that followed and some data from the first year, the following criteria are among those to be considered in improving cropping systems for the Central American Highlands with udic soil moisture regimes. This involves using the four major food crops (corn, rice, beans, and cassava) and introducing two high food value crops (soybeans and sweet potatoes).

1. Bush-type beans need to be grown and harvested during the drier part of the year; therefore, only one bean crop per year is recommended. With climbing varieties, the situation may be different.
2. No advantage appears to be gained in sunlight competition by mixing two tall statured crops (corn and cassava) or two short statured crops (rice and beans). Therefore, any mixed cropping should consider two canopies composed of a tall crop and a short crop.
3. Rather than have cassava in full production during the drier season, it seems more logical to plant it during the dry season. Unless presprouted, one month is lost before a plant develops. A date of planting experiment would test this assumption.
4. Being a tuber crop, sweet potatoes should probably not be harvested during the development of the cassava roots; thus it should be planted so the harvest will coincide as close as possible as that of cassava. This could present problems if a system is developed only for family consumption.
5. Rice is a light sensitive crop during the last 45 days. It should be subjected to minimum shade during this period.
6. A cropping system should complete its cycle in one year to be properly evaluated.
7. Varietal differences within a species may be more important than species differences. Some notable examples are tall versus short corn and bush versus climbing beans.

Table 26. Fertilizer applications for five different cropping combinations at Turrialba, 1973.

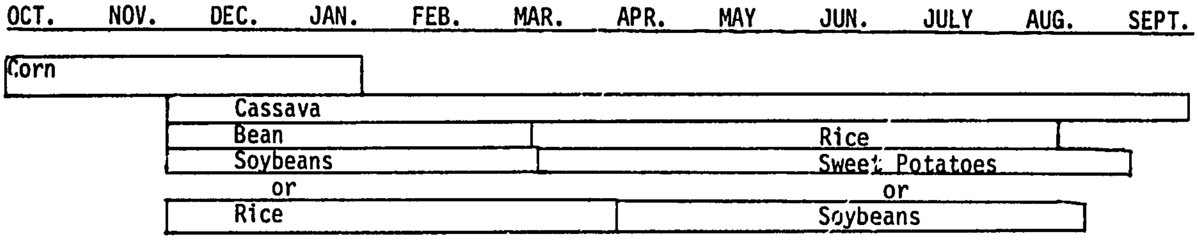
Cropping system	Fertility level	N N	P_2O_5	K_2O
		kg/ha		
A: Corn/beans, Corn, Corn Corn	0	0	0	0
	1	310	295	80
	2	620	590	160
B: Beans, Rice, Corn	0	0	0	0
	1	260	345	105
	2	520	690	210
C: Beans, Rice, Corn	0	0	0	0
	1	200	275	75
	2	400	550	150
D: Corn, Forage Sorghum	0	0	0	0
	1	250	275	75
	2	500	550	150
E: Elephant grass	0	0	0	0
	1	400	325	125
	2	800	650	250

Table 27. Planting date, harvest date, and average yields of five cropping systems at three fertility levels in Turrialba, Costa Rica, 1973.

Cropping system		Planting date	Harvest date	Yields Low fertility	 Medium fertility	 High fertility
				ton/ha		
A.	Corn	Jan. 19	June 1	0.24	0.19	0.13
	Beans	Jan. 19	Apr. 4	0.09	0.31	0.37
	Corn	June 18	Sept. 25	1.89	2.71	3.19
	Corn	Oct. 10	Sept. 25	1.89	2.71	3.19
B.	Beans	Jan. 18	Apr. 4	0.29	0.86	1.08
	Rice	May 10	Lost to blast	-	-	-
	Corn	Oct. 10				
C.	Beans	Jan. 18	Apr. 14	0.32	0.87	1.11
	Cassava	Jan. 20	Dec. 28	36.5	45.2	47.2
	Rice	May 10	Lost to blast	-	-	-
D.	Corn	Jan. 19	Jun. 1	0.29	0.37	0.28
	Forage	Jun. 7	Aug. 6	4.11	9.06	10.15
	Sorghum		Sept. 26	4.90	10.42	12.30
	(dry matter)		Nov. 26	2.68	7.02	8.36
			Jan. 29	1.56	2.89	3.76
	Total one year:			13.54	29.76	38.45
E.	Elephant	Jan. 22	May 21	0.97	1.52	3.94
	grass		July 18	4.22	7.44	10.64
	(dry matter)		Sept. 25	5.57	8.19	13.23
			Nov. 22	2.90	4.54	7.60
			Jan. 30	2.27	3.92	5.74
	Total one year:			15.93	25.61	41.15

8. Due to the high production capability of cassava and marketing problems for small farmers, production per area should be de-emphasized, i.e., row spacings extended to enable higher production of other crops.

Considering the above, the following system with various alterations is now being tried in the field at Turrialba.



Corn is planted at 0.75 cm, cassava at 1.50 x 2.00, beans at 50, rice at 25, and sweet potatoes at 75 cm between rows.

Intensive Forage Production

For livestock production, a cut forage in general will produce about twice the amount of feed per area than if grazed. Therefore, two rapid growing forages, Elephant grass and forage sorghum were compared to determine production and nutrient removal differences. The following graphs show comparisons of dry matter yields for four cuttings (Fig. 17) and the nitrogen, phosphorus, and potassium removal for three cuttings (Figs. 18 to 20).

The decline with time in yields of the two forages could be due to shorter day lengths, a nutrient deficiency unaccounted for or a loss of vigor by the plant. As the nitrogen, phosphorus, and potassium concentrations show no definite trend (see Table 28) it is assumed that the forage sorghum loses vigor with age and is probably also affected somewhat by daylength.

The Elephant grass is probably affected by the shorter daylength. This is substantiated by the solar radiaion curve in Fig. 16.

At this point, it appears that Elephant grass may respond to higher nitrogen levels while the forage sorghum will probably not. On a long-term basis, it is evident from the nutrient removal curves that forage sorghum will require more nitrogen and phosphorus than will Elephant grass, but Elephant grass will remove more potassium. It would appear that for greater efficiency in Elephant grass production, the time of year should be considered when determining rates of fertilizer application.

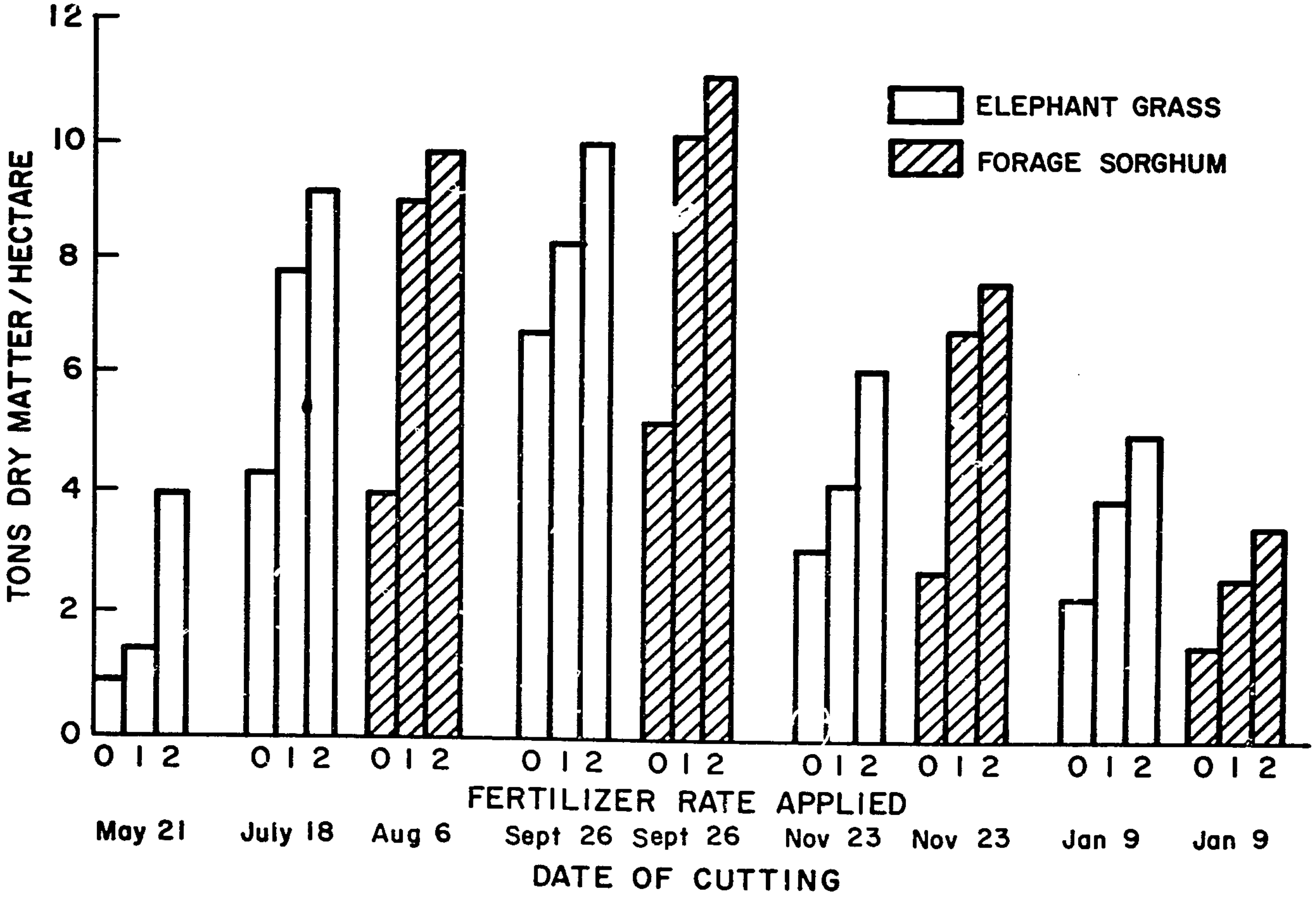


Figure 17. Elephant grass and forage sorghum dry matter yields at different fertility rates and cutting dates. Turrialba, 1973.

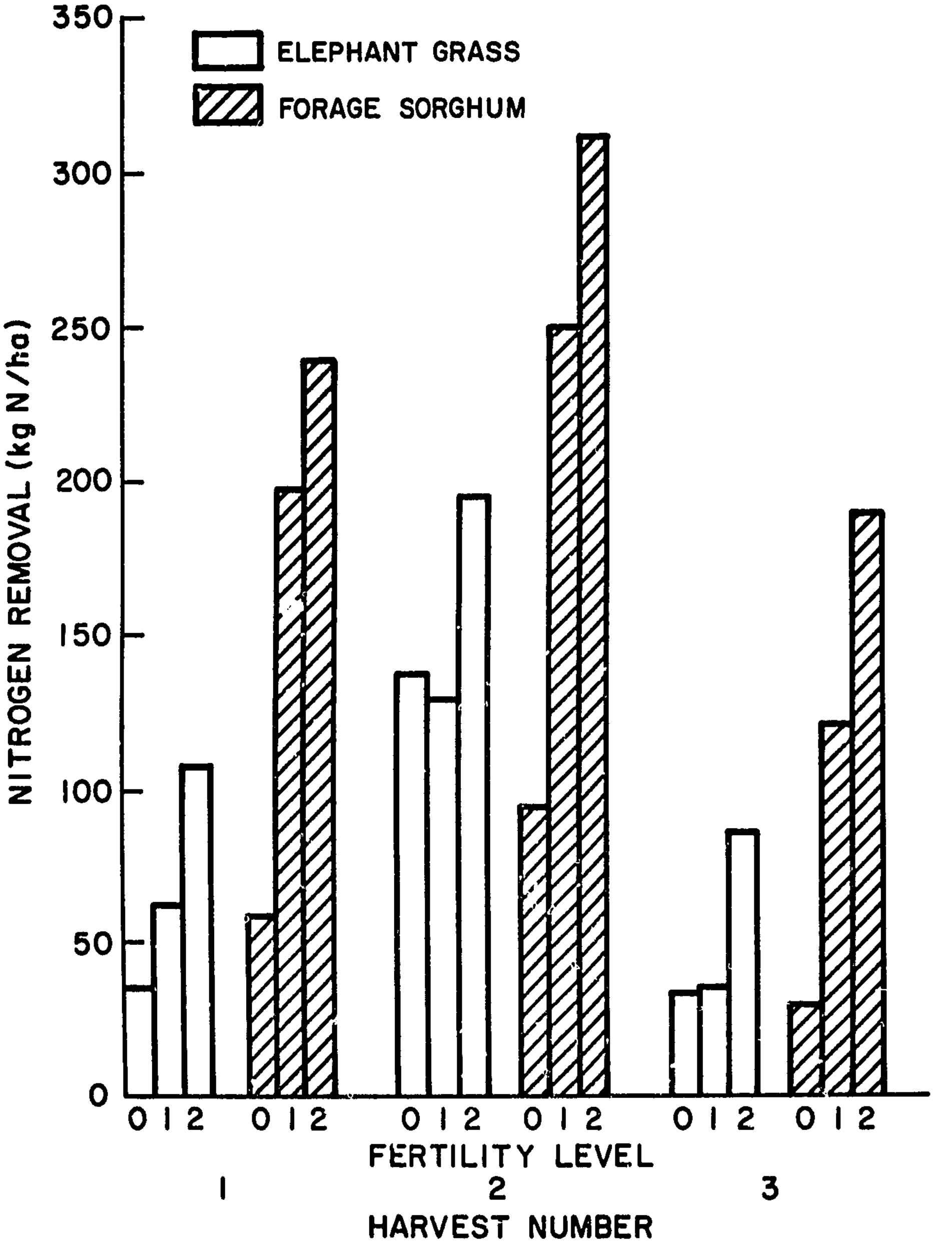
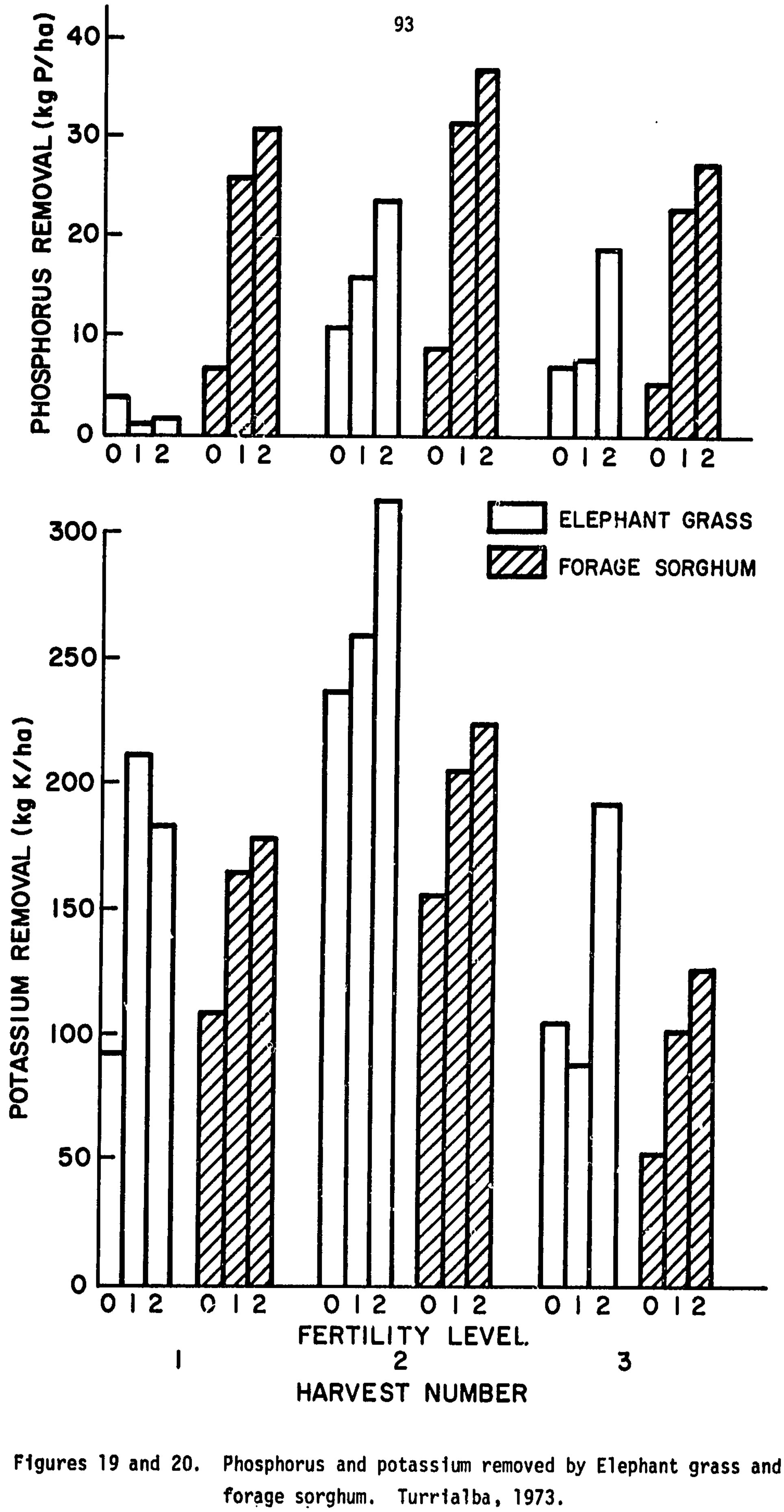


Figure 18. Nitrogen removal by Elephant grass and forage sorghum in three cuts. Turrialba, 1973.



Figures 19 and 20. Phosphorus and potassium removed by Elephant grass and forage sorghum. Turrialba, 1973.

Table 28. Average nutrient contents of forage sorghum and elephant grass at harvest. Turrialba, 1973

	Elephant grass cuttings				Forage sorghum cuttings		
	1	2	3	4	1	2	3
N (%)	1.77	0.92	1.80	1.08	2.03	2.34	1.76
P (%)	0.19	0.14	0.19	0.23	0.25	0.27	0.29
K (%)	3.28	2.32	3.23	2.73	2.09	2.28	1.66

Dry Matter and Nutrient Accumulation by Cassava

Due to the lack of information on cassava growth and fertilization, a study was initiated to measure dry matter accumulation in cassava tops and roots over time and also to measure the accumulation of N, P, and K in these parts of the plant. A 10-month variety, Guaxupe 454, of Brazilian origin from the CATIE collection was used for this study. Twelve plants were sampled within the multiple cropping experiment.

It can be seen in the rainfall curve for 1973 that there was essentially no rain during the month of March (Fig. 16). For this reason, it is believed that at least one month of active growth was lost. Cassava root growth was most active between the ninth and tenth months (Figs. 21 and 22). During this one month period approximately 60% of the dry matter accumulation in the roots occurred. The average yield of the roots at harvest was 43 ton/ha. Yields of this magnitude removed 174 kg N, 21 kg P, and 125 kg K per hectare (Table 30). This is equivalent to a total nutrient removal of 174-48-150 kg/ha of N - P_2O_5 - K_2O, respectively, and 367-95-256 for the whole plant.

During the period of root development, the concentration of nitrogen, phosphorus, and potassium all decreased with time (Table 29). It is interesting to note that this decrease of N and P concentration was most marked in the tops while the decrease in K concentration was more rapid in the roots.

In the latter part of the year, a second experiment was planted in collaboration with Dr. Antonio Pinchinat to determine the effects of nitrogen rates different intercropping combinations of corn with beans. The results will be available in the next annual report.

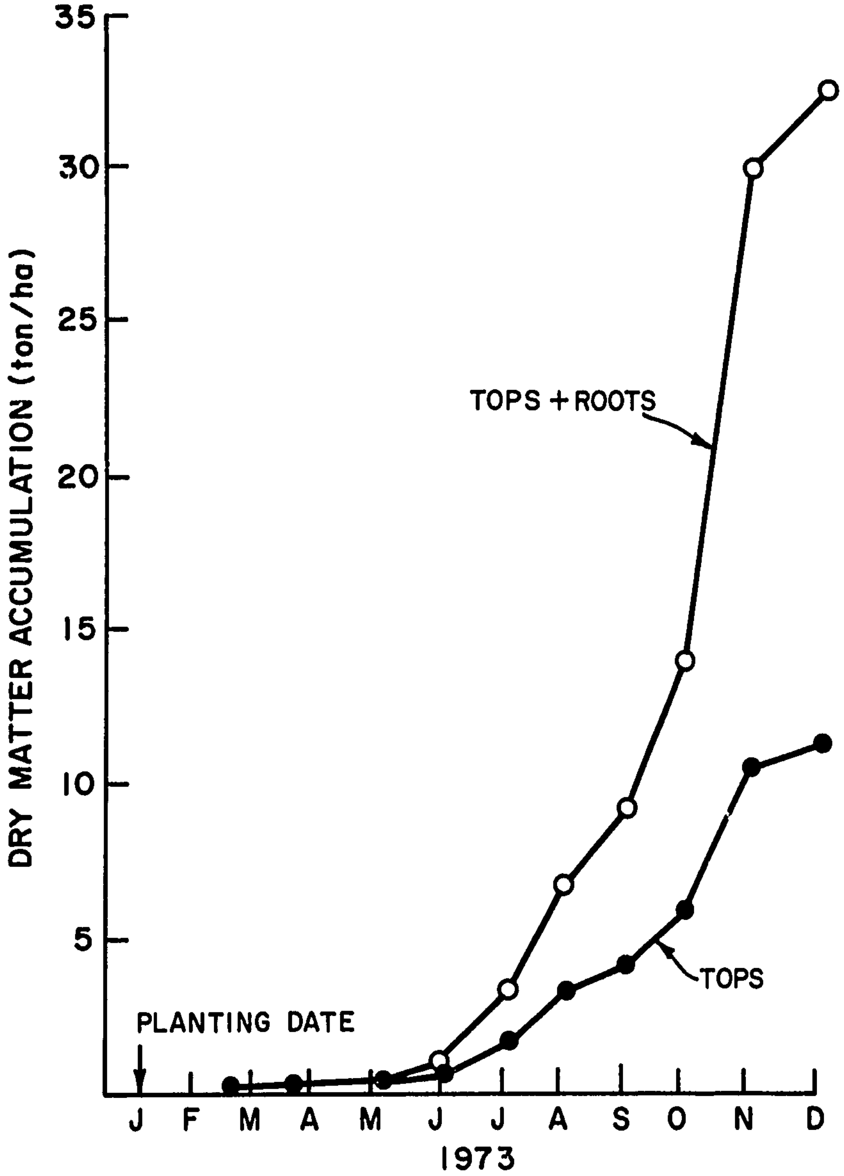


Figure 21. Dry matter accumulation in cassava tops and roots. Turrialba, 1973.

Table 29. Nutrient concentration in cassava tops and roots during period of active root development. Turrialba, 1973.

Months after planting	Nitrogen		Phosphorus		Potassium	
	Tops	Roots	Tops	Roots	Tops	Roots
	% N		% P		% K	
7	3.14	1.11	0.25	0.13	1.05	1.10
8	2.83	0.91	0.27	0.13	1.15	0.92
9	2.41	0.96	0.22	0.10	0.89	0.77
10	1.85	0.78	0.18	0.11	0.93	0.64
11	1.69	0.82	0.18	0.10	0.72	0.59

Table 30. Nutrient accumulation of cassava tops and roots during root development. Turrialba, 1973.

Months after planting	Nitrogen		Phosphorus		Potassium	
	Tops	Roots	Tops	Roots	Tops	Roots
	kg N/ha		kg P/ha		kg K/ha	
7	104	38	82	44	41	37
8	119	46	113	66	48	47
9	142	78	129	81	52	63
10	195	153	190	216	98	126
11	193	174	205	212	88	125

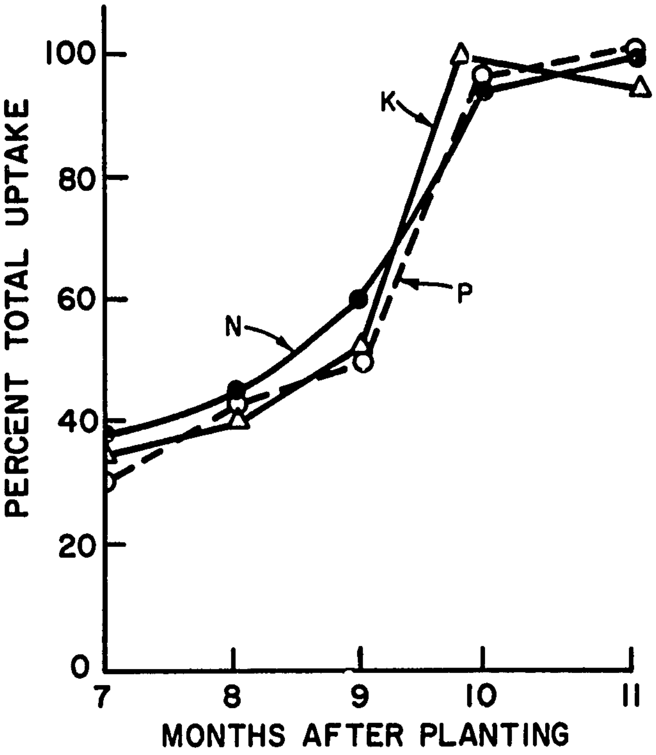


Figure 22. Cumulative nitrogen, phosphorus, and potassium uptake by Cassava as per cent of total uptake. Turrialba.

FORAGE SORGHUM FERTILIZATION - EL SALVADOR

Objectives and Design

One of the research priorities identified in this project's literature review is to find ways to feed cattle during the intense dry seasons common of the ustic tropics. In many small farming enterprises, small herds are raised by the farmers to produce milk for local markets. The animals frequently suffer extreme weight losses during the dry season due to lack of feed. This problem is particularly severe in the northern portion of El Salvador, where a large number of small-holders depend principally on milk production for their income. This area is characterized by an intense six month dry season from December to May. Fig. 23 illustrates the typical rainfall pattern.

A joint program was initiated with the Ministry of Agriculture and U. S. Peace Corps to improve methods of forage production in this region. Improved practices were needed to preserve forages produced during the rainy season for the dry season. Ensiling forage sorghum was one of the practices initiated for this purpose. There was, however, no data available to determine the fertilization needed for maximum economic production of forage sorghum.

Collaborating personnel from the Animal Science Department of the National Agricultural School, the Soil Testing Laboratory and Extension Department of the National Center for Agriculture Technology (CENTA), the U. S. Peace Corps, and various farmers from El Salvador, aided in the installation of six (five in the Northern Zone) field experiments in 1973 to determine the optimum fertilization for intensively managed forage sorghum.

Soil profile samples were taken and analyzed by the Soil Testing Laboratory at CENTA. The results are shown in Table 31. All soils are derived from old volcanic ash materials but none have the properties of Andepts. They are probably classified as Ustropepts (Inceptisols) or Chromusterts (Vertisols).

Seven levels of nitrogen from 0 to 720 kg N/ha, and seven levels of P_2O_5 from 0 to 360 kg/ha were applied in three replications as a modified factorial experiment where N levels were varied keeping P constant at the central levels and vice-versa for P (Table 32). All treatments received potassium (150 kg K/ha) and sulfur (60 kg S/ha). Extra treatments were included to check for possible potassium and sulfur responses. Urea, triple superphosphate, potassium sulphate, and potassium chloride were used as nutrient sources. Nitrogen applications were split as follows: 10% at planting, 30% at 20 days, and 30% after the first and second cuttings. All the phosphorus was applied in the rows at planting and the potassium and sulfur were applied 1/3 at planting, 1/3 after first cutting, and 1/3 after second cutting. The McNair 711-A hybrid was planted at a population of 400,000 plants per hectare. It was necessary to replant twice in Nueva Esparta, the last replanting being with another variety, Grazer. Dates of planting and harvesting are given in Table 33.

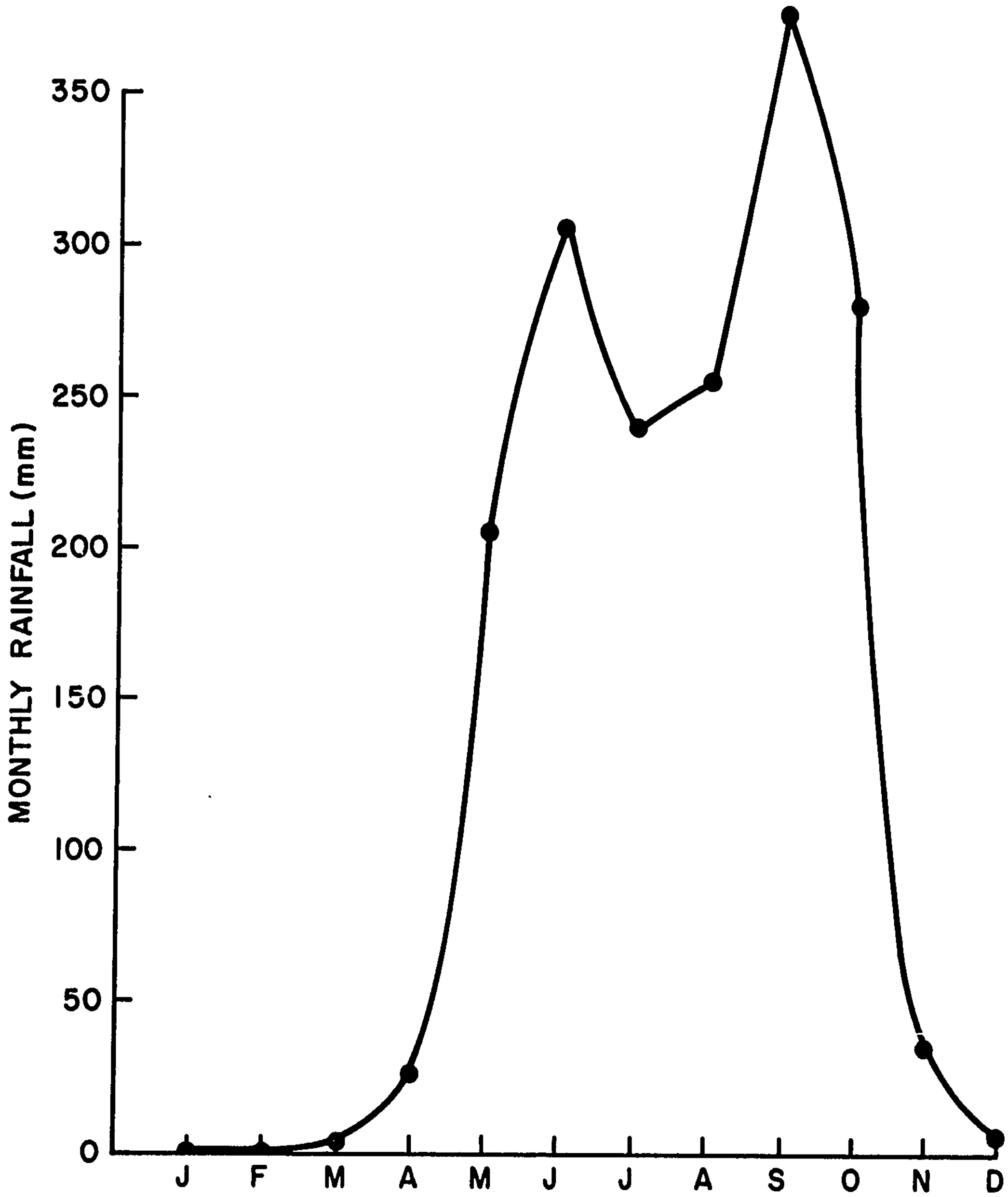


Figure 23. Rainfall distribution pattern at San Miguel, El Salvador. Mean of 43 years.

Table 31. Characteristics of the soils used in the field experiments in northern El Salvador.

Depth	Field texture	pH	P	Al	Ca	Mg	K	CEC (sum)	Base sat.
cm			ppm			meq/100g			%
1. Jocoro. Collaborator: Ciro Joya. Fertility-capability: Cdk									
0-20	clay	5.8	1	0.02	26.9	16.2	0.12	43.2	100
20-40	clay	6.0	100+	0.02	30.4	18.6	0.09	49.1	100
40-60	clay	6.2	100+	0.03	27.3	16.8	0.07	44.2	97
60-80	c. loam	6.3	100+	0.02	26.1	17.3	0.07	43.5	100
80-100	c. loam	6.5	100+	0.04	24.7	14.9	0.07	39.7	99
2. Francisco Gotera. Collaborator: Alsonso Romero. Fertility-capability: Cd									
0-20	c. loam	5.5	0	0.06	22.0	7.0	0.16	29.2	100
20-40	clay	5.7	0	0.06	28.2	8.5	0.11	36.9	100
40-60	clay	6.0	1	0.04	34.2	10.0	0.15	44.4	98
60-80	c. loam	6.2	23	0.04	29.6	8.8	0.13	38.6	100
3. Nueva Esparta. Collaborator: Roberto Canales. Fertility-capability: Cd									
0-20	c. loam	5.3	32	0.06	29.8	2.4	0.21	32.5	100
20-40	c. loam	5.6	20	0.00	29.1	3.3	0.19	32.6	100
40-60	si.c.l.	5.7	28	0.00	28.4	4.5	0.17	33.1	100
60-80	si.c.l.	5.6	13	0.04	30.6	3.1	0.14	33.9	100
80-100	si.c.l.	5.9	17	0.00	28.8	3.1	0.12	32.0	100
4. Nueva Concepción. Collaborator: Hugo Sandoval. Fertility-capability: Ld									
0-20	si.c.l.	5.3	0	0.04	5.5	2.4	0.27	8.2	99
20-40	si.c.l.	5.7	0	0.05	7.3	1.3	0.17	8.8	99
40-60	clay	5.2	0	0.04	9.9	1.7	0.09	11.7	99
60-80	clay	5.2	0	0.04	13.0	2.9	0.10	16.0	100
80-100	c. loam	5.3	1	0.06	12.0	2.7	0.11	14.9	100
5. Azacualpa. Collaborator: Tobías Rivas. Fertility-capability: Cdh									
0-20	clay	5.0	1	0.29	4.9	1.8	0.33	7.3	60
20-40	clay	5.1	1	0.10	5.5	1.2	0.09	6.9	99
40-60	clay	5.5	1	0.04	5.1	0.6	0.04	6.1	99
60-80	clay	5.4	0	0.04	5.9	0.2	0.04	6.2	99
80-100	clay	5.5	0	0.00	5.9	0.7	0.03	6.6	100

Table 32. Rates used in the forage sorghum fertilization trials in El Salvador, 1973.

Treatment No.	N	P_2O_5	K_2O
	kg/ha		
1	0	180	150
2	120	180	150
3	240	180	150
4	360	180	150
5	480	180	150
6	600	180	150
7	720	180	150
8	360	0	150
9	360	60	150
10	360	120	150
11	360	240	150
12	360	300	150
13	360	260	150
14	0	0	150
15	0	360	150
16	720	0	150
17	720	360	150
18	720	360	0
19	720	360	150*

* K as KCl

Table 33. Planting and harvesting dates for El Salvador locations, 1973.

Location	Planting	First Cutting	Second Cutting	Third Cutting	Total days
Jocoro	June 21	Aug. 16	Oct. 12	Dec. 6	168
Gotera	June 20	Aug. 17	Oct. 11	Dec. 6	169
Nueva Esparta	July 16	Sept. 3	Oct. 18	Dec. 5	142
Nueva Concepción	June 26	Aug. 30	Oct. 16	Dec. 3	160
Azacualpa	June 25	Aug. 29	Oct. 15	Dec. 4	162
La Herradura	June 29	Aug. 31	Oct. 17	Dec. 10	164

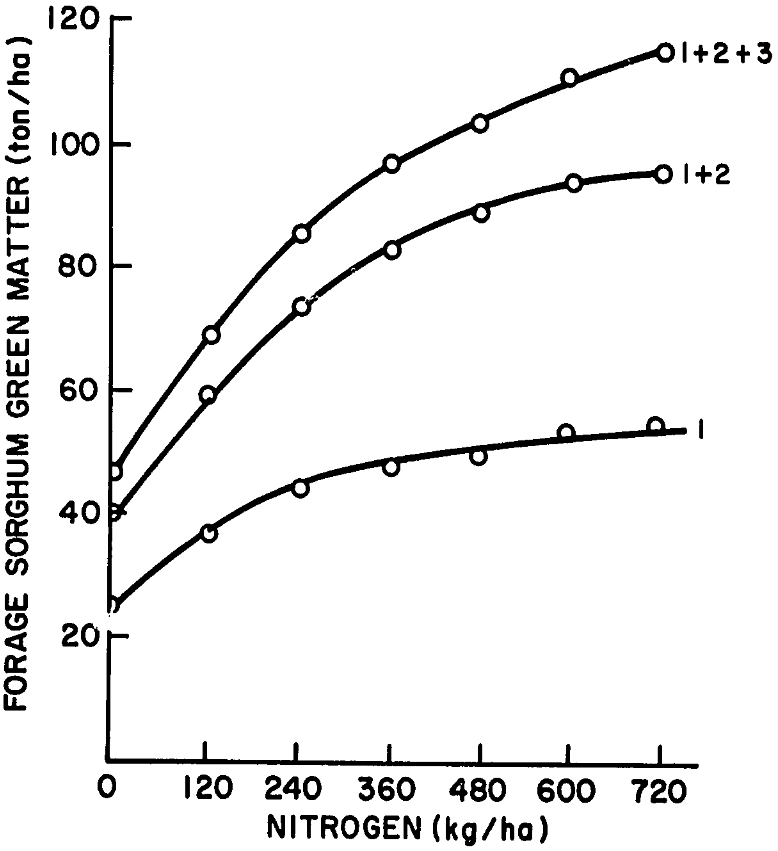


Figure 24. Average response of three cuttings of forage sorghum to applied nitrogen at six locations in El Salvador in 1973.

Nitrogen and Phosphorus Response

In general, the response to nitrogen was greater in the second and third cuttings than in the first. Figure 24 shows the cumulative nitrogen response per cutting averaged for the six locations. There were significant responses to nitrogen at all locations and to phosphorus at Azacualpa, Gotera, and Nueva Concepción. When the data are analyzed by the rectilinear method of Waugh, Cate, and Nelson, the plateau yields, relative yield percentages and optimum nitrogen and phosphorus levels were obtained. These are shown in Table 34.

The average plateau yield for phosphorus is 10.7 ton/ha lower than nitrogen, indicating that perhaps the nitrogen level at which phosphorus was evaluated was a little low. Examples of how the optimum nitrogen levels (Nueva Esparta) and phosphorus levels (Azacualpa) were obtained are given in Figs. 25 and 26, respectively.

Soil Testing Methods

Soil samples from all of the sites were tested for phosphorus using the North Carolina and modified Olson methods by the soil testing laboratories of the Ministry of Agriculture in San Jose, Costa Rica. The results are shown in Table 35.

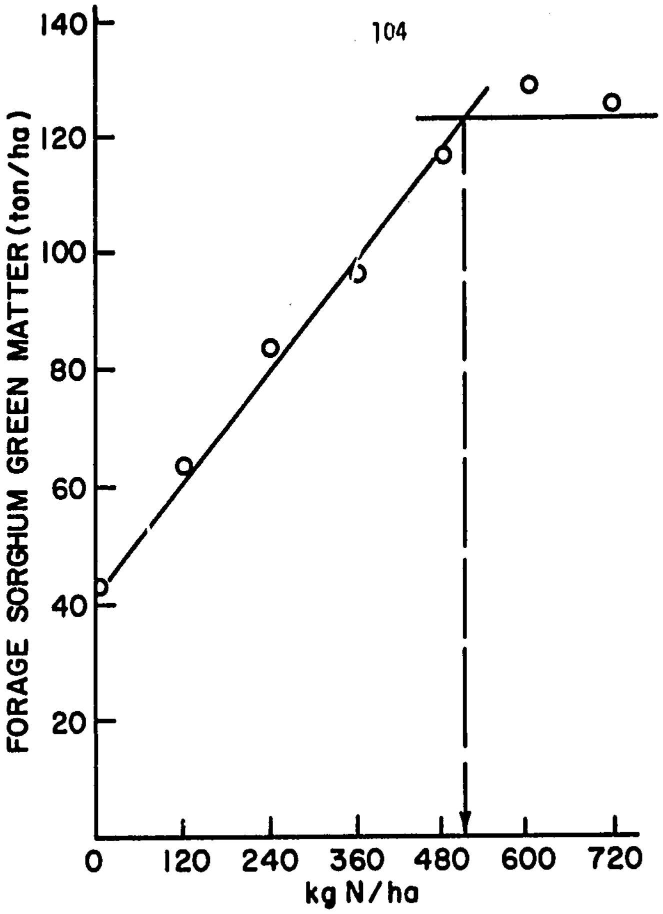
From this data it appears that the North Carolina weak acid method works better than the modified Olson extractant in predicting a forage sorghum response to phosphorus fertilization. However, this is inconclusive and at least one more year of trials in necessary for the correlation of soil test methods with phosphorus response by this crop.

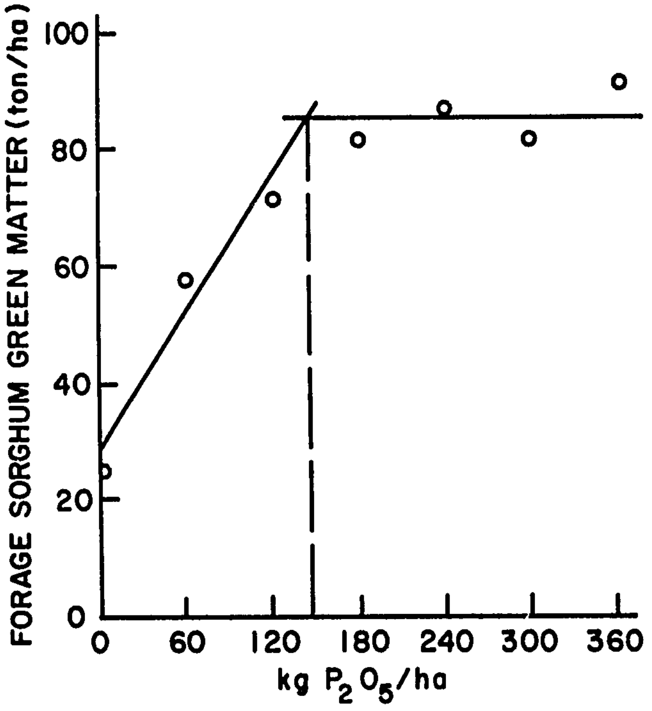
Potassium and Sulfur Responses

Responses to potassium and sulfur were evaluated at the 150 kg/ha and 60 kg/ha levels, respectively. The results are shown in Table 36. A significant response to potassium was obtained at Nueva Concepción and to sulfur at Jocoro and Gotera. Gotera and Jocoro are fairly close and located in the eastern section of the northern zone of El Salvador. We plan to locate one or two more sites in this area next year to see if the sulfur response is local or regional.

Economic Interpretation

A general economic recommendation for nitrogen fertilization for the Northern Zone can be made if values for nitrogen and the forage sorghum are known. Assuming that nitrogen costs ₡0.73 per kg of N (US $0.29) and the forage sorghum is worth ₡5.90 per ton of green matter (US $2.36), the price-cost relationships are shown in Fig. 27.





Figures 25 and 26. Optimum levels determined for the three forage sorghum cuts: Nitrogen at Nueva Esparta (top) and phosphorus at Acacualpa (bottom).

Table 34. Optimum nitrogen and phosphorus levels determined by the rectilinear method. El Salvador, 1973.

Location	Nitrogen Plateau Yield	 Relative Yield	 Optimum N level	Phosphorus Plateau Yield	 Relative Yield	 Optimum P level
	ton/ha	%	kg N/ha	ton/ha	%	kgP_2O_5/ha
Jocoro	119	25	480	95	85*	60
Gotera	120	33	430	108	81	110
Nueva Esparta	123	34	510	98	99*	0
Nueva Concepcion	109	74	230	114	76	100
Azacualpa	83	50	240	85	29	148
La Herradura	101	44	390	91	78*	75
Average	109	43	380	98	75	82

*Response to phosphorus applications not statistically significant.

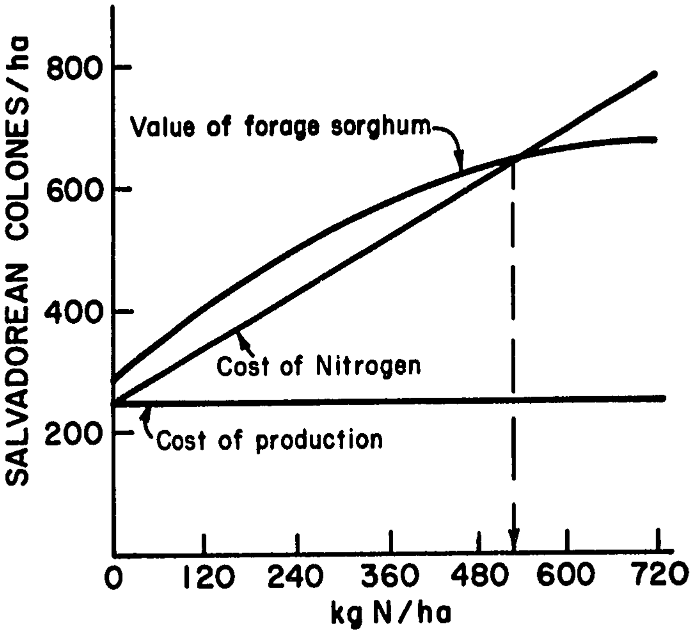


Figure 26. Optimum phosphorus level determined for three forage sorghum cuttings at Azacualpa, El Salvador.

Table 35. Soil test phosphorus comparisons for El Salvador locations, 1973.

Location	P extracted Mod. Olson	P extracted N.C.	Relative yield - P/P
	ppm	ppm	%
Jocoro	3	4	86 *
Gotera	2	7	82
Nueva Esparta	5	50	99 *
Nueva Concepción	5	2	76
Azacualpa	4	1	29
La Herradura	24	48	79 *

* Response to P was not statistically significant.

Table 36. Potassium and sulphur response data, El Salvador, 1973.

Fertility	Green matter of three cuttings Jocoro	Gotera	Nueva Esparta	Nueva Concepción	Azacualpa	La Herradura
	ton/ha					
NP	85	92	134	111	82	88
NPK	82	91	144	140	87	100
NPKS	120	129	134	123	88	107
$LSD_{.05}$	27	24	20	20	18	24

The variable cost of production should be similar at all nitrogen levels except for fertilizer costs. If it is assumed that this cost is ₡250/ha (according to U. S. Peace Corps estimate) the optimum economic level should be estimated as the point where the value of the forage sorghum curve intercepts the cost of nitrogen line, 510 kg N/ha.

To aid in obtaining the maximum economic return to nitrogen fertilization, regression equations were computed for the first two cuttings of the five Northern Zone sites. Putting the first derivative of these equations equal to the price of nitrogen/value of the forage sorghum, the maximum economic return can be computed.

For the first cutting the values were:

$Y = 29.05 + 0.0771\ N - 0.000059\ N^2$

N = 395 kg/ha x 40% of N applied for first cutting

N = 158 kg/ha

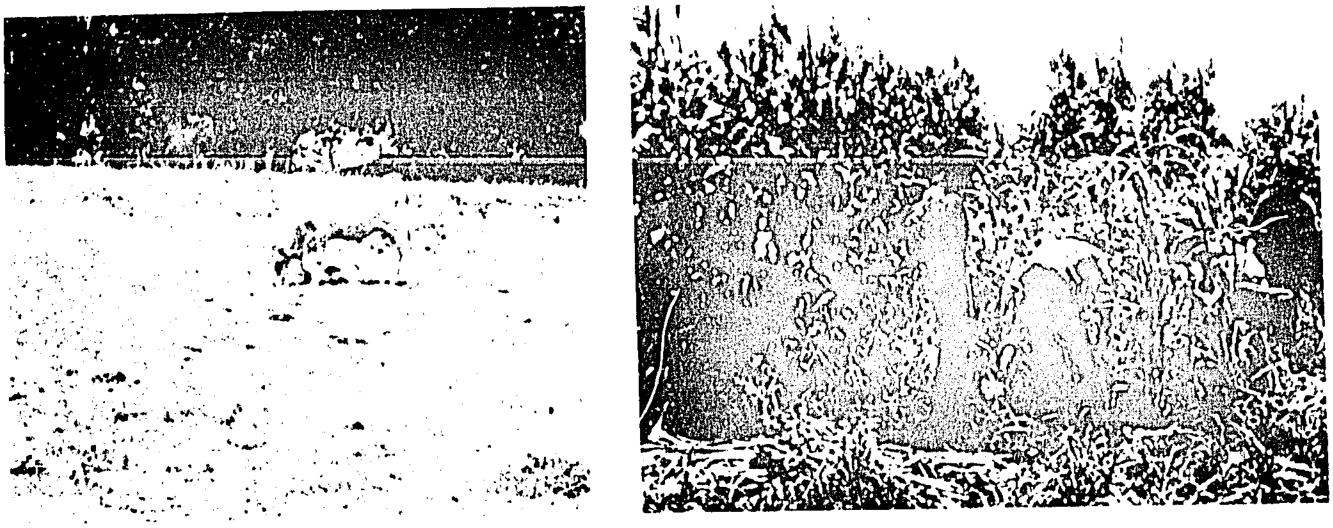
Second cutting:

$Y = 13.65 + 0.0745\ N - 0.000050\ N^2$

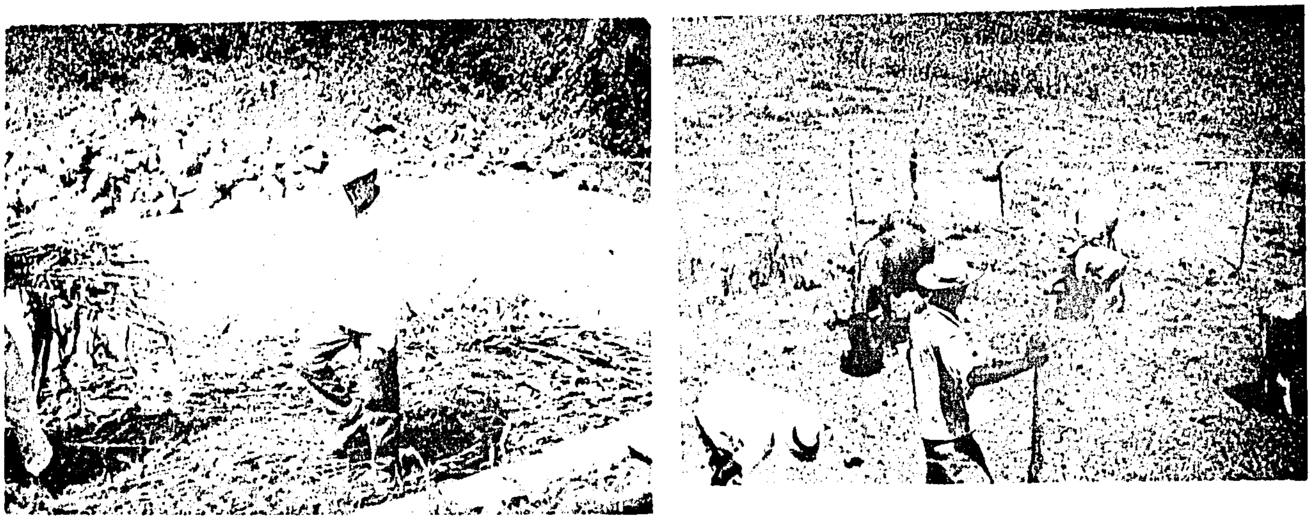
N = 492 kg/ha x 30% of N applied for second cutting

N = 148 kg/ha

Due to the uncertainty of the rainfall for the third cutting, no values were computed for this harvest. Considering the difficulty in establishing a value for the forage sorghum without feeding trials and current fertilizer price fluctuations, the economic optimum of 510 kg N/ha and the 158 and 148 kg N rates for the first and second cuttings, should be used at best as estimates.



Lack of pasture during the dry season (top left) decreases milk production sharply in northern El Salvador. Adequately fertilized forage sorghum (top right) can be grown during the rainy season, stored in inexpensive trench silos (bottom left) and fed to cattle during the dry season (bottom right).



NITROGEN MANAGEMENT IN UPLAND RICE-COSTA RICA

Although upland rice is one of the most important food crops in tropical Latin America as well as Central America, little information is available on the most efficient fertilizer management practices. This is because most of the research has been conducted under lowland irrigated conditions. With the increasing cost of nitrogen fertilizer it was considered desirable to determine which are the most efficient nitrogen fertilization practices for this very important crop.

Objectives and Design

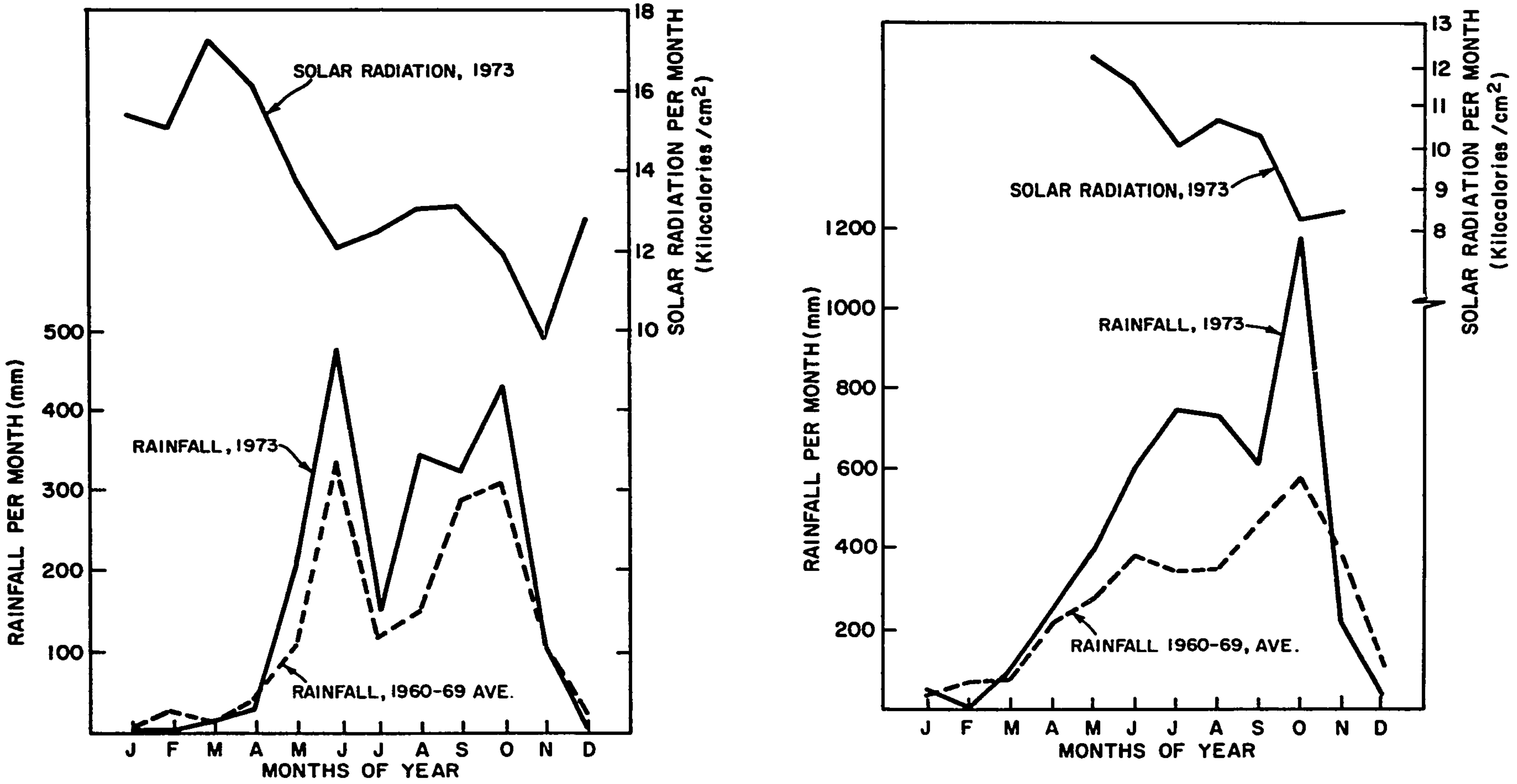
Two types of field experiments were conducted in cooperation with the Ministry of Agriculture of Costa Rica in 1973. The objectives were to study nitrogen management for upland rice production, evaluate sulfur-coated urea as a nitrogen source for upland rice, and determine the effect of light intensity and soil moisture regimes on the nitrogen response by rice through successive plantings. The nitrogen management experiments were installed at Palmar Sur, Taboga, and Cascante. The date of planting experiment was installed at Palmar Sur. Palmar Sur is located in the "humid" southern Pacific Coast of Costa Rica; Taboga and Cascante are located in the "dry" northern Pacific Coast on the Guanacaste Peninsula. These are the main rice growing areas of Costa Rica. Nitrogen is the only nutrient considered to be deficient in these soils.

The soil properties at the three locations are shown in Table 37. These are very fertile soils and are probably classified as Eutropepts, Ustalfs, and Ustropepts, respectively. The fertility-capability classification indicates no limitations except for the dry season in the Guanacaste sites.

In both areas, the 1973 rainfall was above the 1960-69 average. The rainfall and solar radiation of the two areas are given in Figs. 27 and 28. In the three sites a field experiment was planted at the beginning of the rainy season using the CICA-4 variety drilled in 18 cm rows at a seeding density of 100 kg/ha. A factorial design of four nitrogen rates and 10 management practices were installed. The treatments included urea and ammonium sulfate applied all at planting, half at tillering and panicle initiation, and in thirds at planting, tillering and panicle initiation. In addition, sulfur-coated urea was applied all at planting and half at tillering and at panicle initiation.

Table 37. Characteristics of the soils used in the upland rice experiments. Costa Rica, 1973.

Depth	Field texture	pH	Double acid P	Al	Ca	Mg	K	CEC (sum)
cm			ppm	meq/100g				
1. Palmar Sur. Collaborator: Alvaro Cubero. Fertility-capability: L								
0-20	si. loam	6.1	7	T	13.0	2.3	.20	15.5
20-35	si. loam	6.0	6	T	16.5	3.0	.46	19.9
35-55	sa. loam	6.2	10	T	19.0	3.4	.28	22.7
55-92	sa. loam	6.7	6	T	23.5	4.5	.16	28.1
92-130	c. loam	6.6	9	T	19.0	3.9	.22	23.1
2. Cascante, Guanacaste. Est. Exp. Enrique Jimenez Nuñez. Fertility-capability: LCd								
0-20	sa. loam	6.6	10	T	21.0	8.3	.62	29.9
20-40	cl. loam	6.8	3	T	26.0	20.0	.62	28.6
40-60	clay	7.0	1	T	28.5	28.0	.56	57.1
60-80	si. cl loam	7.4	1	T	24.0	30.0	.32	54.3
80-100	loam	7.6	3	T	22.0	32.0	.20	54.2
3. Taboga, Guanacaste. Est. Exp. Enrique Jimenez Nuñez. Fertility-capability: Cd								
0-20	clay	5.9	18	0	24.5	7.2	.86	32.6
20-40	si. clay	6.4	13	0	25.5	7.2	.62	33.3
40-60	si. c. d.	6.7	13	0	15.5	7.2	.38	23.1
60-80	si. c. l.	6.8	10	0	18.5	6.8	.30	25.6
80-100	si. c. l.	7.0	9	0	18.0	7.2	.30	25.5



Figures 28 and 29. Rainfall and solar radiation patterns at Taboga (left) and Palmar Sur (right).

Results

No difference between urea and ammonium sulfate was observed in any of the sites. The results of the urea and sulfur-coated urea treatments are shown in Fig. 30. Considerable variability in nitrogen response occurred between sites. At Taboga, significant responses were obtained with rates up to 180 kg N/ha. No responses were observed at Palmar Sur and negative responses predominated at Cascante. The maximum yields in each experiment ranged from 5.5 to 5.9 ton/ha. These are extremely high yields for upland rice and no doubt are due to the excellent soil properties, high rainfall and the use of a short-statured variety. The yields without nitrogen were in the order of 3, 4, and 5 tons/ha for Taboga, Palmar Sur, and Cascante, respectively. These yields seem to be directly related to the inorganic nitrogen content of the top 40 cms of soils prior to planting. The $NH_4^+ + NO_3^-$ contents were 80, 124, and 111 ppm respectively.

At Taboga, a basal application of sulfur-coated urea was superior to the basal application of conventional urea. Both basal applications were less efficient than split applications of urea in three parts. At Palmar Sur, there were no significant differences between sources or timing variables although the best yields were obtained with a split urea application. At Cascante, the negative response was associated with lodging. Yield decreases were more pronounced with the split applications. This situation probably reflects a higher nitrogen availability in these split treatments.

These experiments show no advantage of sulfur-coated urea for upland rice in these soils. Splitting applications seem recommendable over basal ones. The main issue, however, is how to predict whether there will be a nitrogen response or not, particularly in light of the extremely high cost of fertilizers in Costa Rica. Preliminary results of the date of planting experiment indicates considerable variability in yield response and optimum nitrogen rates due to climatic parameters in the same soil. Through periodic monitoring of solar radiation, soil moisture tension, soil inorganic nitrogen, and plant nitrogen uptake, we hope to obtain better information on this issue.

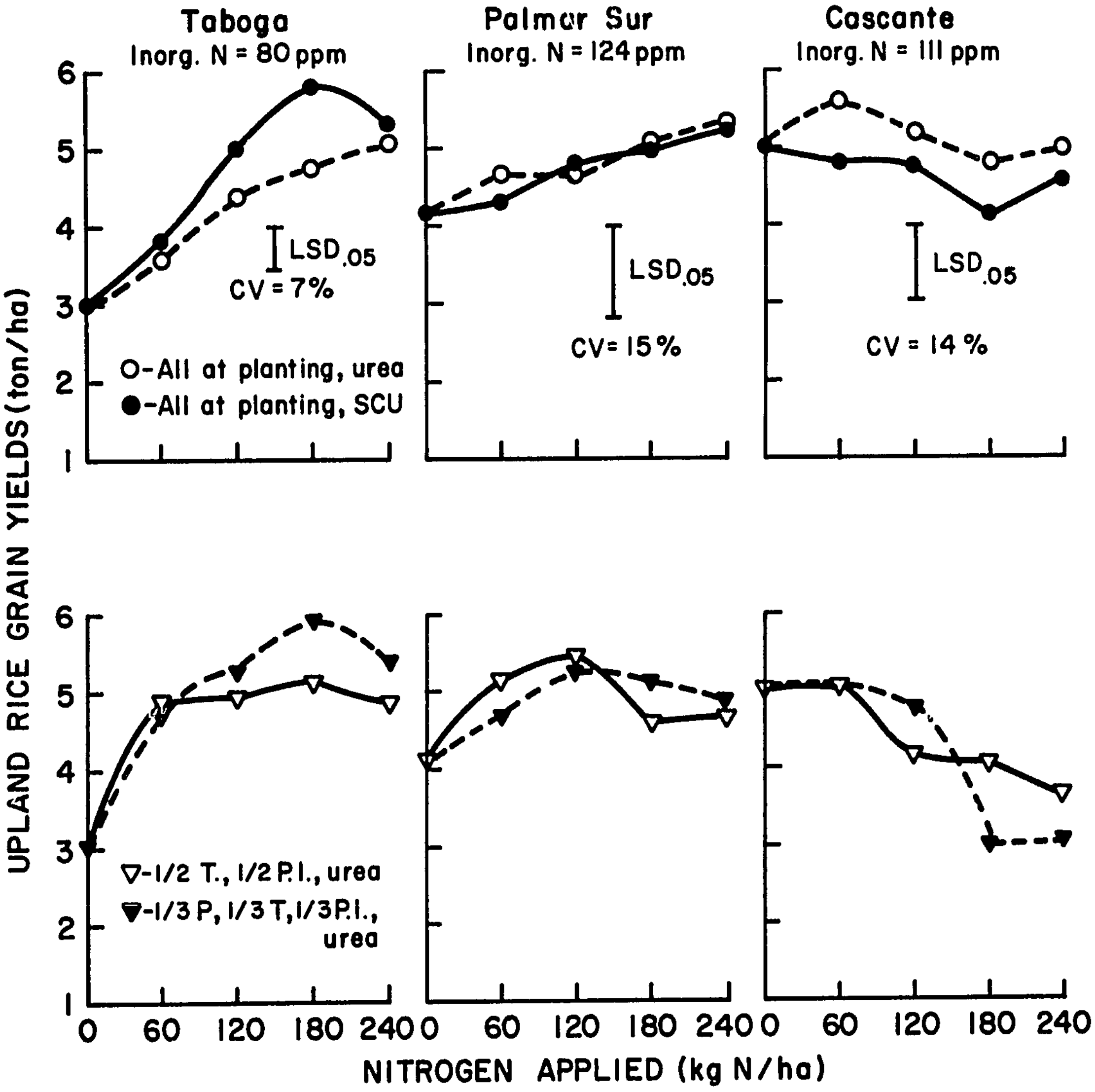


Figure 30. Influence of sources, rates, timing of nitrogen application and original inorganic N contents on the nitrogen response of upland rice in three sites of the Pacific Coast of Costa Rica, 1973.

Above: Drs. Sanchez, Oelsligle, and Ing. Romero in the process of sampling soils at the Palmar Sur rice experiments for inorganic nitrogen determinations.

Below: Ing. Aridio Perez observing sulfur deficiency symptoms (light colored plants) in many soils of Costa Rica at the Turrialba greenhouse.

SOIL SULFUR STUDIES, COSTA RICA

Objectives and Design

A study was initiated in 1973 after discussions with Ing. Alvaro Cordero and Dr. Gordon S. Miner of ISFEIP, to evaluate the sulfur status of the major agricultural soils of Costa Rica. Two graduate students at Turrialba, Ing. Aridio Perez and Edgardo Ramirez, decided to use this project for their M.S. thesis under Dr. Oelsligle's direction. Thirty soils were sampled for two studies: 1) Evaluation of the ability of current sulfur extracting methods to predict a sulfur response in the greenhouse; and 2) Sulphate-phosphate adsorption phenomena and the sulfur fractions at various depths in the profile.

Visual symptoms in the greenhouse indicated that 10 of the 30 soils responded to sulfur applications. Five different sulfur extractants were compared to evaluate their predictive capacity for sulfur response. Laboratory work is also in progress to determine sulphate adsorption.

The five soil extractants tried were:

1. $Ca(H_2PO_4)_2$
2. $Ca(H_2PO_4)_2$ + 0.01 M $CaCl_2$
3. $Ca(H_2PO_4)_2$ + 2 N HOAc
4. KH_2PO_4
5. 0.025 M $CaCl_2$

The phosphorus concentration in all of the phosphate extractantions were 500 ppm P. Soil-solution ratios for all extractants were 20-50 and the methodology was as follows:

a. 1/2 hour shaking

b. Centrifuge for 5 minutes at 4000 rpm at then filter

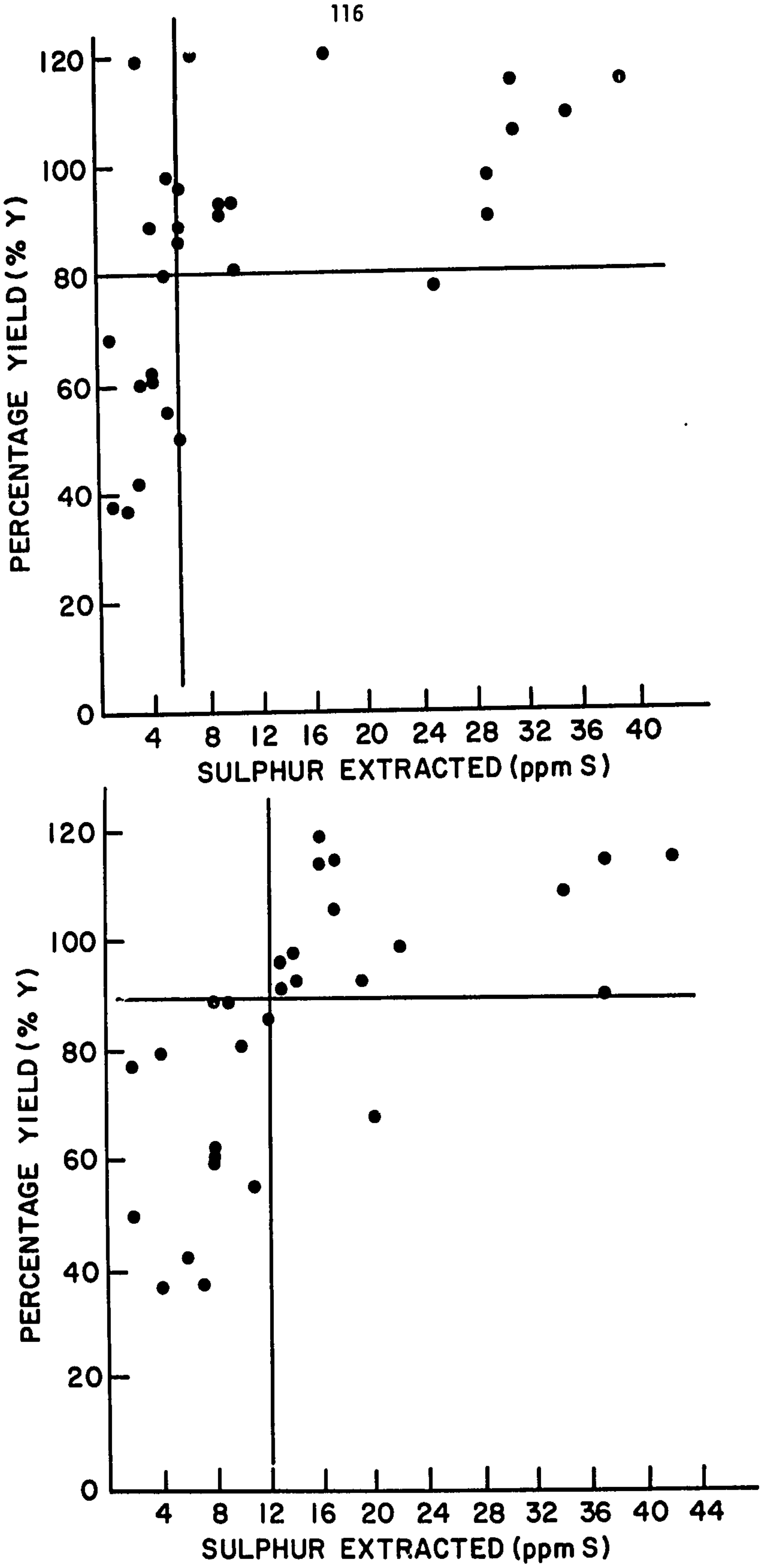
c. 10 ml aluquot to which was added:

   10 ml of a solution 6.25% HNO_3 and 2 ppm S

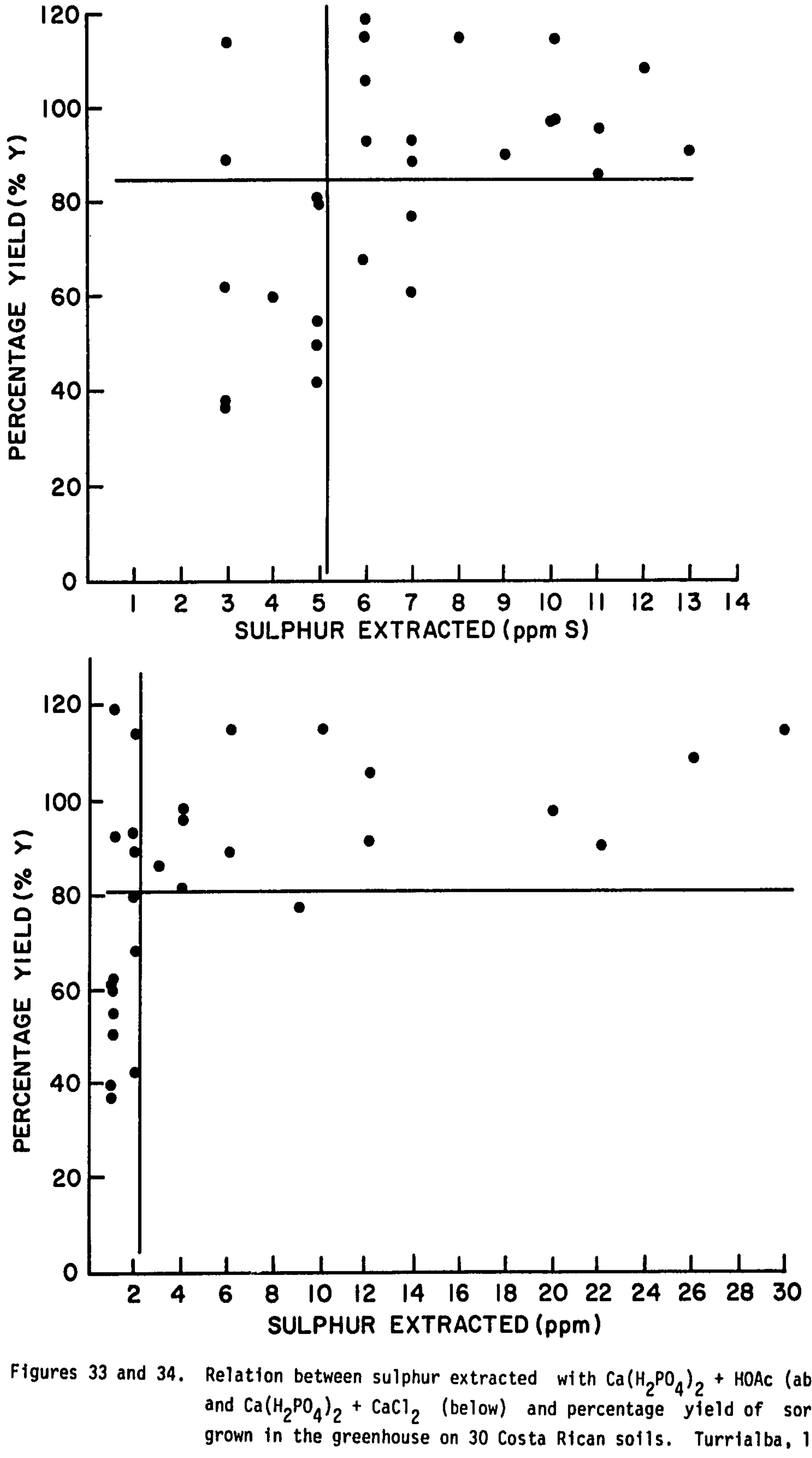
   5 ml of a solution 8.7 N HOAc and 0.5% gum acacia

   Approximately 1 g crystal $BaCl_2$

d. Shake for 1 minute and read against a standard curve at 420 μm



Figures 31 and 32. Relation between sulphur extracted with KH_2PO_4 (above) and $Ca(H_2PO_4)_2$ (below) and percentage yield of sorghum grown in the greenhouse on 30 Costa Rican soils. Turrialba, 1973.



Figures 33 and 34. Relation between sulphur extracted with $Ca(H_2PO_4)_2$ + HOAc (above) and $Ca(H_2PO_4)_2$ + $CaCl_2$ (below) and percentage yield of sorghum grown in the greenhouse on 30 Costa Rican soils. Turrialba, 1973.

Calcium chloride alone failed to remove significant amounts of sulfur. The highest amounts of sulfur were extracted with KH_2PO_4 and $Ca(H_2PO_4)_2$ with values varying from 1 to 40 ppm S. When $Ca(H_2PO_4)_2$ was mixed with $CaCl_2$ or HOAc, the amounts of S removed were 1 to 30 and 3 to 13 ppm S, respectively. Figures 31 to 34 show the relationships between the amounts of S removed by the different extractants and the dry matter percentage yields (-S/S) of sorghum grown for 60 days in the greenhouse. As can be seen when using this evaluation method, $Ca(H_2PO_4)_2$ alone appears to give the best separation of the soils which would be expected to respond to sulfur applications under greenhouse conditions. The tentative critical levels established for the four extractants are:

$Ca(H_2PO_4)_2$	12 ppm
$Ca(H_2PO_4)_2$ + HOAc	5 ppm
$Ca(H_2PO_4)_2$ + $CaCl_2$	2 ppm
KH_2PO_4	6 ppm

The modified Olson extractant and ammonium acetate are also under study for use as a sulfur extractant. Correlation studies will also be made for the sulfur uptake in the greenhouse when these values are available. It is hoped to obtain some field information in the coming year to refine these critical levels to make them more practical.

COPPER TOXICITY IN UPLAND RICE

Objectives and Design

There are large areas of soils in Central America that contain toxic levels of copper for rice production. These sites have been in banana production between 1938 to 1958, during which the Bordeaux mixture was applied frequently for control of the Panama and Sigatoka diseases. Copper sulfate and lime are the principal compounds of this fungicide. As a result, these soils are very high in copper.

Copper toxicity caused by these applications occurs in large rice areas of Panama, Costa Rica, Honduras, Nicaragua, and Ecuador. In Costa Rica alone about 5000 acres are involved. The topography, physical, and chemical properties of these soils aside from the Cu problem indicate they should be highly productive. The climate is extremely favorable for rice in these areas, and yields are normally high. Rice, however, is quite sensitive to copper toxicity, as well as some vegetable crops and pasture species. Corn and sorghum are less sensitive.

A series of studies have been initiated to see if this problem can be alleviated. Bulk soil samples were collected from three general areas in Costa Rica and from one area in Honduras. The Costa Rican areas are in the Humid Pacific coast near Parrita, Palmar Sur and Coto. The latter is near the Panamanian border. Ing. Alvaro Cordero and others assisted in the collection of these samples. The Honduran site was near San Pedro Sula. Dr. Francisco Sierra assisted with those samples.

At each location, two samples were collected. One was high in copper and the other low. These sites were relatively close together so soil properties other than copper level were similar.

The samples were shipped to Raleigh. After grinding and screening, they were analyzed by the modified Olson procedure as suggested by ISFEIP. The results are presented in Table 38. The pH of the samples from Costa Rica ranged from 5.3 to 5.9, whereas that from Honduras was 7.4. Free lime is observable in the latter sample. The low copper sample from Honduras also contained a contamination of zinc. All soils were quite low in phosphorus.

A greenhouse study was initiated to see if the symptoms developed well under a given experimental procedure and to evaluate the effect of levels of soil copper. The procedure used was to mix 200 g of soil with 15 g of 20% superphosphate, place it in a cup fitted with a wick, and insert the wick in an NH_4NO_3 solution. This kept the soil at about 50% H_2O.

To evaluate levels of soil copper, the low and high copper soils were used plus three mixtures of these soils: containing 25, 50, and 75 percent of the high copper soil.

Prior to conducting the study, another analysis of soil copper was conducted. The results differed from the first analysis in that the copper level of the "low" soils decreased by an average of 6.5 ppm whereas that from the "high" soils increased an average of 76 ppm.

Results

CICA 4 rice was grown for six weeks and then harvested. The results are shown in Fig. 35 using estimated values of soil copper for the three intermediate levels. On the high pH soil from Honduras, there was essentially no yield at any copper level. The high pH and possibly zinc deficiency are the probable causative factors. With the Costa Rican soils, dry

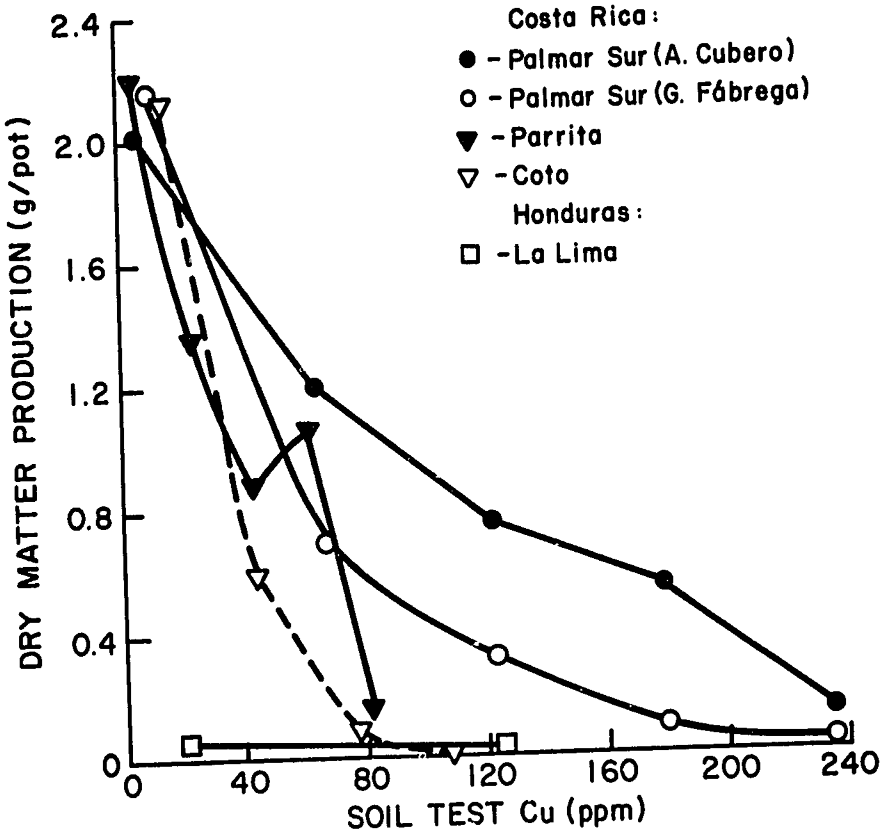


Figure 35. Dry matter of CICA-4 upland rice grown in small pots as a function of soil copper level.

Appearance of rice seedlings grown in a soil mixture from Palmar Sur. Left to right: 0, 25, 50, 75, and 100% of copper-affected soils. Visual symptoms were typical iron deficiency chlorosis.

matter production was good on the "low" soils and decreased rapidly with even a 3/4 low, 1/4 high soil mixture. This indicates it takes very little additional copper to cause this problem.

The rate of decrease among the Costa Rican soils varied with increasing soil copper level. This offers promise in being able to evaluate other soil properties that may modify this effect.

After harvesting the crop, the soils used were dried to about 20% H_2O, screnned, and stored in plastic bags. Analyses were then conducted for copper and iron on the moist samples. The results are presented in Table 39. In comparison with previous determinations, the copper levels were extremely high. The average copper level at this time was about 15 ppm in the "low" samples and nearly 1000 in the "high" samples. On the other hand, iron tended to decrease with increasing copper level. This may be a function of the nature of the extracting solution, though.

The highly variable data regarding soil copper level indicates the need for studies on factors affecting the copper status in the soil. The modified Olson extractant has not worked well with certain atomic absorption instruments. Studies are now being made with double acid extractant. This probably will not be satisfactory on the soil from Honduras but may be better on the Costa Rican samples. The plant samples also are being analyzed at present. From the data collected this far, however, it appears that the extreme variation in soil copper levels needs to be studied carefully before proceeding toward possible solutions of the problem.

COOPERATIVE FIELD FERTILITY STUDIES - GUATEMALA[1/]

Objectives and Design

The soils research program in Guatemala is production-oriented with emphasis in fertility management. During 1972-73, the field work was concentrated in the Central Highlands (Altiplano) and on the Pacific coastal lowlands. The principal crops in the Highlands are corn, wheat, and potatoes. On the Pacific lowlands, they are corn, rice, grain, sorghum, and sesame. These were used as test plants in the field work during the 1972-73 crop year.

[1/] This program was conducted in cooperation with and under the general supervision of Dr. James L. Walker, Regional Director, International Soil Fertility Evaluation and Improvement Program, contract AID/la 646. Portions of the data may appear in reports on that project.

Table 38. Soil test data by the modified Olson procedure on the high and low Cu soils collected from Central America.

Location	Cu level	pH	Ca	Mg	K	P	Mn	Zn	Fe	Cu
			(ppm)							
Cubero	low	5.9	4330	465	165	3	49	2	165	9
(Palmar S.	high	5.5	3800	595	139	3	77	7	200	120
Parrita	low	5.5	5930	843	176	2	64	1	86	8
	high	5.8	6700	845	121	4	53	2	43	48
La Lima	low	7.4	4230	243	260	1	12	72	55	31
Honduras	high	7.4	6030	403	194	5	20	4	24	280
Fabrega	low	5.3	6230	618	221	2	86	3	87	17
(Palmar Sur)	high	5.6	6550	585	258	2	66	6	59	180
Coto	low	5.4	6000	955	380	3	24	4	122	23
	high	5.8	7730	1005	420	3	20	3	65	118

Table 39. Cu and Fe levels of moist samples after six weeks cropping.

		Mixture				
	% "low Cu"	100	75	50	25	0
Location	% "high Cu"	0	25	50	75	100
		Cu (ppm)				
Cubero		10	305	558	886	1055
Parrita		5	152	123	374	466
La Lima		22	726	1347	1820	2396
Fabrega		11	359	690	928	1299
Coto		14	46	412	521	705
		Fe (ppm)				
Cubero		531	1083	459	830	730
Parrita		74	64	56	52	46
La Lima		33	29	23	20	19
Fabrega		122	72	56	62	46
Coto		732	90	63	43	35

A country-wide soil testing program, in collaboration with the International Soil Fertility Evaluation and Improvement Program (ISFEIP), had been underway for some 10 years. In 1972, the Guatemalan Ministry of Agriculture, the U. S. Peace Corps, and ISFEIP initiated a joint effort to obtain soil and crop yield data for improving the correlation of responses to fertilizers with soil tests. Dr. Robert E. McCollum joined this program on a part-time basis as a representative of the tropical soils research project. He was stationed in Guatemala for a total of six months between February, 1972 and February, 1973.

The experimental procedure followed by the joint project in 1972-73 consisted of the following steps. 1) Potential experimental sites, mainly on farmer-owned land, were located by cooperating Peace Corps volunteers (PCV). 2) The volunteers then sampled the soil on each site, according to a set of directions provided by Soils Department personnel in the Ministry of Agriculture, and sent the samples to the soil testing laboratories for routine analyses. 3) Once the samples were analyzed, the soil test results were scanned for site-specific uniformity and a decision concerning the site's acceptability for experimental purposes was made. 4) If accepted as sufficiently uniform, a set of treatment variables based on the crop to be grown and on current fertilizer recommendations for that crop-soil combination was prepared. Variables included rates of N, P_2O_5, and K_2O each nutrient being varied singly (not factorially) and each of the unvaried nutrients being applied at the so-called "adequate" rate according to current recommendations. 5) The experiment was installed under the supervision of the cooperating PCV and/or technical personnel of the Ministry. 6) Routine cultural practices (cultivation, pest control, etc.) during the growing season were handled by the PCV and the farmer-cooperator. 7) At harvest, final yield data were taken by Ministry personnel or by the PCV's according to a set of instructions provided by the Ministry. 8) Finally, all yield and other relevant data were sent to Ministry personnel for compilation and for subsequent analysis and interpretation.

Results

The 1972-73 crop year was one of the driest on record for Guatemala. Because of the drought, many experiments were lost, especially on the Pacific lowlands, but what may be considered reliable yield data were collected from approximately 50 sites, mostly with corn, wheat, and potatoes. Relevant soil test values (pH, and dilute acid-extractable P and K) and ultimate crop yields associated with them are summarized in Tables 40 to 42.

Table 40. Relevant soil properties and yields of corn, wheat, and potatoes on check (testigo) treatments compared with yields under adequate fertilization (1972 data).

Location	Soil property			Yield[1/]			
				Reference Treatment	Check treatment for		
	pH	P	K		N	P	K
		ppm	ppm	tons/ha			
Corn (Highlands)							
Chimaltenango	6.0	3	242	5.43	1.24*	4.49	4.70
Chimaltenango	6.0	2	101	6.39	5.23*	5.17*	6.91
Malacatoncito	5.9	6	83	3.80	0.55*	1.95	3.99
Malacatoncito	5.8	9	126	3.31	1.32*	3.45	2.79
Cabrican	6.4	4	351	6.34	2.48*	5.57	4.82
Olintepeque	6.2	6	185	6.39	2.60*	6.18	6.16
Olintepeque	5.9	10	101	5.60	2.39*	5.24	5.48
San Pedro	6.1	57	191	6.08	1.71*	5.82	5.35
San Pedro	6.5	34	137	7.62	2.45*	6.53*	7.06
Tejutla (S. Marcus)	6.2	9	176	3.89	1.21*	2.77*	3.41
Tejutla (S. Marcus)	6.5	26	171	3.92	1.18*	4.06	4.21
Corn (Pacific lowlands)							
La Maquina	6.5	23	55	3.40	1.59*	3.53	2.32*
La Maquina	6.4	12	135	2.65	2.31	2.00*	2.82
La Maquina	7.2	15	259	2.87	2.34	2.77	3.22
La Maquina	6.8	2	341	3.35	3.71	4.01	3.98
La Maquina	6.6	4	155	5.17	4.42	4.26	5.39
La Maquina	6.5	4	262	3.97	3.84	4.15	4.03
Cuyuta (Est. Exp.)	7.0	17	291	3.39	2.99	3.49	3.28
Cuyuta (Est. Exp.)	6.4	5	221	2.02	1.14*	1.49*	1.45

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* Response to nutrient was positive and statistically significant at P>.10 or greater.

[1/] Reference-treatment yields are those predicted for the "optimum" rate of N fertilization adjusted for the mean level of applied P and K. Check-treatment yields are those predicted at zero fertilization with the nutrient indicated but adjusted for the mean rate of fertilization with the other two nutrients.

Table 40. (Continued)

				Yield1/			
	Soil property			Reference treatment	Check treatment for		
Location	pH	P	K		N	P	K
		ppm	ppm	tons/ha			
Wheat (highlands only)							
Chimaltenango	6.1	4	218	1.59	0.48	1.38	1.55
Chimaltenango	6.0	5	266	1.52	1.27	0.91*	1.55
Huehuetenango	5.4	2	60	1.14	0.72*	0.04*	0.83
Olintepeque	6.1	4	190	2.86	2.79	2.49	2.92
Olintepeque	6.0	3	173	3.01	1.67*	1.88	2.90
Olintepeque	5.8	12	245	3.53	3.02*	3.21	3.38
Calapte	5.9	19	108	1.43	1.17	0.41*	1.54
Calapate	6.3	10	74	1.53	1.33	1.29	1.29
A. Rindon (S. Mandos)	5.9	40	--	0.92	0.61	0.24*	0.64
Tejutla (S. Marcos)	6.3	6	306	2.65	2.26	1.71*	2.15
Totonicapan	6.4	4	224	2.49	1.58*	1.55*	2.27
Totonicapan	6.3	6	103	1.43	0.29*	1.06	1.35
Potatoes (Highlands only)							
Chimaltenango	5.9	24	263	23.8	15.4*	22.7	23.6*
Chimaltenango	6.3	5	335	22.1	10.6*	8.9*	18.9
Huehuetenango	5.0	6	47	28.1	23.3	12.7*	20.2*
Olintepeque	5.2	3	48	22.9	8.2*	5.0*	16.0
Olintepeque (Est. Exp.)	5.8	10	168	33.6	12.7*	23.5*	22.3*
Calapte (S. Marcos)	5.6	11	83	29.0	10.2*	2.2*	22.7*
Santa Lucia (Solola)	5.3	8	160	24.3	17.0*	16.2*	25.7

Potatoes responded to nitrogen, phosphorus, and potassium fertilization about as predicted by prior soils analyses. For highland corn, the response to nitrogen was also about as predicted by experience. Furthermore, most of the soils are well supplied with potassium and, as predicted, positive responses to potassium fertilizers for crops, other than potatoes, were rare. Finally, soil pH data show that the base status of essentially all soils used was high. It seems logical to conclude that soil acidity is not a management problem in those parts of Guatemala studied during 1972-73.

For the remaining soil-crop-fertilizer treatment combinations, however, the data suggest that our capability to analyze the soil and make fertilizer recommendations according to the results obtained therefrom is far from adequate. To what extent the observed nutrient responses--or lack of them--were affected by the abnormally dry year cannot be documented. The data reported, however, included crops that developed without extreme drought, since no yields were obtained from the experiments most affected by drought.

Two features of the yield data pose particularly intriguing questions. One of them concerns the essential absence of any response of corn to nitrogen on Pacific lowland soils. Corn yields in this area were low with or without fertilization. Although factors other than mineral nutrition may have been limiting, the consistently poor response to nitrogen either in vegetative growth or in ultimate yield, suggests a need for studies of a more fundamental nature than those made to date, It is quite apparent that the plants were accumulating N from the soil; it is pertinent to determine the magnitude of this native supply, how long it may last, and to what extent the supply is seasonal. Given the fact that two crops are often produced on the same land during one rainy season (e.g., corn-corn, corn-beans, corn-sesame), the nitrogen-supply problem becomes doubly relevant.

The other feature of the 1972 results concerns the crop response to phosphorus fertilizers. Dilute acid-extractable P was low to very low in well over half of the soils used, but positive responses to phosphorus were, at best, sporadic. Furthermore, a statistically measureable yield increase was observed on several sites where little or no response was predicted from prior soil analysis. Results of this sort suggest that the plants are extracting phosphorus from soil-P fractions not readily soluble in the dilute acid used. Laboratory studies with different P extractants are particularly relevant.

Table 41. Corn yields for differing rates of N, P_2O_5, or K_2O fertilization in the highlands and Pacific lowlands of Guatemala (1972 data).

Fertilizer variable and rate of application[1]	Grain Yields			
	Highlands Av. of 11 sites		Pacific lowlands Av. of 8 sites	
kg/ha	ton/ha			
Nitrogen				
0	2.07		2.79	
60	3.53		3.25	
120	4.68		3.30	
180	5.25		3.35	
240	5.65		3.47	
-Sulfur	5.60		3.12	
+Zinc	5.46		3.28	
	All responses positive at $P=.05$		2 positive responses	
P_2O_5	$P_s < 25$ ppm[2] (5 sites)	$P_s > 25$ ppm (6 sites)	$P_s < 25$ ppm on all sites	
0	4.69	6.71	3.26	
30	--	7.18	--	
60	4.80	6.87	3.42	
90	--	6.75	--	
120	4.98	6.49	3.47	
180	4.92	--	3.35	
240	5.15	--	3.34	
	3 positive responses		2 positive responses	
K_2O	$K_s < 155$ ppm (5 sites)	$K_s > 155$ ppm (6 sites)	$K_s < 155$ ppm (3 sites)	$K_s > 155$ ppm (5 sites)
0	6.32	4.93	3.67	3.20
30	--	5.40	--	3.22
60	5.89	5.17	3.84	3.20
90	--	4.91	--	3.15
120	5.64	--	3.95	--
180	5.97	--	3.73	--
	No positive responses		No positive responses	

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[1] All experiments had single-variable fertilizer treatments, and nutrients were applied at rates considered adequate according to prior soil test.

[2] P_s and K_s refer to soil-test level of dilute acid-extractable P and K, respectively.

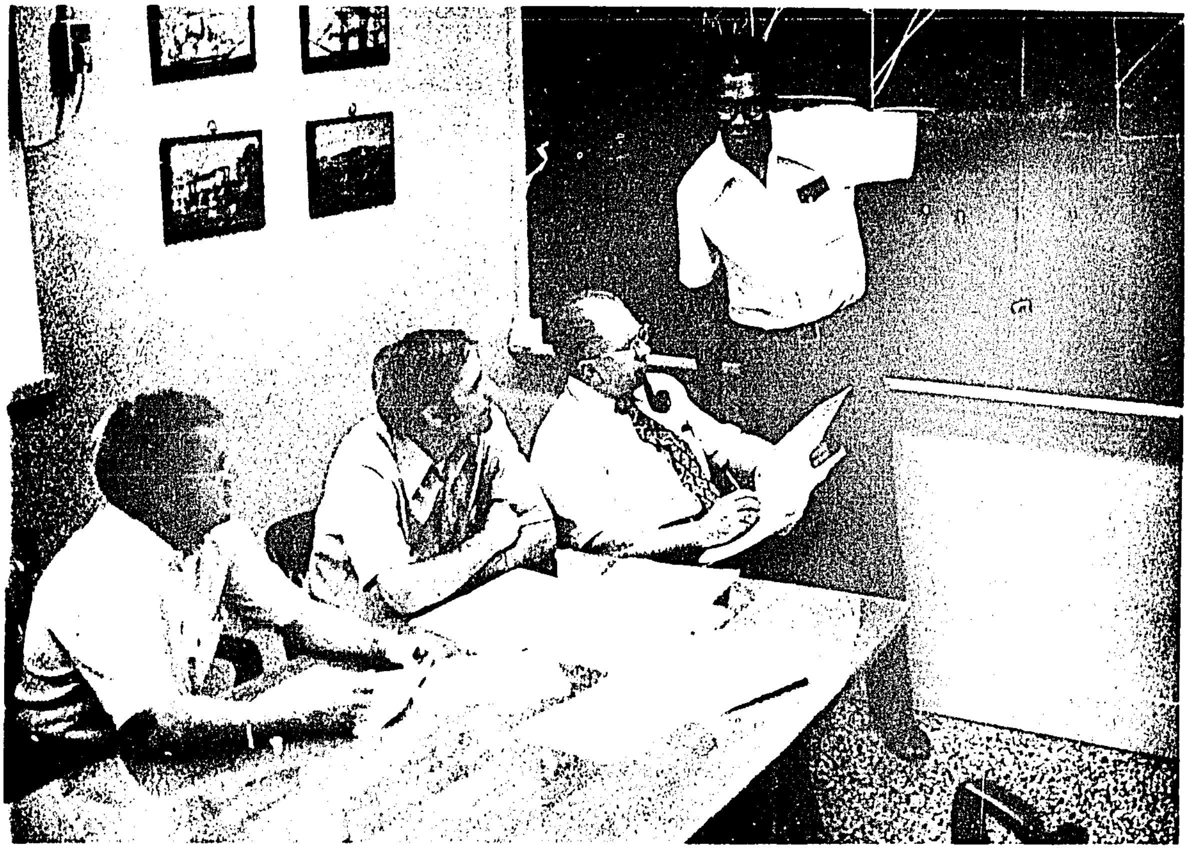
Table 42. Yields of potatoes and wheat for differing rates of N, P_2O_5, or K_2O fertilization in Guatemala (1972 data).

Rate of fertilization	Yields for indicated variable					
	Potatoes (Av. of 7 sites)			Wheat (Av. of 12 sites)		
(kg/ha)	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	tons/ha					
0	16.2	15.4	24.8(7)*	1.50	1.44	2.04
30	--	24.7(1)	26.4(4)	1.85	1.79	2.09
60	23.6	23.0	27.3(7)	2.02	1.97	2.03
90	--	25.7(1)	27.8(4)	2.15	2.15	2.15
120	27.9	26.1(6)	30.0(5)	2.03	2.15	--
180	28.8	29.3(6)	26.8(5)	--	--	--
240	28.4	--	30.7(3)	--	--	--
App. LSD at P = .05		5.0 M.T.			0.5 M.T.	
No of positive responses	6	6	4	7	5	None

*Numbers in parenthesis indicate number of sites included in the average for that treatment level.

As a final point, attention is called to the fact that the present soils research effort in Guatemala is almost wholly devoted to the soil-nutrient regime. There are substantial observations to suggest that there are many other soil and crop management problems that may be equally or more important than fertility *per se*. Some of these have been pointed out in trip reports, and some fairly initial experimental approaches have been discussed with local personnel. However, there is an acute shortage of adequately trained personnel to implement these studies.

FERTILITY-CAPABILITY SOIL CLASSIFICATION SYSTEM



Dr. Granger discusses on the blackboard Brazilian fertilizer response data used for evaluating the fertility capability classification system with the Program's soil genesis specialist (Dr. Buol), economist (Dr. Perrin), and soil fertility specialist (Dr. Sanchez).

The remaining sections of this annual report describe several region-wide studies designed primarily to aid in data extrapolation, interpretation, and to attack some problems of wide regional interest. These region-wide studies include the development of the fertility - capability soil classification system, economic studies, soil characterization, and supporting laboratory studies.

Substantial progress was attained this year in the development of the fertility - capability soil classification system and the assessment of its utility in grouping soils with similar fertilizer response. Dr. Michael A. Granger was hired as a Research Associate in May 1973 to devote full-time efforts to this project. Drs. Buol, Sanchez, Perrin, and Cate of ISFEIP continued developing and evaluating this system.

DEFINITION OF CATEGORIES AND CLASSES

The rationale guiding the development of this technical classification system stated in the 1971 Annual Report remains unchanged. As more information became available during this year, it became possible to more accurately define the classes in both categories used in a modified format shown in Table 43.

The soil criteria chosen are those that appear to have a direct influence on the interactions of applied fertilizers and closely related fertilizer management practices.

The present format is still in an evolutionary stage since neither the type nor amount of parameters employed have been thoroughly tested. Nevertheless, in its current phase, it provides a base from which to begin. The format consists of three levels or categories: type, substrata type, and condition modifiers.

Type

Type is the highest category. It is determined by the average texture of the plow-layer or upper 20 cm of the soil, whichever is shallower. Field estimates of textures by feel are probably adequate.

Substrata Type

Substrata type is the second highest category. It is the texture of the subsoil. However, its use in the system is invoked only if it differs from the textural class of the

Table 43. Fertility-capability classification.

TYPE: Texture is average of plowed layer or 20 cm depth, (8") whatever is shallower.

S = Sandy topsoils: Loamy sands and sands (USDA).
L = Loamy topsoils: < 35% clay but not loamy sand or sand.
C = Clayey topsoils: > 35% clay.
O = Organic soil: > 30% O.M. to a depth of 50 cm or more.

SUBSTRATA TYPE: Used if textural change or hard root restricting layer is encountered within 50 cm (20").

S = Sandy subsoil: texture as in type.
L = Loamy subsoil: texture as in type.
C = Clayey subsoil: texture as in type.
R = Rock or other hard root restricting layer.

CONDITION MODIFIERS: In plowed layer or 20 cm (8"), whichever is shallower unless otherwise specified (*).

*g = (Gley): Mottles ≤ 2 chroma within 60 cm of surface and below all A horizons or saturated with H_2O for > 60 days in most years.

*d = (Dry): Ustic or xeric environment; dry > 60 consecutive days per year within 20-60 cm depth.

e = (low CEC): < 4 meq/100 soil by Σ bases + unbuffered Al.
< 7 meq/100 soil by Σ cations at pH 7.
< 10 meq/100 soil by Σ cations + Al + H at pH 8.2.

*a = (Al toxic): > 60% Al saturation of CEC by (Σ bases and unbuffered Al) within 50 cm.
> 67% Al saturation of CEC by (Σ cations at pH 7) within 50 cm
> 86% Al saturation of CEC by (Σ cations at pH 8.2) within 50 cm
<u>or</u> pH < 5.0 in 1:1H_2O except in organic soils.

*h = (acid): 10-60% Al saturation of CEC by (Σ bases and unbuffered Al) within 50 cm.
<u>or</u> pH in 1:1 H_2O between 5.0 and 6.0.

i = (Fe-P fixation): % free Fe_2O_3/clay > 20 <u>or</u> hues redder than 5 YR and granular structure.

x = (X-ray amorphous): pH > 10 in 1 N NaF <u>or</u> positive to field NaF test <u>or</u> other indirect evidences of allophane dominance in clay fraction

v = (Vertisol): Very sticky plastic clay > 35% clay and > 50% of 2:1 expanding clays;
COLE > 0.09. Severe topsoil shrinking and swelling.

*k = (k deff): < 10% weatherable minerals in silt and sand fraction within 50 cm <u>or</u> exch. K < 0.20 meq/100 g <u>or</u> K < 2% of Σ of bases, if Σ of bases < 10 meq/100 g.

*b = (Carbonate): Free $CaCO_3$ within 50 cm (fizzing with HCl) or pH > 7.3.

*s = (Salinity): > 4 mmhos/cm of saturated extract at 25° within 1 meter.

*n = (Sodic): > 15% Na saturation of CEC within 50 cm.

*c = (cat clay): pH in 1.1 H_2O is < 3.5 after drying, Jarosite mottles with hues 2.5Y or yellower and chromas 6 or more within 60 cm.

type. Code letters indicative of type, substrata type, or both, are capitalized.

Condition Modifiers

Condition modifiers, refer to chemical or physical properties of the plow-layer or top 20 cm, whichever is shallower, unless otherwise specified. The modifiers indicate specific fertility limitations with different possible interpretations. However, it is not necessary to obtain characterization with the degree of precision specified in Table 43 to make the system functional.

Thirteen condition modifiers have been so far recognized in this system. Letter-coding of the condition modifiers are given as lower case letters which are selected to provide easy association with conditions they describe.

The following discussion imparts some of the rationale involved in selection and use of each of the thirteen condition modifiers:

g: refers to a gley condition in the soil indicative of water-saturation within 60 cm of the surface during some part of the year. It should be indicative of soils that could benefit from drainage practices. It fits the Aquic soil moisture regime definition of the U. S. Soil Taxonomy but is not mutually exclusive of the "d" modifier when strong monsoon climates prevail. It also identifies soils suitable for rice production.

d: refers to an annual dry season of more than 60 consecutive days. It roughly corresponds to the Ustic, Xeric, Torric, and Aridic moisture regimes defined in the U. S. Soil Taxonomy. Its significance in fertility is not fully recognized but might indicate different nitrogen relationships at the onset of rains following a dry period.

e: refers to a soil condition of very low cation exchange capacity in the plow layer. Three levels are indicated as diagnostic depending upon the techniques used for determination of CEC. Significant fertility problems related to cation leaching could be inferred by this condition as well as its relationship to liming recommendations.

a: refers to high concentrations of exchangeable aluminum which could be toxic to most agronomic crops. It also implies a high degree of phosphorus-fixation as aluminum compounds and utilization of different soil test functions.

h: refers to a moderate level of acidity that would retard the growth of some aluminum-sensitive plants. Since both "a" and "h" conditions are often altered by liming and by the residual acidity of various fertilizer sources, these modifiers should be ascertained by examining the soil to a depth of 50 cm. Their presence will reflect the severity of continued lime requirements.

i: This modifier is intended for those soils in which phosphorus fixation by iron compounds is of major importance. The iron/clay ratio criterion set forth in Table 43 is frequently difficult to obtain and thus a color-structure criterion has been given for field use. It is believed that this modifier will be closely aligned with the Oxisol order.

x: This modifier attempts to delimit soils with allophane-dominated mineralogy. This condition reflects a potentially high phosphorus-fixing capacity, a low rate of nitrogen mineralization and perhaps, a low available moisture range in such soils. Preliminary indications are that the simple NaF tests do correlate well with the phosphorus-fixation potential of these soils.

v: refers to clayey soils dominated by 2:1 type expanding clays. The fertility implications are for high permanent charge CEC, and difficulty in water relationships and soil tillage. It is thought that this modifier will be closely aligned with the Vertisol order and some vertic subgroups.

k: many soils have small quantities of potassium bearing minerals and as such good responses to added potassium fertilizers are obtained. This modifier attempts to delimit those soils where it is almost certain that potassium will be needed in an agronomic fertility program. The criteria set forth in Table 43 has been adapted from taxonomic limits and critical soil test limits from several reports.

b: This modifier delimits calcareous soils or, more specifically, the presence of free carbonate within 50 cm of the surface. It further implies probable phosphorus fixation by calcium compounds.

s: This modifier attempts to separate those soils with salinity problems for most crops. It is based on criteria developed by the U. S. Soil Salinity Laboratory.

n: Sodium is considered because of its effect on clay dispersion and on moisture availability. This modifier is designed to delineate soils with sodium problems. These limits, like those of the "s" modifier are set by the U. S. Soil Salinity Laboratory.

c: This modifier is indicative of the presence of acid sulphate soils (cat-clays) and their associated management problems.

SYSTEM ASSESSMENT

In assessing the applicability of the system in grouping soils several sources of information were used. In many modern soil surveys sufficient data are given to allow the classification of model pedons in the fertility capability system. However, care should be exercised when such information is used since considerable fertility variability can and does exist within both taxonomic and mapping units. Nevertheless, the system, in its present state, was found to be elastic enough to group any soil type into one of its classes. Three distinct levels of aereal extent of soils were used: a worldwide sample, a country sample, and a county soil map.

Worldwide Sample

In the worldwide sample published profile descriptions and analytical data of 244 soil profiles, representing a broad geographical and morphological range of soils were classified in this system. This sample consisted of soils from the United States, South America, Africa and Southeast Asia taken from the 7th Approximation, the FAO Map of South America, D'Hoore's soil map of Africa and other sources.

Eleven of the 13 possible type-subtype combinations were identified in this sample. Types L (loamy), C (clayey), LC (loamy topsoil over clayey subsoil), and S (sandy) accounted for 91% of the population (Table 44). A total of 68 modifier combinations were found. Table 45 lists the ten most commonly found combinatioss which accounted for 51% of the population. About 5% of the profile samples had no modifiers, implying no particular fertility management limitations.

A total of 117 type-subtype-modifier combinations were identified. Many possible combinations were not found due to the mutual exclusiveness of the criteria. Five of the 13 modifiers (v, n, x, i, s) never occurred alone, reflecting the fact that several of these fertility related parameters occur together in many soils (Table 46). No profile characteristics produced the modifier "c" (cat clay) in this particular sample.

Table 44. Frequency distribution of fertility-capability groupings in the world-wide survey.

Type	Frecuency of occurrence		Condition modifier combinations
	No.	%	No.
L	82	34	31
C	72	34	31
LC	47	19	24
S	22	9	14
SL	4	1	4
CL	3	1	3
Others (5)	14	6	10
Total	244	100	117

Table 45. Most common modifier combinations found in the world-wide survey.

Modifier	Interpretation	Frequency
		No.
a	Aluminum toxic	28
gak	Aquic, Al toxic, K deficient	17
ga	Aquic, aluminum toxic	14
eah	Low CEC, Al toxic, K deficient	13
---	No limitations	12
g	Aquic	11
d	Dry season	8
gh	Aquic, acid	8
db	Dry season, calcareous	8
dvb	Dry season, vertic, calcareous	6

Table 46. Occurrence of condition modifiers alone or in combination with others in the world-wide sample.

Modifier	Alone	In combination with others	Total
	No. of profiles		
a	28	78	106
g	11	74	85
d	8	64	72
k	3	70	73
e	1	39	40
b	1	36	37
h	4	20	24
v	0	17	17
n	0	13	13
s	0	11	11
x	0	10	10
i	0	6	6
c	0	0	0

Table 47. Frequency distribution of fertility-capability groupings found in 678 soils of Brazil.

Type	Frequency of occurrence		Condition modifier combinations
	No.	%	No.
L	223	33	17
C	195	29	19
LC	112	16	14
S	93	14	12
SL	39	6	9
CL	7	1	4
Others (3)	7	1	7
Total	678	100	84

The Country Sample

The second level of aerial extent of applicability of the soil fertility capability classification system was to determine the range in properties found within national boundaries. All the 678 soil profiles described in the soil survey reports of Brazil were classified according to this system. This data was collected by Dr. R. B. Cate, Jr. in collaboration with the Divisão de Pesquisas Pedológicas, DNPEA and EMBRAPA. The modifier "d" was present in all areas. Nine of the possible 13 type-subtype combinations were found in this study (Table 47). The L, C, LC, and S classes accounted for 92% of the population, in striking agreement with the worldwide sample. A total of 84 type-subtype-modifier combinations were found. Considering only those combinations that comprise at least 1% of the population would reduce the total to 23 type-subtype-modifier combinations and account for 75% of the soil profiles from Brazil. The Brazilian survey did not include several modifiers which were simply not found in the profiles such as "y", "x", and "c".

The interpretation of this survey showed that the large majority (78%) of the soils were either clayey, loamy, or loamy over clayey without physical root-restricting layers. About 20% of the profiles did not have any fertility limitations except for "d" or "k". More than 35% of the profiles showed low cation exchange capacities ("e") on the surface in spite of their relatively fine texture. This modifier ("e") appeared almost always in combination with others, appearing alone only 10 times. About 27% are aluminum toxic ("a") and 28% have the "h" modifier. Only 5% were calcareous. About 27% of the samples had the "i" modifier denoting high phosphorus fixation due to iron compounds.

The County Sample

The third level of aerialextent of applicability was tested at a county level by determining the number of classes in a 2200 km^2 area of North Carolina. The detailed soil survey of Wake County was used for this purpose. This survey report has 145 mapping units (soil phases) from 40 soil series. When the soils were classified according to the fertility capability system, only 6 type-subtype and five modifier combinations were found (Table 48).

The worldwide, the Brazilian, and the Wake County surveys showed that soils belonging to the same taxonomic groups (i.e. Paleudults, Latosol Roxo, etc.,) have different fertility capability ratings. Consequently, in many cases, natural taxonomies cannot be directly translated in their entirety into this technical system. By definition, however, direct

Table 48. Fertility-capability grouping of Wake County, North Carolina soils.

Condition modifier combinations	Type Substrata Types							Total
	LC	C	SC	L	SL	LR	S	
	No. of mapping units							
h	34	17	-	6	-	2	-	59
a	48	-	-	-	-	-	-	48
eh	-	-	12	-	-	-	-	12
ea	-	-	-	-	7	-	-	7
av	4	2	-	-	-	-	-	6
ga	2	-	-	3	-	-	1	6
gh	2	-	-	2	-	-	-	4
geh	-	-	-	-	-	-	1	1
Total	90	19	12	11	7	2	2	143

Most of the information needed to classify soils in this system can be obtained in the field followed by simple laboratory analysis. Photo shows Mr. E. J. Tyler classifying a soil in the Amazon Jungle.

translation of some parameters can be made. Most Oxisols will have the "i" modifier, all Vertisols will have the "v", most Andepts will have the "x", and all aquic subgroups will have the "g" modifier. It should be pointed out that in the case of the detailed soil survey of Wake County, many mapping units of soil series are classified into different fertility capability classes, primarily because past erosion has removed the A horizon leaving the clay textured argillic horizon as the surface material.

In every case, the use of the fertility capability system had a homogenizing effect on soil units, reducing the number of working units to a relatively few fertility capability classes.

DATA ACCUMULATION AND WORK IN PROGRESS

All incoming soil samples from tropical areas will be classified according to the Soil Fertility Capability Classification. The first such set were from 18 pedons sampled and described in Costa Rica by Mr. Alfredo Alvarado. These samples are being used in Mr. Alvarado's thesis research project and have been no more than partially classified. Fourteen soils classify as "L", with no subtype delineation indicating no textural change in the subsoil material. Twelve bear the condition modifier "d" indicative of an annual dry season. Five bear the modifier "g" indicating water saturation within 60 cm of the surface. These soils have, in part, been influenced by volcanic ash depositions, and, as such, may also bear the "x" modifier by the completion of Mr. Alvarado's study.

Work is now in progress in Brazil to characterize the soils for which abundant fertility trial data exists. Fertility data from such projects as the FAO-ANDA-ABCAR in Goiás and Minas Gerais states have little or no soil characterization data. The acquisition of such information and accumulation of data will allow for the first initial testing of the extrapolatory value of the system in the next few months. It will further aid in better evaluating the accuracy of the parameters used.

Another aspect of the work in progress is the testing of the usefulness of the system to areas with long histories of fertilizer applications, in intensive types of agriculture. Such an area is represented by the Upper, Middle, and Lower Coastal Plains of North Carolina where tobacco, corn, and peanuts have been under long periods of intensive management. The data gathered so far are very inconclusive but indications are that the fertility capability classes may not contribute as much as would soil testing in intensively fertilized areas.

RELEVANCE OF FERTILIZER RESPONSE

The first test of usefulness of the system in terms of fertility response data was done by Dr. R. K. Perrin on data generated by Drs. R. E. McCollum and C. Valverde from potato fertilizer experiments conducted throughout the Sierra of Peru. Yield data was obtained along with soil test data. The soils from the 73 experimental sites were grouped into 5 fertility capability classes (Table 49). The average yield response to phosphorus of the five groups is shown in Fig. 36. The response curves of the Lhd and Lad soils were completely different from the other three. The response pattern of Lbd, Lbxd, and Cbd soils were essentially linear and not significantly different. Consequently for this case, the response pattern of the 73 experiments can be grouped into 3 categories, Lhd, Lad, and the bd combinations soils. Fig. 36 shows the maximum and optimum phosphorus rates between the Lhd and Lad soils. The optimum level for the other soils is probably beyond the range of rates studied.

Estimation of the gross return to added fertilizers showed that if fertilizer recommendations were on a blanket recommendation for all soils the gross return would have been US $770/ha. When recommendations were based on soil test data (pH, P, K) alone the average return would be on the order of US $860/ha. If recommendations were based on the fertility capability classes, the average return would have been US $920/ha. However, had recommendations been based on both the soil fertility capability classes and on the soil test data, indications are that the average returns would have further increased to about US $960/ha.

This analysis is only partially valid. However, there are indications that it is complementary in nature with soil test for better economic returns in extensive farming systems. It appears to be superior to blanket recommendations, and to soil tests alone. Furtner and more complete economic analyses will be made on other data for better assessing the relevance of fertilizer response within the fertility capability classes.

RELEVANCE TO PRESENT FIELD EXPERIMENTS

An application of this system to the soils used in this project's field experiments in Brazil, Peru, Costa Rica, and El Salvador illustrates its usefulness in separating fertility

Table 49. Classification of soils in 1967-71 Peru, potato trials.

Number of sites	Fertility-capacity classification
23	Lad (Loamy, aluminum toxic)
27	Lhd (Loamy, acid)
11	Lbd (Loamy, $CaCO_3$)
6	Lbxd (Loamy, $CaCO_3$, amorphous)
6	Cbd (Clayey, $CaCO_3$)

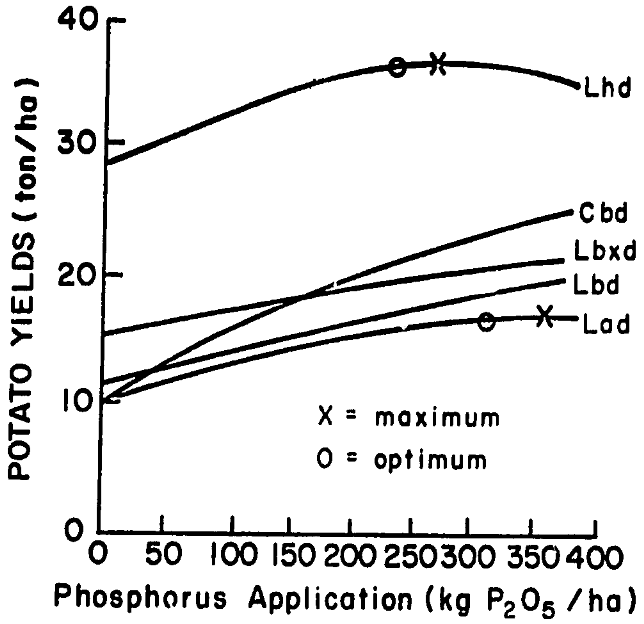


Figure 36. Average phosphorus response curves of each fertility-capability grouping for potatoes in the Sierra of Peru.

problems. This is illustrated in Table 50. The Oxisol from Brasilia presents the most extensive fertility limitations particularly in terms of phosphorus fixation by iron and aluminum compounds. The Ultisol from Yurimaguas is also quite infertile but has a much lower phosphorus fixation problem due to lower iron contents. The absence of a "d" modifier in this soil illustrates its capability of year round crop production without irrigation. The Andept from Turrialba has only a phosphorus problem due to its allophane content ("x") but it is of less magnitude than in Brasilia.

The soils from El Salvador respond to N, P, K, and S. The main limitation is water during the strong dry season. The Inceptisols from Palmar Sur and Guanacaste produce very high yields of upland rice with minimum fertilization. The soil from Palmar Sur shows no fertility problems. Farmers grow two crops of upland rice a year. In our experiments, the response to nitrogen was only moderate. Due to the "d" modifier, only one crop of upland rice can be grown yearly in Guanacaste. A stronger nitrogen response was observed in the coarser-textured soil possibly because of greater leaching losses.

CONCLUSIONS

The Soil Fertility Capability Classification System groups soils having similar fertility management problems. It is providing a mechanism whereby either existing soils data from soil survey reports or on-site examination of an area can be used to classify soils into reasonably homogeneous classes for the purpose of extrapolating fertility management practices. In no way does it replace soil testing which is necessary to monitor annual changes in soil fertility levels due to management practices. It does, however, provide the "soil tester" with somewhat uniform groups within which he can feel comfortable in extrapolating soil test interpretations.

It is, however, necessary to start a "data bank" to test the validity of the parameters and the long term usefulness of the system. The homogenizing effect brought about by the use of criteria, significant to soil fertility evaluation, tends to reduce the number of mapping units or soil series of a large management area to a relatively few working classes. It will also aid in the analysis of economic returns from fertilizer use by classes of soils expected to respond similarly to fertilizer use.

Table 50. Relationship between fertility-capability soil classification and the type of resposes obtained in the various field experiment of this project.

Location	Soil	Fertility-capability classification	Type of fertility problems and solutions
Brasilia	Dark Red Latosol	Cdeaik	Liming necessary to overcome Al toxicity in corn. Extremely high P-fixation by iron. Low moisture availability range and CEC despite high clay content. Responses to N, K,and Zn. Irrigation necessary during the dry season. Short term droughts very important.
Yurimaguas	Paleudult	Leak	Liming necessary to overcome Al toxicity in some species Low P-fixation capacity. Soil responds alto to N, P, K, S, B, and Mo. Susceptible to soil compaction. Short-term droughts less important.
Turrialba	Colorado	Lx	Phosphorus is the main limiting nutrient. Moderate responses to N.
El Salvador	Several	Cd - Ld	Strong dry season. Sharp responses to N, P, and in some cases to K, S.
Palmar Sur	Inceptisol	L	Moderate N response. Two upland rice crops a year. No other fertility problems.
Guanacaste	Toboga Cascante	Ld Cd	Strong N response. One upland rice crop a year. No fertilizer response and high yields. One upland rice crop a year.

The first agronomic evaluation shows promise for the implementation of the classification system. Its complementary nature with soil test recommendations suggest that the use of both tools has a positive interaction. The relative contribution of the fertility capability classes and soil tests will vary with the degree of management intensity. In relatively extensive farming systems such as the example from Peru, fertility capability classes may play a more sensitive role than soil testing. As fields develop a fertilizer history, soil testing may be the more sensitive parameter. However, vast land areas with agricultural potential still exist in the tropics on which extensive agriculture will be the initial phase of crop production. As such, the use of the fertility capability system will tend to greatly reduce developmental costs and aid in the better management of these soils.

ECONOMICS OF FERTILIZER RESPONSE

Although of undisputed value, high phosphorus applications such as this in Central Brazil might not be economized.

Dr. R. K. Perrin and associates continued evaluating models which give the most realistic fertilizer recommendations based on data previously gathered by other institutions in Latin America. After completing the analyses of potato fertilization in Peru, efforts were directed at evaluating data supplied by research institutions in Costa Rica and Brazil. The economists also evaluated the fertility-capability classification system.

THE PROFIT PREDICTION CRITERION

A variety of theoretical models are available for analyzing the economic implications of crop response to fertilizer. They range in sophistication from simple graphic techniques which require no statistical or economics expertise to very complex models requiring a great deal of statistical and/or economics expertise plus the use of a computer. The relative desireability of these models is a significant issue, particularly in those areas where personnel with statistical and economics training do not abound.

Two kinds of criteria have been offered in the literature for choosing among the available models; statistical criteria such as F-tests and R^2 which indicate how well a particular response model fits a given set of data, and biological criteria which evaluate the a priori appropriateness of the models in view of existing theories of soil-plant relationships. When the objective of crop response analysis is to make recommendations to farmers, however, a third kind of criterion is appropriate: the ability of the models to predict profitable fertilizer treatments for farmers.

The profit-prediction criterion (as we shall call the latter of the three mentioned above) was refined during 1973, and the criterion was applied to various models used in the analysis of response to fertilizer of corn and rice in Costa Rica and corn in Brazil. Two theoretical models were considered explicitly, the linear response and plateau response model (LRP) with Cate-Nelson analysis of critical levels for soil nutrients, and the generalized quadratic response model (GQRF).

The profit-predictability of a model is determined by reference to the net return (gross value of the crop minus fertilizer costs) obtained for each treatment in a fertilizer experiment. Each analytical model is asked to predict, a priori, which of the treatments in an experiment will provide the highest net returns. That treatment is the treatment which would be "recommended" by the model. The actual net return for that treatment can be determined *ex post*. By the profit-prediction criterion, that analytical model which results in the largest *ex post* net returns over a number of experiments is presumed also to provide farmer recommendations which will yield the highest net returns to the farmer, on the average.

The concept of a generalized response function is neither new nor complicated. The traditional response function model specifies that yield on a given plot is a function of applied nutrients and a random error component. This model is easily generalized to hypothesize that yields on a number of experimental plots in some region are a function of applied nutrients, soil characteristics as measured by soil tests, and weather variables. The motivation for the generalized response is that in making recommendations, one is interested in inferences about fertilizer response on *all* soils of some population, rather than response on each of several plots drawn from the population. The approach allows direct estimation of the effects of soil characteristics, again as measured by soil tests, on fertilizer response and desirable levels of fertilizer application.

A number of algebraic specifications of the generalized response function have been utilized, including the square-root function, the quadratic function and the power function.

The quadratic is by far the simplest of these, though it has been subjected to criticism that it may over-estimate maximum yield and the fertilizer rates required to attain these yields. The quadratic form is nonetheless utilized in this study, with no attempt to compare it with alternative algebraic specifications. If any estimation bias is present, it will be reflected by lack of the model's ability to predict profitable fertilizer levels.

The linear response and plateau approach has its origin in the ideas of Von Liebig, who over one hundred years ago theorized that crop yields are proportional to amount of the most limiting nutrient in the soil, up to some upper limit on yields. In recent years, the International Soil Fertility Evaluation and Improvement Program (ISFEIP) at NCSU has advocated a rather specific embodiment of this theory in the form of linear response and plateau analysis (LRP).

Detailed procedures for LRP analysis are summarized in a separate paper. The approach assumes that when other nutrients are adequate, the response to any one applied nutrient begins at some "threshold" yield and increases linearly up to a "requirement" level of the applied nutrient, at which point yields will reach a plateau where yields are unaffected by further nutrient applications. The great *a priori* appeal of the approach lies in its simplicity--it takes very little time or sophistication to plot yields on a graph and draw in the appropriate LRP following the ISFEIP procedure. By contrast, most other techniques require computers, statistical analysis, and sometimes considerable economic sophistication.

In analyzing data from several experiments in an area, the ISFEIP suggests the following sequence. Fit LRP's for each of the nutrients on each experiment separately, and from these LRP's determine relative yields (threshold yield divided by plateau yield) for each nutrient. For each nutrient, the relative yields are then plotted against soil test levels to determine the critical level of soil nutrient (if any) by the Cate-Nelson technique. Having determined critical levels, the experiments on soils with soil tests below (or above) the critical level are pooled, and a single LRP is fitted to the pooled data to determine the "requirement" level of nutrient for soils with tests below (or above) the critical level.

The fitting of the pooled-data LRP curve can present problems when the experiments being pooled do not have identical treatments. It is possible that the experiments with, say, 50 & 150 kgs/ha, may have basically higher yields than experiments with, say, 60 & 120 kgs/ha. In such a case, there will tend to be two sets of pooled LRP curves apparent in the plot, and if there are three or four experimental designs included, there may be three or four LRP curves. This problem was encountered in both the Minas Gerais corn data and the corn and rice data from Costa Rica. The most obvious solution would be to fit a separate LRP to each set of experiments with identical experimental designs, and to average the "requirement" levels so obtained as a basis for recommendations. In consultation with Dr. Larry Nelson, we decided for purposes of this study to average together the "requirement" levels obtained for all of the individual experiments, provided at least half of the experiments resulted in a response. By also averaging the threshold yields and the slopes of the linear responses for these experiments, a "composite" LRP was obtained, rather than a "pooled" LRP as suggested by ISFEIP.

CORN RESPONSE IN MINAS GERAIS, BRAZIL

Response data from 61 experiments in the state of Minas Gerais (1967-1969) was made available by EMBRAPA through the efforts of Dr. Robert Cate of ISFEIP. Thirty-one experiments were selected at random to form the analytical subset of experiments. The remaining thirty experiments, designated the evaluation subset, were used for evaluation the profitability for the recommendations to be derived from the analysis of the analytical subset. This evaluation subset we consider to represent a sample of thirty producers who would receive and make use of fertilizer recommendations. The data of this set will include the random effects of weather, soil type, insect damage, and to some extent management variability which would occur among the population of farmers who normally make use of recommendations.

The quadratic function fitted to the pooled data from the analytical subset of the Minas Gerais corn experiments is:

$$(1)\quad Y = c_1 + \sum_{i=1}^{m} b_i M_i + c_2(NA) + c_3(PA) + c_4(KA) + c_5(PS) + c_6(KS) + c_7(pH) + c_8(NA)^2 + c_9(PA)^2 + c_{10}(KA)^2 + c_{11}(PS)^2 + c_{12}(KS)^2 + c_{13}(pH)^2 + c_{14}(NA)(PA) + c_{15}(NA)(KA) + c_{16}(PA)(KA) + c_{17}(NA)(pH) + c_{18}(PA)(PS)$$

where Y = corn yield in kgs per ha

M_i = dummy variable; = 1 for municipio i; = 0 for municipio other than i

NA = applied nitrogen, in kgs per ha

PA = applied phosphate, in kgs per ha

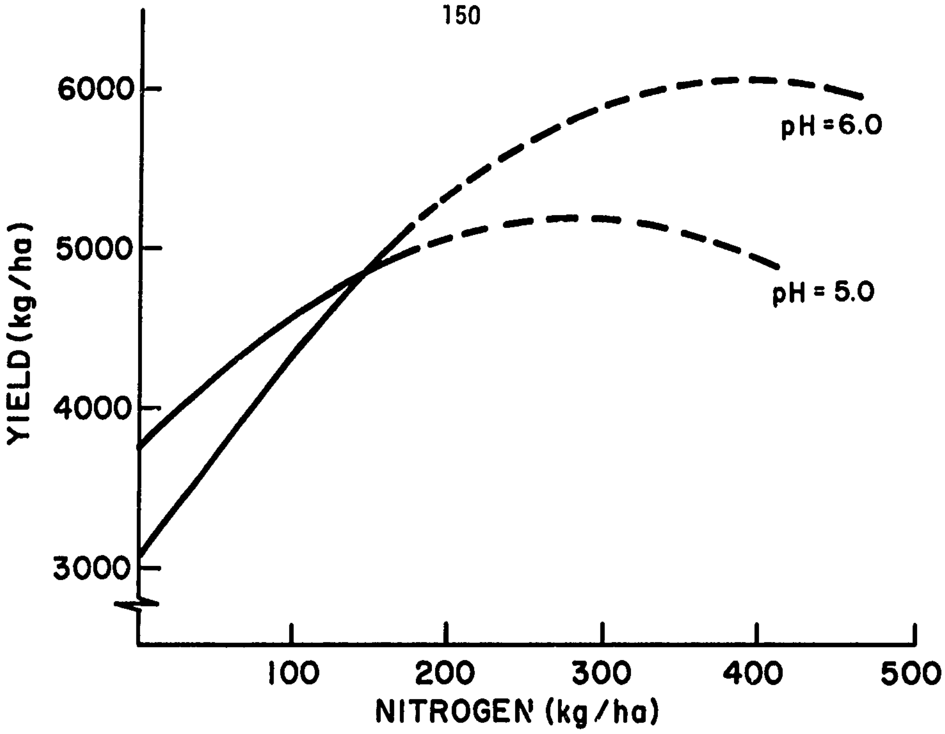
KA = applied potash, in kgs per ha

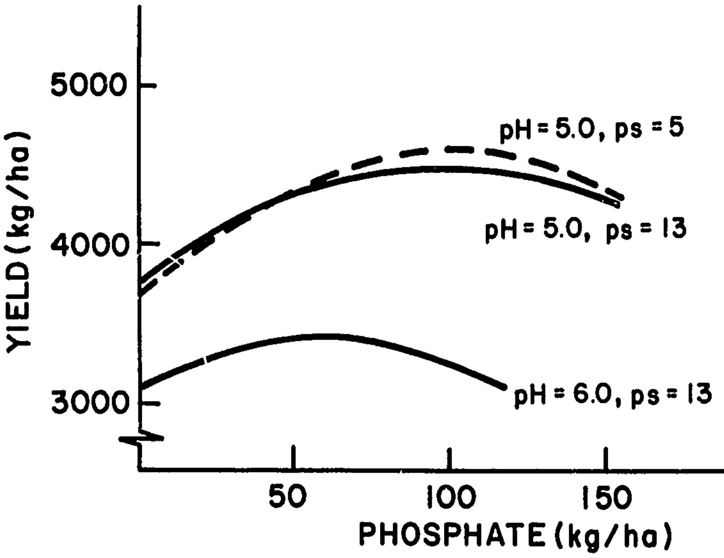
pH = soil pH

PS = soil phosphorus, in ppm

KS = soil potassium, in ppm

The estimated coefficients of this GQRF are shown in Table 51. The response implications of these coefficients can be appreciated by reference to Figs. 37-40. The fact that the coefficient of the nitrogen--pH interaction term is significantly positive means that response to nitrogen increases with increasing pH. This is illustrated by the two N response





Figures 37 and 38. Corn response to nitrogen (top) and phosphorus (bottom) at two soil pH levels in Minas Gerais, Brazil.

curves of Fig. 37, one calculated for soils with a pH of 5.0 and one for a pH of 6.0[1]. These curves indicate that the level of N required for maximum yields is considerably beyond the levels observed in the experiments. Whether or not these yields can be obtained cannot be determined from the existing data. Given the range of nitrogen used in the experiments (0-160 kgs per ha), only the solid portions of the response curves can be considered very useful and the usefulness of these portions can be determined best by their predictive ability.

The response to applied phosphates is likewise significantly affected by soil pH, but in the opposite direction, as illustrated by the two solid curves of Fig. 2, calculated for soils with pH of 5.0 and 6.0, and soil phosphorus at the average level of 13.24. Yield for a soil with a pH of 5.0 is not only higher than that for a soil with pH 6.0 (but identical in other respects), the maximum response occurs at a higher level of applied phosphate. Response to phosphate is also affected by soil phosphorus (coefficient 18 in Table 51), but the impact is negligible. This is illustrated by the dashed curve of Fig. 38 calculated for a soil with pH = 5.0 and PS = 5.0, which is only slightly more responsive than the curve for a soil with pH = 5.0, PS = 13.24.

The coefficients for potash response (coefficients 4 and 10) are small and not significantly different from zero, indicating the absence of potash response on these soils.

Recommendations can be readily derived from the response equation of Table 51. Since potash response is negligible and since the interaction between nitrogen and phosphate is also negligible (coefficient 14), it is only necessary to consider the application of nitrogen and phosphate as separate nutrients. Classic profit maximization with respect to nitrogen and phosphate leads to the following two equations for optimum levels of nitrogen (N*) and phsophate (P*):

(2) $N^* = -316 + 119.49\,(pH) - 27.49\,P_N,$

(3) $P^* = 279 - 34.73\,(pH) - 0.750\,(PS) - 5.76\,P_p,$

where P_N is the ratio of the price of one kg of nitrogen to one kg of corn, and P_p is the ratio of the price of one kg of phosphate to one kg of corn. These equations show the direct relationship between fertilizer recommendation and soil test which can be estimated using the GQRF approach.

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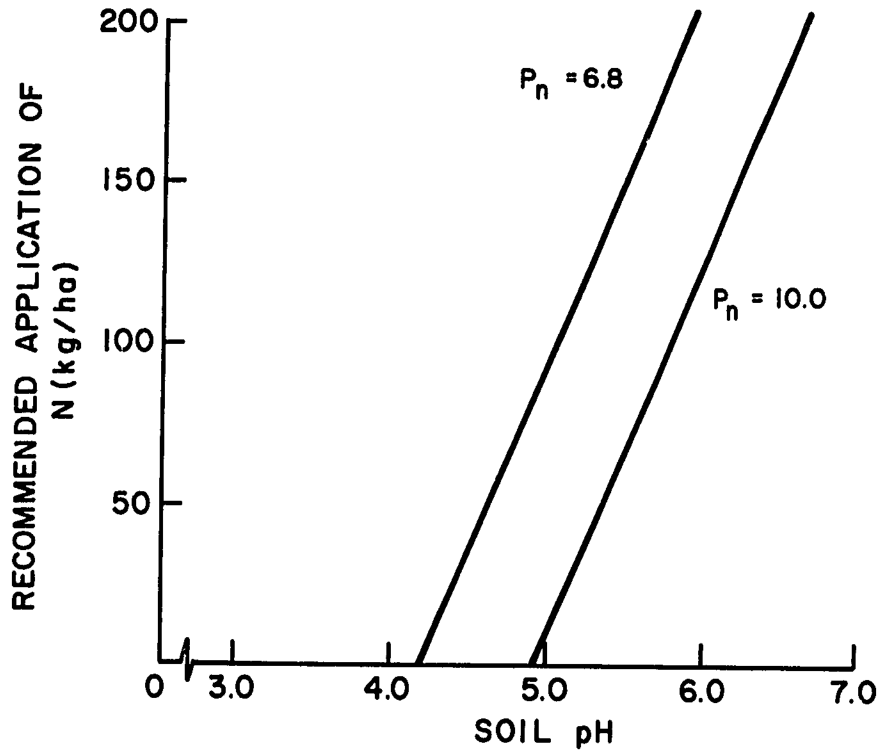
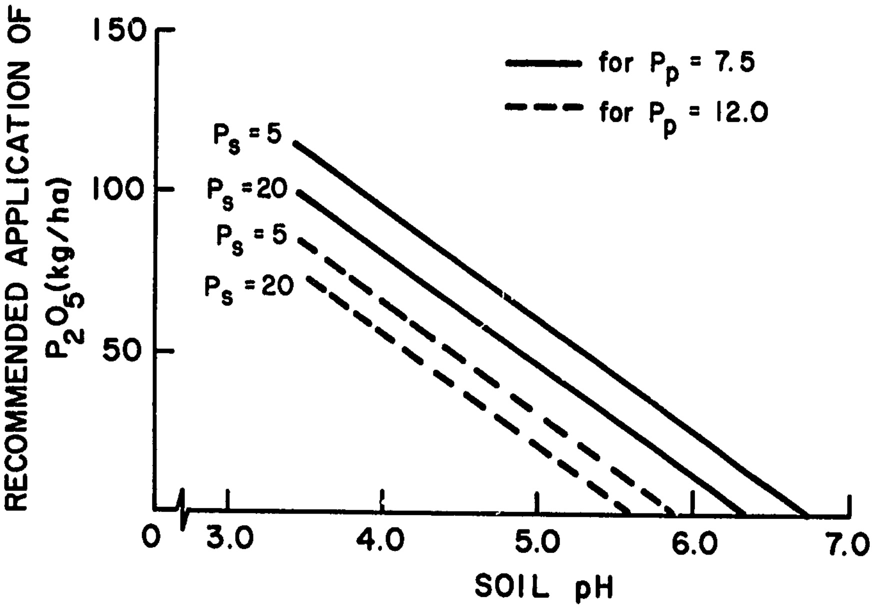
[1] The response curves are drawn with variables set at the following levels; PS = 13.24, KS = 85.68, KA = 0.0, pH as indicated, and PA = 74 for the nitrogen response curves and NA = 128 for the phosphorus response curves.





Figures 39 and 40. Nitrogen (top) and phosphorus (bottom) recommendation charts for corn in Minas Gerais.

The recommendations can be more easily understood in the graphic formats of Figs. 39 and 40. Here we show the recommendations appropriate for various soil tests for P_N at 6.8 and 10 and P_p at 7.5 and 12[2].

Fig. 39 shows nitrogen recommendations for two price levels, as a function of soil pH. For a price ratio of 10, nitrogen response is not sufficient to be profitable unless the soil pH is at least 4.9. For the average soil test in the experiments analyzed (pH = 5.28), the recommendation should be 40 kg for the higher price ratio, or 128 kg for the lower price ratio. This indicates, whether we like it or not, that the desirability of nitrogen application to these soils is highly sensitive to both soil pH and expected prices. For the lower price ratio, the net returns to the optimum amount (213 kg) of nitrogen fertilizer on a soil with pH = 6.0 are Cr $ 233 per ha, 27% of the value of the crop with no fertilizer.

Figure 40 shows the relationships between phosphate recommendations and soil tests, for two price ratios. Recommendations for soils with as little as 5 ppm P and as much as 20 ppm P differ by only 11 kg per hectare, illustrating the point previously mentioned, that soil P has only a negligible effect on phosphorus response. The two upper curves are for a price ratio of 7.5 and indicate that at this price ratio, phosphate application is not profitable unless pH is less than about 6.5. For the higher price ratios, phosphate application is not profitable unless pH is below approximately 5.7, and the amounts are not large in this case. As was the case for nitrogen, the desirability of phosphate application is very sensitive to soil pH and prices. For the lower price ratio, PS = 5 and a pH of 5.0, the net returns to the optimum amount of phosphate (58 kgs/ha) is Cr $ 210 about 20% of the value of the crop with no fertilizer. It appears then that returns to both phosphate and nitrogen are indeed significant where soil tests warrant their use.

These results suggest that soil phosphorus and potassium tests provide very little information of value in making fertilizer recommendations, while the soil pH is an extremely valuable piece of information.

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[2] Base prices are: corn Cr $ 0.28/kg, nitrogen Cr $ 1.90, phosphate Cr $ 2.10/kg. These prices imply P_N =6.8 and P_p = 7.5. The higher values of 10 and 12 are approximately 50% higher, which has been suggested to be more appropriate in view of uncertainties about both prices and yields.

Table 51. Generalized quadratic response function estimated for the analytical subset[a] of the Minas Gerais corn experiments.

Variable number and description	units	average value	Regression coefficient[b]
1. intercept[c]	kgs/ha	--	23,302
2. applied N, (NA)	kgs/ha	74.67	-11.52 (-0.85)
3. applied P_2O_5, (PA)	kgs/ha	68.62	48.49 (3.48)**
4. applied K_2O, (KA)	kgs/ha	33.49	- 1.12 (-0.10)
5. soil P, (PS)	ppm	13.24	6.67 (0.18)
6. soil K, (KS)	ppm	85.68	73.39 (6.56)**
7. pH, (PH)	standard	5.28	-8515.18 (-1.51)
8. $(NA)^2$			-0.0181 (-2.90)**
9. $(PA)^2$			-0.0869 (-3.17)**
10. $(KA)^2$			0.0042 (0.03)
11. $(PS)^2$			0.0460 (0.12)
12. $(KS)^2$			-0.1953 (-3.64)**
13. $(pH)^2$			721.5745 (1.36)
14. (NA) (PA)			-0.0023 (-0.12)
15. (NA) (KA)			-0.0139 (-0.33)
16. (PA) (KA)			0.0794 (1.83)*
17. (NA) (PH)			4.3470 (1.75)*
18. (PA) (PS)			-0.1302 (-2.29)*
19. (KA) (KS)			-0.0420 (0.89)
20. (PA) (PH)			-6.0331 (-2.36)**

$R^2 = 0.65$, $\bar{Y} = 4022$, std. error = 1190

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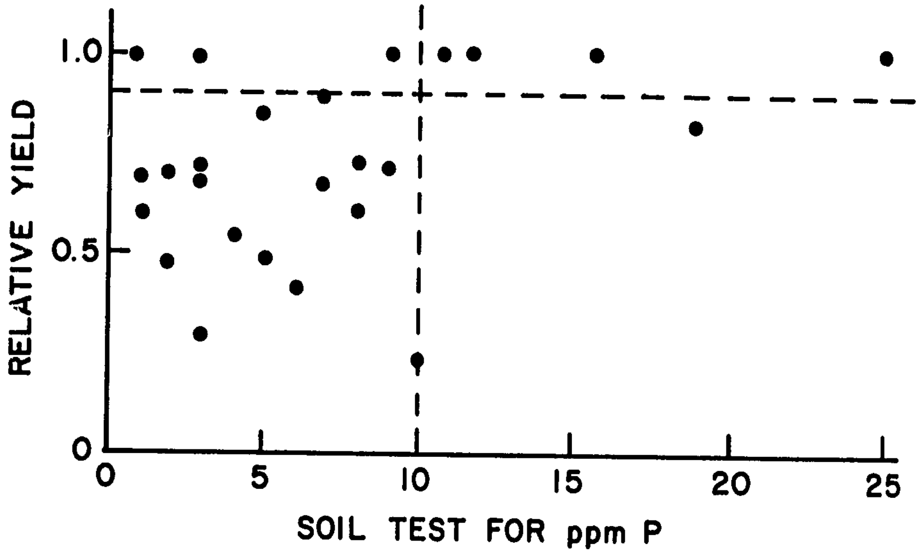
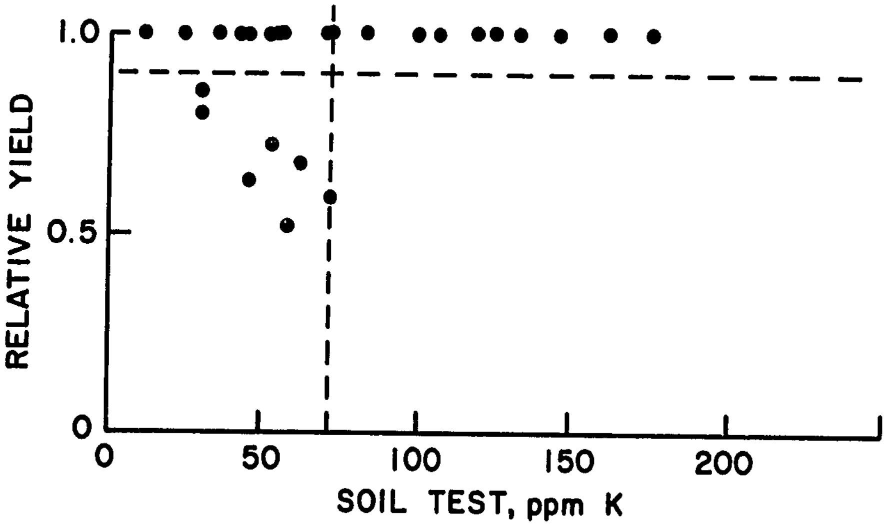
[a] a total of 26 experiments (5 of the 31 experiments in the analytical subset had no soil tests).

[b] numbers in parentheses are t-values, with * and ** indicating significance at .10 and .01 levels, respectively.

[c] including average value of dummy variables for municipios.





Figures 41 and 42. Determination of critical levels of soil phosphorus (top) and potassium (bottom) for corn in Minas Gerais using the Cate-Nelson technique.

Since space precludes presentation of the 93 LRP's fit to the analytical subset of experiments (3 nutrients times 31 experiments), a summary of results will have to suffice. Twenty-five of the 31 experiments showed a response to nitrogen, with an average nitrogen "requirement" of 95 kgs/ha. (a range of 60 to 125). Nineteen showed a response to phosphate, with an average requirement of 73 kgs/ha (a range of 50 to 120). Only nine of the 31 experiments showed a response to potash, with average of 37 kgs/ha (range 30 to 60).

Cate-Nelson plots of relative yields and soil tests are shown (for the 26 experiments with soil tests)[3/] in Figs. 41 and 42. The graphic Cate-Nelson procedure for estimating critical levels leads to estimated critical levels of 10 for P and 70 for K, although the K determination is not very pleasing because of the large number of experiments below the critical level but with relative yields of 1.00. Use of the Cate procedure available in the SAS computer system resulted in identical determinations of critical levels.

Figure 43 shows the plots of average yields for each treatment for all 31 experiments pooled. The problem of basically different yield levels for the experiments with different experimental designs is clearly revealed here. The lower yields (for N treatments 80 & 160 and P_2O_5 treatments 50 & 100) occurred on the ANDA/BNDE/VIÇOSA experiments while the higher yields (for other treatments) occurred on the ANDA/BNDE/IPEACO experiments. The composite LRP's were determined in the manner described above, by averaging the results of those individual experiment LRP's with significant response. Figures 44 and 45 show the phosphate LRP's when the experiments are pooled into those with soil tests above 10 and those with soils less than or equal to 10. Figures 46 and 47 show potash LRP's for soils above and below the potassium critical level of 70.

The LRP equations for all cases are shown in Table 52. Since none of the analyses showed a response to potash, the potash results need not be discussed.

It is interesting to note the effect of partitioning soils into those above and below the critical level of soil phosphorus. Of the 19 experiments showing phosphate response, 17 were in the low soil phosphorus group and only two were in the high soil phosphorus group.

[3/] One of the experiments showed a soil P test of 81, and is not included in the plot.

Table 52. Linear response and plateau functions.

Nutrient and soil grouping	Composite LRP's estimated from graphic LRP's for each experiment			
	threshold	slope	nutrient requirement	plateau
(1) nitrogen: all soils	2954	20.38	95	4890
(2) phosphate: all soils	3003	23.67	73	4724
(3) P $\leq$ 10	2817	25.00	73	4641
(4) P $\geq$ 10	4267	0	0	4267
(5) Potash: all soils	4550	0	0	4550
(6) K $\leq$ 70	4465	0	0	4465
(7) K > 70	4711	0	0	4711

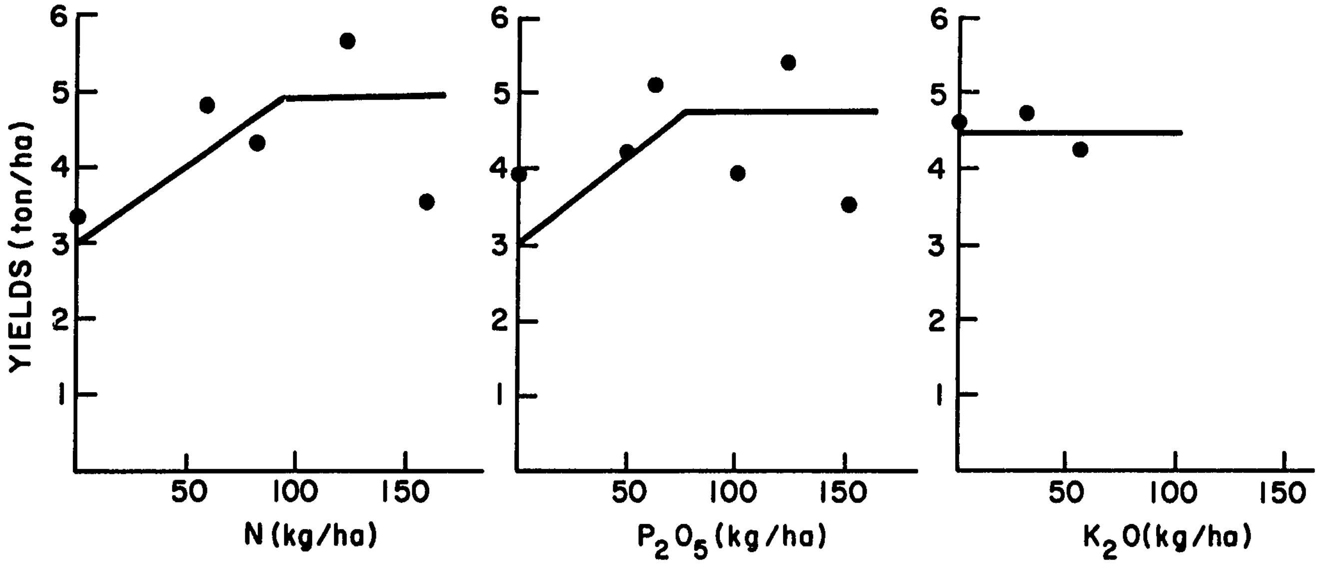


Figure 43. Pooled LRP responses for 31 experiments.

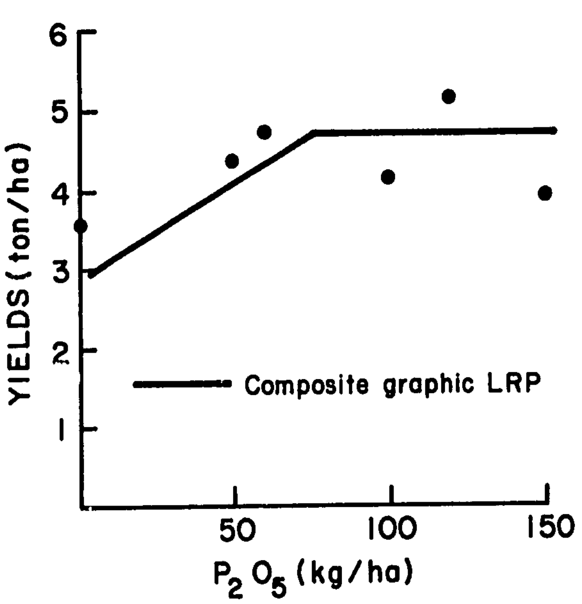


Figure 44. Phosphorus LRP response for soils with P ≤ 10 ppm.

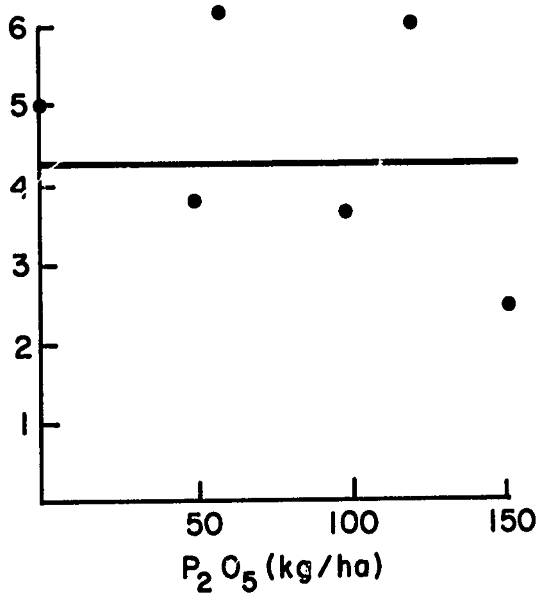


Figure 45. Phosphorus LRP response for soils with P > 10 ppm.

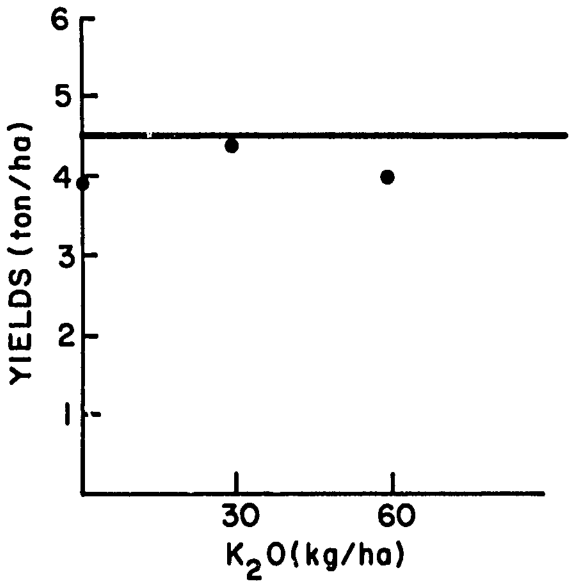


Figure 46. Potash LRP response for soils with K ≤ 70 ppm.

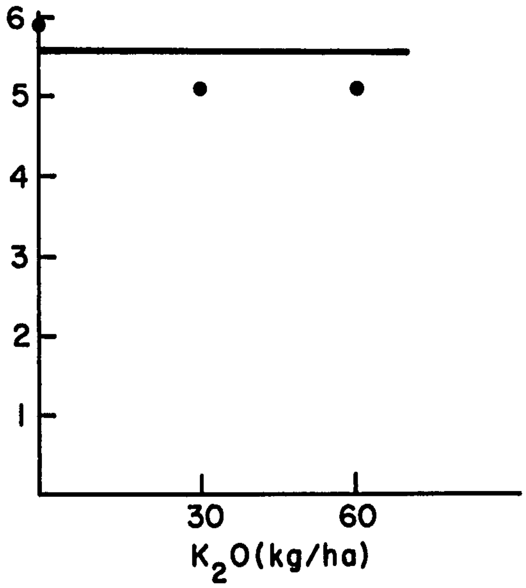


Figure 47. Potassium LRP response for soils with K > 70 ppm.

Thus when the experiments are partitioned, the LRP for the low soils is essentially the same as that for the average of all soils. On the other hand, only 2 of the 6 experiments on high phosphorus soils showed response, so the estimated LRP for this group shows no response.

Given the estimated response functions of Table 51 and 52, blanket recommendations can be derived by rising the "all soil" LRP's and by inserting average soil test values into the GQRF. Alternatively, recommendations can be tailored by using the soil test values (a) to select the appropriate LRP, and (b) as variables in the GQRF.

To compare the profitability of the predictions from the alternative approaches, each of the functions were used to predict the net returns from each treatment in the evaluation subset of 30 experiments.[4] For each experiment, the treatment with the highest predicted net returns is the recommended treatment. The actual net revenue realized on that treatment is the figure of interest, since it is the return which a producer would have realized had he followed the recommendation.

The results for the four analytical approaches on the 30 experiments are shown in Table 53. In the first experiment, for instance, the graphic LRP (without soil test) predicted that the 80-0-30 treatment would be the most profitable of the seven treatments in the experiment, and this in fact turned out to be the case, with a realized net return to fertilizer of Cr $ 656 per hectare. If the treatment recommended by the GQRF's had been followed (160-50-30), a net return of only Cr $ 535 would have been realized, etc.

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[4] The functions whose parameters are shown in Tables 51 and 52 were used to predict yields for the levels of N, P, and K used in a given treatment. Net returns is the value of this production minus the cost of the fertilizer. With the price of corn, Cr $ 0.28, price of N Cr $ 1.90, price of P_2O_5 Cr $ 2.10, and price of K_2O Cr $ 0.90, To determine blanket recommendations, the GQRF of Table 51 was used with average values of the soil tests, while the linear response and plateau functions numbered (1), (2), and (5) of Table 52 were used. In the "with soil test" predictions, soil test values for each experiment were used in the GQRF and to determine whether the LRP's (3) vs. (4) and (6) vs. (7) were to be used. The yield predictions for the LRP's were determined as the minimum predicted yield from among the N, P, and K curves. That is, if the P treatment is adequate to reach the plateau of, say, 4724 kgs/ha, while the N treatment is adequate only for a yield of 4,000 on the linear response portion of the N curve, the predicted yield for the plot is 4,000 kg/ha.

The average (over the 28 experiments with soil tests) net returns for each of the analytical approaches are shown on the last line of Table 53 and in the first column of Table 54. The analytical approach which resulted in the highest average net returns of Cr $ 1118/ha, is the graphic LRP with no soil test. Recall that this was derived as the average composite of all the LRP's for the 31 experiments in the analytical subset of experiments--without regard to critical levels. The second highest returns of Cr $ 1109, were obtained on the treatments recommended by the GQRF, using soil tests. The ranking of the various approaches is clear from the first column of Table 54, with the lowest average return of Cr $ 924 being realized on the graphic LRP's with soil test. The second column of Table 54 shows the results of a similar analysis of the 31 experiments in the analytical subset of experiments, though these figures are not as interesting as forecasts as are those from the evaluation experiments.

A t-test can be used in the following manner to test whether the net returns from the various approaches are really different from each other. Assume that the difference between net returns from approach i and from approach j is a random variable with mean δ_{ij}, and that the 28 experiments represent 28 drawings from this population. A t-test applied to these 28 differences can be used to test the hypothesis that $\delta_{ij} = 0$. As shown in Table 54, very few of the adjacently-ranked approaches differed by amounts that were significant in this sense. In fact, few if <u>any</u>, of the paired differences were significantly different from zero. In other words, given the variability from experiment to experiment of the difference between the returns for any two recommendations, differences as extreme as those shown in Table 54 would occur at least once in twenty times, even if the average difference were zero. Even so, the results shown are our best available estimates of the returns which farmers would realize if they followed the various recommendations.

Several aspects of Table 54 are worthy of comment. Primary emphasis should be given to the results in column one, since the true test of the predictive ability of a model is its ability to predict <u>outside</u> the data set from which it was estimated. The GQRF models predict as well as, if not better, than the LRP models, despite some probably upward bias in the estimates of optimum levels due to the quadratic characteristics. The graphic LRP with soil tests and critical levels results in the highest net returns, while the graphic LRP ignoring

Table 53. Net returns[a] to recommended treatments on 30 experiments.

Experiment		Most profitable treatment[b]		GQRF				Graphic LRP			
				with soil test		without soil test		Overall		by critical level	
Year	Area	N-P	Returns	N-P	Returns	N-P	Returns	N-P	Returns	N-P	Returns
67	540	80-0	656	160-50	535	160-50	535	80-0	656	80-100	250
67	46	80-0	1426	100-50	1039	160-50	1039	80-100	1244	80-100	1244
67	685	160-50	1310	160-50	1310	160-50	1310	80-100	1045	80-100	1045
67	657	80-50	1358	160-50	773	160-50	773	80-0	572	80-100	1314
67	23	80-50	1574	160-50	1095	160-50	1095	80-0	1454	80-100	950
67	868	160-50	395	160-50	395	160-50	395	80-100	75	80-100	75
67	327	80-0	1233	160-50	1100	160-50	1100	80-0	1233	80-100	1041
67	394	80-100	2518	80-100	2518	160-50	1879	80-0	1958	80-100	2518
67	713	80-50	1248	160-50	913	160-50	913	80-100	924	80-100	924
68	713	160-50	1077	160-50	1077	160-50	1077	160-0	840	80-50	566
68	153	160-100	1453	160-50	480	160-50	480	160-0	879	160-100	1453
68	699	0-0	1010	160-50	459	160-50	459	160-100	70	160-100	70
68	558	160-0	1626	160-100	1276	160-50	1180	160-0	1626	160-100	1276
68	46	160-100	1691	160-50	956	160-50	956	160-100	1691	160-100	1691
69	685	160-150	1693	160-100	1125	160-50	1174	160-0	937	160-100	1125
69	638	160-50	1236	*	*	160-50	1236	*	*	160-100	1187
69	713	160-100	1727	160-100	1727	160-50	1534	160-0	861	160-100	1727
69	549	160-0	1756	160-50	977	160-50	977	160-100	1040	160-100	1040
69	657	0-0	1105	*	*	160-50	510	*	*	160-100	872
69	134	160-50	420	80-150	121	160-50	420	160-0	-13	160-100	295
67	480	60-0	2709	120-0	2306	120-60	2600	60-60	2357	120-60	2600
67	367	60-120	1942	60-120	1942	120-60	1142	120-0	742	120-60	1142
67	480	120-60	1564	120-0	1158	120-60	1564	60-60	761	120-60	1564
67	283	60-60	2133	120-60	1508	120-60	1508	120-0	1102	120-60	1508
67	287	60-120	636	120-60	388	120-60	388	120-0	598	120-60	388
68	480	120-0	1404	120-60	1368	120-60	1368	60-60	1069	120-60	1368
68	367	60-60	833	60-120	609	120-60	178	120-0	-87	120-60	178
69	480	120-0	1797	120-60	1496	120-60	1496	60-60	1223	120-60	1496
69	479	120-120	2204	120-60	1447	120-60	1447	120-0	640	130-60	1447
69	196	120-60	1390	60-60	943	120-60	997	120-0	383	120-60	997
Av. of 28 with soil tests:			1460		1109		1071		924		1118

[a] calculated with the following prices: corn Cr. $0.28/kg; nitrogen Cr. $1.08/kg; phosphate Cr. $2.10/kg; potash Cr. $0.90/kg.

[b] potassium levels of the various treatments are not shown, since there was little or no response to K_2O.

* no soil test included for this experiment.

Table 54. Ranking of recommendation procedures based on profitability of predictions.

Analytical approach	Average net returns to recommended treatments Evaluation subset of experiments[a]	Analytical subset of experiments[b]
	Cr. $/ha	
Actual best treatment	1459.75 (1)*	1185.65 (1)*
Graphic LRP, with soil test	1117.57 (2)	829.69 (4)
GQRF, with soil test	1109.32 (3)	822.88 (5)*
GQRF, with no soil test	1070.86 (4)*	879.62 (3)*
Graphic LRP, no soil test	924.29 (7)	696.50 (7)

[a] calculated for 28 experiments with complete soil tests.

[b] calculated for 26 experiments with complete soil tests.

*t-test on paired observations indicates these returns are significantly higher (5 percent level) than returns from the next-ranking approach.

Table 55. Multiple correlation for GQRF functions at various levels of aggregation.

Aggregation set	R^2
Soils with $P \leq 10$	0.57
Soils with $P > 10$	0.84
Vicosa data	0.60
IPEACO data	0.73
Pooled	0.66

soil tests result in the lowest net returns of the group. From this set of data we must conclude that if this approach is to be used in Minas Gerais corn, soil test information is of significant value in making recommendations to farmers. The GQRF approach resulted in Cr $ 38 /ha higher returns when soil test information was utilized, as compared to the blanket GQRF recommendations. This difference, however, is not statistically significant.

At the suggestion of Brazilian soil scientists who reviewed this study, the project predictability criterion was utilized on these same data to test the desirability of disaggregating the data. The 30 experiments in the evaluation subset were separated into the Viçosa experiments and the IPEACO experiments, which were conducted in different areas of the state and employed different experimental designs. The GQRF was then estimated for each group separately. The 30 experiments were then separated into those with $P \leq 10$ and those with $P > 10$, and the GQRF was estimated for these groups separately. The R^2 for each of these regressions is shown in Table 55, along with the R^2 for the original pooled regression. It is not clear that either of the classification schemes enhanced R^2, on the average.

The four new GQRF's were then utilized to predict the most profitable treatments in the corresponding subgroups of the evaluation subset of experiments. The average net returns from these four GQRF's are presented in Table 56, along with the returns for the aggregate GQRF and the LRP's, for comparison. The net returns for the disaggregated GQRF on soils with $P \leq 10.0$ was Cr $ 943, compared to Cr $ 1098 for recommendations from the aggregate GQRF, and Cr $ 1069 for the LRP. The returns on soils with $P > 10.0$ was no better. In this case, we conclude that farmers will earn more using our recommendations if we aggregate the data rather than disaggregate by soil test.

The net returns for the disaggregated GQRF for the Viçosa experiments was Cr $ 1033 compared to Cr $ 1045 for the aggregate GQRF. (The returns to the LRP functions were not claculated by geographic grouping.) The disaggregated GQRF also performed worse than the aggregated GQRF on the IPEACO data. Complete pooling of the data for GQRF analysis results in Cr $ 57 per hectare greater returns than if the response data were disaggregated by area, and Cr $ 145 per hectare greater average returns than if the data were disaggregated by soil test level. We are forced to conclude that it is <u>not</u> necessarily desirable to group soils into homogeneous classifications in order to analyze fertilizer response. The implications of this conclusion are that it may be desirable to formulate recommendations to cover a more heterogeneous range of soils than was previously thought possible.

CORN AND RICE RESPONSE IN COSTA RICA

Response data from nine corn experiments and 11 rice experiments in Costa Rica were provided by Ing. Alvaro Cordero, with the cooperation of other researchers in the Ministry of Agriculture. The number of experiments for these crops is not sufficient to provide analytical and evaluation subsets, so the entire sets of experiments were used for both purposes. The analyses reported below should be considered only preliminary, because additional weather data has been received but not yet incorporated into the quadratic functions. Therefore, the response estimates are not reported in detail.

The LRP analyses of corn response indicated a critical level for soil P of 4.5 ppm, and for K, 155 ppm. The estimated GQRF coefficients, however, suggested that there was little relationship between soil tests and nutrient response. In prediction, however, the use of soil test information with the GQRF resulted in average returns 10% higher ($25/ha) than without soil test information, whereas the use of the soil test information with the LRP resulted in a slight reduction of net return (Table 57). With or without soil tests, the GQRF resulted in higher net returns than did the LRP, but the difference was not tested for statistical significance.

The LRP analysis of the Costa Rica rice data indicated no critical levels and no response for either phosphate or potash, and a nitrogen recommendation of 66 kgs per ha. The GQRF recommendations were slightly higher for N, but there was also significant phosphorus response in the case of low soil phosphorus. Table 57 shows the profitability of the recommended treatments. The GQRF with soil test information resulted in 5% higher returns than the GQRF with no soil test information. As in the case of Costa Rica corn, these differences were not tested for statistical significance.

Table 56. Average net returns from treatments recommended by disaggregated GQRF functions, compared to graphic LRP and aggregate GQRF functions.

Subgroup of evaluation subset	Disaggregate GQRF's by soil phosphorus	Disaggregate GQRF's by area	Aggregate GQRF	Graphic LRP
	(Cruzeiros per hectare)			
P ≤ 10.0	943	--	1098	1069
P > 10.0	996	--	1135	1192
Vicosa	--	1033	1045	?
IPEACO	--	1088	1225	?
All	964	1052	1109	1117

Table 57. Average net returns per hectare for treatments recommended by alternative analytical models[a]/

	Costa Rica Corn	Costa Rica Rice
Number of experiments	9	11
Average net returns from the ex-post best treatment	$308	$620
Average net returns from recommended treatments, with soil tests:		
LRP model, graphic estimates:	$254	b
GQRF Model:	$276	$595
Average net returns from recommended treatments, ignoring soil tests:		
LRP model, graphic estimates:	$263	$567
GQRF Model:	$250	$584

[b] Cate-Nelson correlation of soil tests and relative yields failed to reveal any critical level of soil P or soil K for Costa Rica rice. Hence the LRP models made no use of soil test information.

[a] Prices used were: corn -- $0.092/kg; rice - $0.18/kg; nitrogen - $0.42/kg; phosphate - $0.42/kg; potash - $0.12/kg.

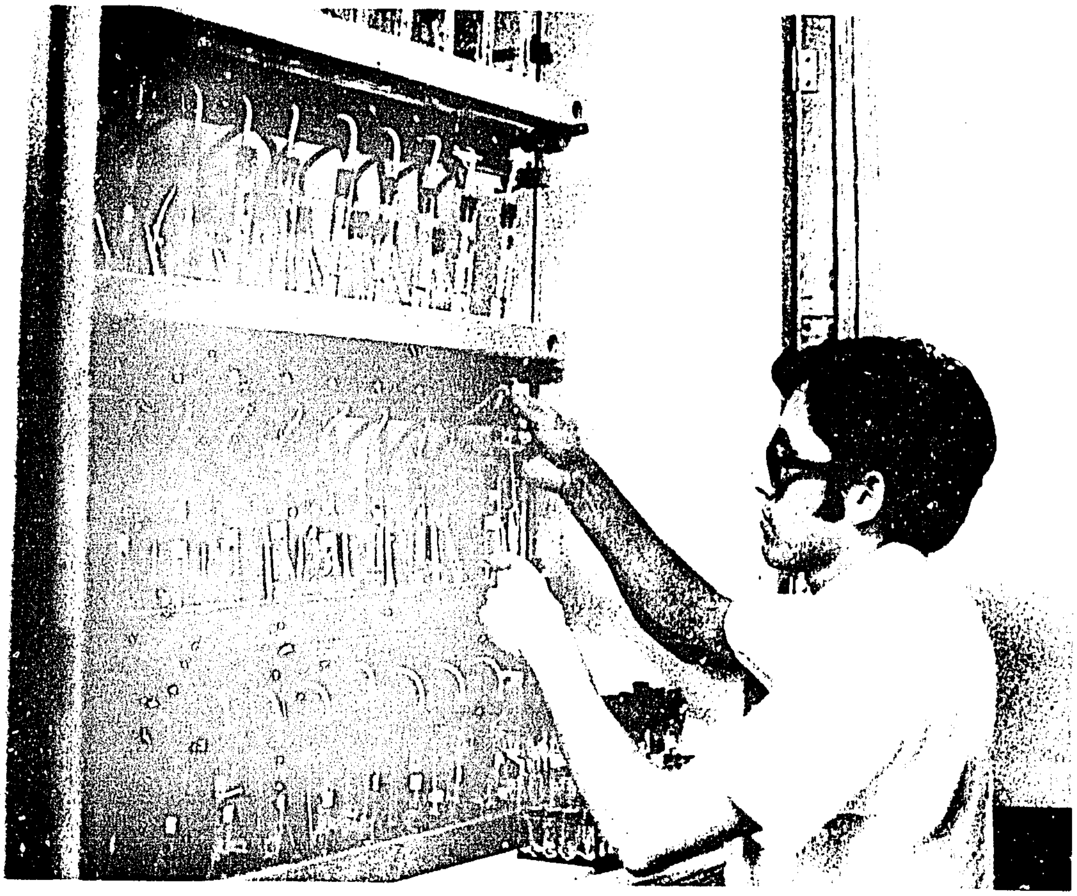
ECONOMIC EVALUATION OF THE FERTILITY CAPABILITY SOIL CLASSIFICATION SYSTEM

The Fertility Capability Soil Classification System (FCSCS) is designed to identify soils which may be grouped together for fertility management purposes. An economic question pertinent to the evaluation of the FCSCS is whether fertilizer recommendations based on FCSCS soil groups result in higher average farmer profits than recommendations based on the same experimental data without benefit of the FCSCS groupings.

A preliminary answer to the above question has been provided by an analysis of 73 field experiments on potato fertilization in the Sierra of Peru. The sites classified into the groups shown in Table 49 of the previous chapter, and statistical tests showed that the responses for soils in various groups were indeed different from group to group.

When soils were grouped and recommendations were based on the grouped analyses, the average prediction of net revenue was $195 per hectare higher than for recommendations based on an analysis of soils in which the soil groupings were not employed. We stress that this is a difference in <u>predictions</u> of net revenues, rather than realized net revenues. Further analysis is being conducted to determine the <u>ex post</u> profitability of recommendations with and without the soil classification.

CAMPUS-BASED SOIL STUDIES



Mr. Fernando Munevar from Colombia, studying factors affecting organic matter mineralization in volcanic ash soils.

Several projects were conducted primarily in Raleigh, using samples collected from Latin America and elsewhere to provide answers to more specific questions. These include five projects on soil characterization, one on soil microbiology, and three on soil chemistry-fertility.

SOIL CHARACTERIZATION STUDIES

One of the main objectives of this research contract is to adequately characterize soils from tropical areas where such information is limited. The largest activities in this area have been already reported in the Campo Cerrado and Amazon Jungle sections of this report. In addition, there are soils from other areas which have been characterized with emphasis on their relationships in the landscape. During this year, studies have been made in western São Paulo State in Brazil, central Costa Rica, the Llanos Orientales of Colombia, and the Maracaibo Basin of Venezuela.

All these studies received partial support from this research contract and from the institutions sponsoring the graduate students involved.

Oxisol - Ultisol Toposequence in Western São Paulo

Oxisols and Ultisols are often found in close association in well drained areas of the humid tropics. Characteristics of both oxic and argillic horizons frequently occur in the same profile. In order to determine the landscape relationships and therefore the predictability of occurrence four profiles were studied along a 550 m toposequence in the Municipality of Rio Claro. Three geomorphic surfaces were identified in the sampling site. Profile 1 located in the Middle Plieistocene surface is a Typic Haplorthox (Latosol Vermelho Escuro Ortho). Slightly down slope the organic matter increases and Profile 2 classified as a Typic Umbriorthox. Profile 3 further down the slope is an Oxisol-Ultisol intergrade (Orthoxic Palehumult). Profiles 2 and 3 are located in the same surface at 5% slopes. The fourth profile is located at the third surface at undershade. It is classified as a Typic Paleudult. These relationships are illustrated in Fig. 48. The genesis of these soils appears to be controlled mostly by the age of the geomorphic surfaces and by the nature of the parent material. Oxisols cover the most stable surfaces and Ultisols the less stable ones. This information confirms similar relationships observed elsewhere in the tropics.

A paper with the complete results has been approved for publication at the Soil Science Society of America Proceedings. Further studies are in process at about 220 km northwest of Campinas to explore similar relationships between Oxisols, Ultisols, and Alfisols.

Andept Toposequence in Costa Rica

Mr. Alvarado and Dr. Buol sampled three profiles representing the near level hilltop, steeply sloping and depressional topographic positions in Andepts located on a saddle between the Barba and Irazu volcanoes in central Costa Rica. These sites and the characterizations were selected to determine the degree of variation encountered in a volcanic ash parent material areas. This study is nearing completion and it can be seen from the following data (Table 58) that topographic variations related to soil development less direct than usually found in other soil areas. This is thought to be due to the youthfulness of the area and the repeated recent ash deposits.

One of the very practical aspects of the study is the comparison of analytical techniques employed on the Andept soils. It should serve as a useful tool in comparing much of the existing data presented by various scientists that employed different analytical techniques.

The study has also provided critical data needed to distinguish spodic horizon in volcanic ash derived soils. Detailed mineralogical studies are being made for inclusions in the final report.

Toposequence in the Llanos Orientales of Colombia

Mr. Leonidas Mejia has sampled and described nine soil profiles in a transect across a shallow depression ("Esteros") at Carimagua, Colombia. Open wells have been installed along the same transit and the water table flucuations will be monitored through the years by Colombian soil scientists. The samples have been divided between the Instituto Geografico's laboratories at Bogota for routine analysis and the Soil Science Department at NCSU for detailed analysis. The samples are presently being analyzed and no data is available.

Alfisol-Aridisol Characterization in the Maracaibo Basin of Venezuela

Mr. Ramon Parades has sampled nine profiles representing the climosequence of the Maracaibo Basin. These samples are presently en route and no data is available at this time.

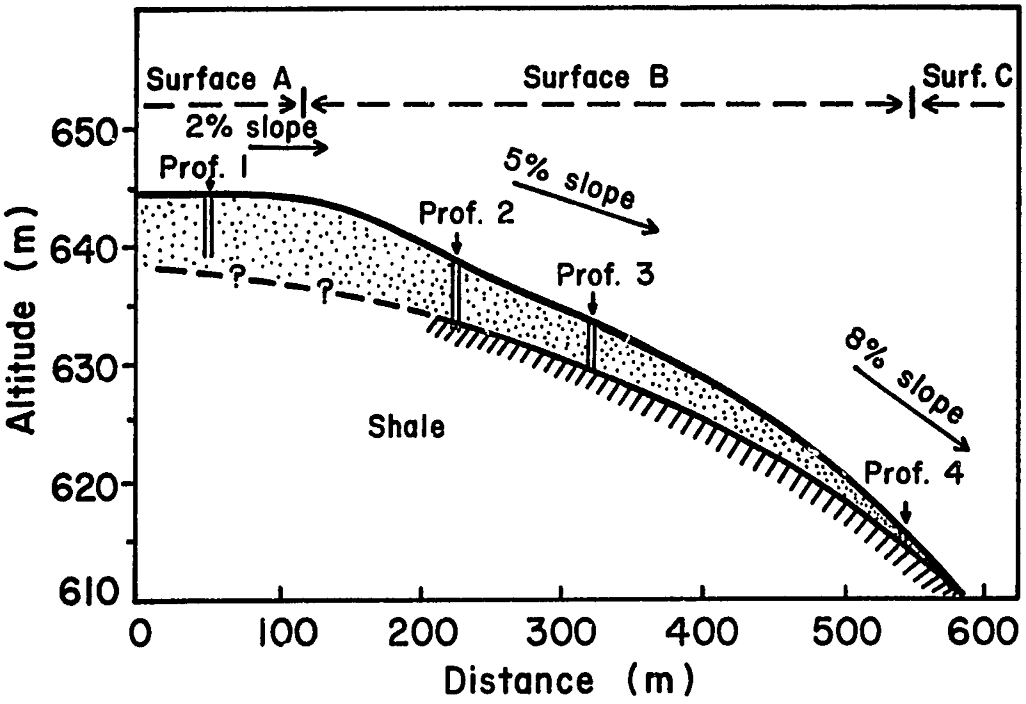


Figure 48. Oxisol-Ultisol toposequence in Western Sao Paulo State, Brazil.

Table 58. Selected properties of three Costa Rican andepts in a toposequence.

Horizon and depth		pH	pH	OM	CEC (sum)	Bulk density	H_2O at 15 bars	Olsen P
	cm	H_2O	NaF	%	meq/100g	g/cc	%	ppm
Profile 1. At 1500m on a flat area. Dystrandept. Fertility-capability: Lhx								
A1	0-25	5.7	10.4	15.8	10.1	1.02	42	3
B1	90-130	6.1	10.3	2.0	3.5	0.97	32	0
B2	130-200	6.1	10.5	1.5	5.8	1.13	45	0
Profile 2. At 1450m, conclave slope. Dystrandept. Fertility-capability: Lhx								
A1	0-24	5.5	10.3	17.4	6.8	1.02	44	6
B1	90-115	6.1	10.7	5.5	4.5	0.79	32	3
CIII	115-200	6.1	10.7	1.6	4.3	0.80	43	6
Profile 3. At 1420m, 20% slope. Dystrandept. Fertility-capability: Lhx								
A1	0-30	5.3	9.5	14.2	11.4	1.10	41	6
A3	80-130	6.1	10.2	5.9	5.9	0.70	39	5
B2	140-210	6.0	8.6	9.6	9.6	1.24	43	6

Charge Characteristics of Soils High in Oxides

Dr. S. B. Weed has studies in progress to investigate charge characteristics of soil clays as related to content of hydrous iron and aluminum oxides and amorphous constituents. Comparisons are to be made of soils of the Southeastern United States exhibiting a wide range in content of these constituents and selected tropical soils. Special measurements include determination of zero point of charge and phosphate adsorption isotherms. Studies of the North American soils are nearing completion; the tropical soil materials are being prepared for study.

FACTORS AFFECTING THE RATE OF ORGANIC MATTER MINERALIZATION IN VOLCANIC ASH SOILS OF COLOMBIA

Objectives and Design

Soils derived from volcanic ash having significant amounts of amorphous minerals in the clay fraction are found covering about 20% of the area of Colombia. They are also quite extensive in Central America, the Andean Highlands, and the Caribbean. These soils have very low levels of available nitrogen in spite of their generally high organic matter contents and low C/N ratios. It is generally believed that the rates of nitrogen mineralization are very low in such soils. In view of the economic limitations associated with the applications of fertilizer nitrogen, an understanding of the factors limiting the rate of N mineralization is not only desirable but essential for increasing plant yields on these soils. The objective of this project was to determine what factors are responsible for the stability of organic matter in volcanic ash soils. Mr. Fernando Munevar and Dr. Arthur Wollum have been in charge of the following project.

A number of hypotheses have been suggested to explain the stability of organic matter in volcanic ash soils. However, it is widely accepted that the lack of a suitable energy source for microbial growth is the causative factor for the low mineralization rates previously observed. Based on our preliminary experiments, this hypothesis is difficult to accept. Thus we have formulated the following hypothesis: The level of phosphorus available for microbial growth is the rate limiting factor in volcanic soils which governs the stability of organic matter. The formulation of this hypothesis was based on three observations: (1) the low levels of available phosphorus found in volcanic soils along with the high phosphorus fixation capacity, (2) the increased carbon mineralization due to additions of phosphorus observed in Chile, and (3) the apparent correlation between soil-test phosphorus and mineralized nitrogen as inferred from the data presented by Benavides in Colombia.

In order to test these hypotheses, thirteen top-soil samples were collected from three regions in Colombia, i.e. Antioquía, Pasto-Nariño, and Cundinamarca. Ten are Andepts and the other three belong to andic subgroups of Inceptisols. The following chemical analyses have been completed: pH in water, KCl, and 1 N NaF (as an indication of amorphous materials), exchangeable aluminum, available phosphorus, and organic, ammonium, nitrate, and nitrate-N.

Aerobic, constant temperature incubation experiments have been conducted on 10 g soil samples amended with differing levels of glucose, a readily available energy source for microorganisms. After the desired incubation time, mineralization rates of K and N were determined.

Phosphorus adsorption curves have been determined by adding different concentrations of $Ca(H_2PO_4)_2$ and analyzing for available phosphorus after 14 days of incubation, by using the Bray II extracting solution (0.03 N NH_4F and 0.1 N HCl).

Results

The evolution of CO_2 and the changes in inorganic nitrogen were monitored throughout a 30 day incubation period. The amount of CO_2 evolved per unit of soil carbon (Table 59) seemed to be related to the amorphous content of the soils as determined by the NaF qualitative test. The Tibaitata soil which apparently has the least amount of amorphous materials gave greater amount of CO_2 for all the glucose levels than the other two soils which had less. In addition, the amount of evolved CO_2 was related to the amount of glucose added. This increased respiration could have been due either to an increase in the mineralization of organic matter or to the metabolism of the added glucose. However, additional experimentation is necessary to elucidate this point.

The relationship between mineral nitrogen and energy level (glucose rate) is showed in Table 60. For two soils, Le Ceja and Tibaitata, the additions of 100 ppm of glucose increased mineral N slightly during 30 days of incubation, whereas for Faca, the same amount of carbon reduced mineral N by a small amount. Subsequently, mineralized N decreased with increasing amounts of glucose. At the 10,000 ppm rate of glucose net immobilization was observed.

Table 59. Carbon dioxide evolution from Andepts ammended with different rates of glucose after 30 days of incubation.

	pH in	Glucose added (ppm)			
Soil	1:50 NaF	0	100	1000	10000
		mg $CO_2/_g$ soil C			
Faca	11.6	38	39	46	97
La Ceja	11.6	36	39	38	109
Tibaitata	9.6	41	48	55	173

Table 60. Nitrogen mineralized in three Andepts ammended with different rates of glucose after 30 days incubation.

	Glucose added (ppm)			
Soil	0	100	1000	10000
Faca	129	110	74	-45*
La Ceja	55	61	36	-100
Tibaitata	46	52	11	-30

* Negative values indicate net immobilization.

Based on these data, it does not appear that the addition of an energy source to these soils enhanced nitrogen mineralization. Additional experiments are being planned to verify this contention.

In order to determine the influence of additions of phosphorus on the rate of mineralization of organic matter, experiments are being conducted. Based on the P adsorption curves it was decided to use Faca and Cabrera soils, as representative of the types collected, ammended with P at the rates of 0, 400, 800, and 1200 ppm. Additional treatments to which 1000 ppm glucose were added along with 0 and 1200 ppm P were included to observe possible interactions between phosphorus and glucose. CO_2 evolution and nitrogen mineralization are being measured at different time intervals. A similar experiment will be conducted with limed soils. Phosphorus adsorption curves are being run for soils which have been ammended with the amount of $CaCO_3$ required to neutralize the exchangeable aluminum.

EFFECT OF LIME ON PHOSPHORUS FIXATION AND PLANT GROWTH IN OXISOLS AND ANDEPTS OF PANAMA

Laboratory studies were conducted by Mr. Jose Mendez-Lay and Dr. E. J. Kamprath with three Andepts and six Oxisols to determine their buffer capacity and phosphorus fixation. All of the soils were highly buffered, particularly at above pH 6. The practical implications are that very high rates of lime would be required to raise these soils to pH 7. The Oxisols had a range of 45 to 70 percent aluminum saturation while the Andepts had less than 10 percent aluminum saturation. The addition of lime at an equivalent rate of 1.5 time the exchangeable aluminum reduced the aluminum saturation to less than 20 percent and resulted in a pH of 5.5.

Fixation studies indicated that the volcanic ash soils fixed considerable higher amounts of phosphorus than did the Oxisols. Liming of soils to neutralize the exchangeable aluminum reduced the amount of phosphorus fixed by the Oxisols.

Greenhouse studies with millet as the test crop indicated that 18 ppm P extracted with the dilute double acid was the critical level above which no response to phosphorus was obtained. Neutralization of exchangeable aluminum by liming reduced by one-half the amount of added phosphorus required for maximum growth of millet.

A summary of the results appear in Table 61. The behavior of these Oxisols is quite similar to those obtained in the field at Brasilia. It seems reasonable to assume that the Brazilian results could be reasonably extrapolated to these Panamanian Oxisols.

Table 61. Effect of neutralization of exchangeable Al on the amount of fertilizer P required for maximum growth of millet on two Oxisols from Panama.

Dry location	pH	Lime	Exch. Al	Al Sat.	P added	Dry Matter
		kg/ha	meq/100g	%	ppm	g/pot
La Mesa	4.8	0	0.60	70	0	0.02
					230	0.59
					460	0.68
	5.5	600	0.25	20	0	0.04
					230	0.75
Pacora	5.0	0	3.00	65	0	0.04
					70	0.68
					140	0.82
	6.0	3000	0.35	9	0	0.06
					70	0.96

DIFFUSION: A MAJOR FACTOR IN THE AVAILABILITY OF PHOSPHORUS IN FLOODED SOILS

Objectives and Design

Phosphorus soils tests have almost without exception failed as a means of estimating phosphorus availability in flooded rice soils. After a Ford Foundation assignment in India, Mr. F. T. Turner, initiated a study to determine more precisely what are the factors affecting the availability of phosphorus in some tropical rice soils. It was thought that a better understanding of the process might clear the way for better soil tests. A series of studies were conducted in Raleigh under the direction of Dr. J. W. Gilliam.

To study the phosphorus supply characteristics of alkaline rice soils, several samples were collected from representative areas of the neutral to alkaline Vertisols from a major rice producing area of India and an alkaline soil representative of the Mollisols of the Peruvian coast. Soils from other areas of India, Peru, North Carolina, and Louisiana were included for comparison. Phosphorus adsorption by anion resin, measurement of the phosphorus supply factors (capacity, kinetic, intensity, and diffusivity), and evaluation of plant growth were the three approaches used to assess phosphorus supply of flooded rice soils.

Results

Phosphorus accumulated on an anion resin in stationary contact with soil to a greater extent in water-saturated soils than in moist soils. The enhanced phosphorus accumulation in water-saturated soils was not related to the release of phosphorus during soil anaerobioses as the phosphorus accumulation occurred prior to the reduction of soil iron (Fig. 49). The increased phosphorus accumulation in the water-saturated system was attributed to the improved diffusion brought about by a decrease in tortuosity.

Increased in the capacity, intensity, and kinetic factors as measured by E-value, solution P concentration and soil P release rate to a distilled water "sink", respectively, were unpronounced and infrequent upon water-saturation and concomitant anaerobiosis. In most

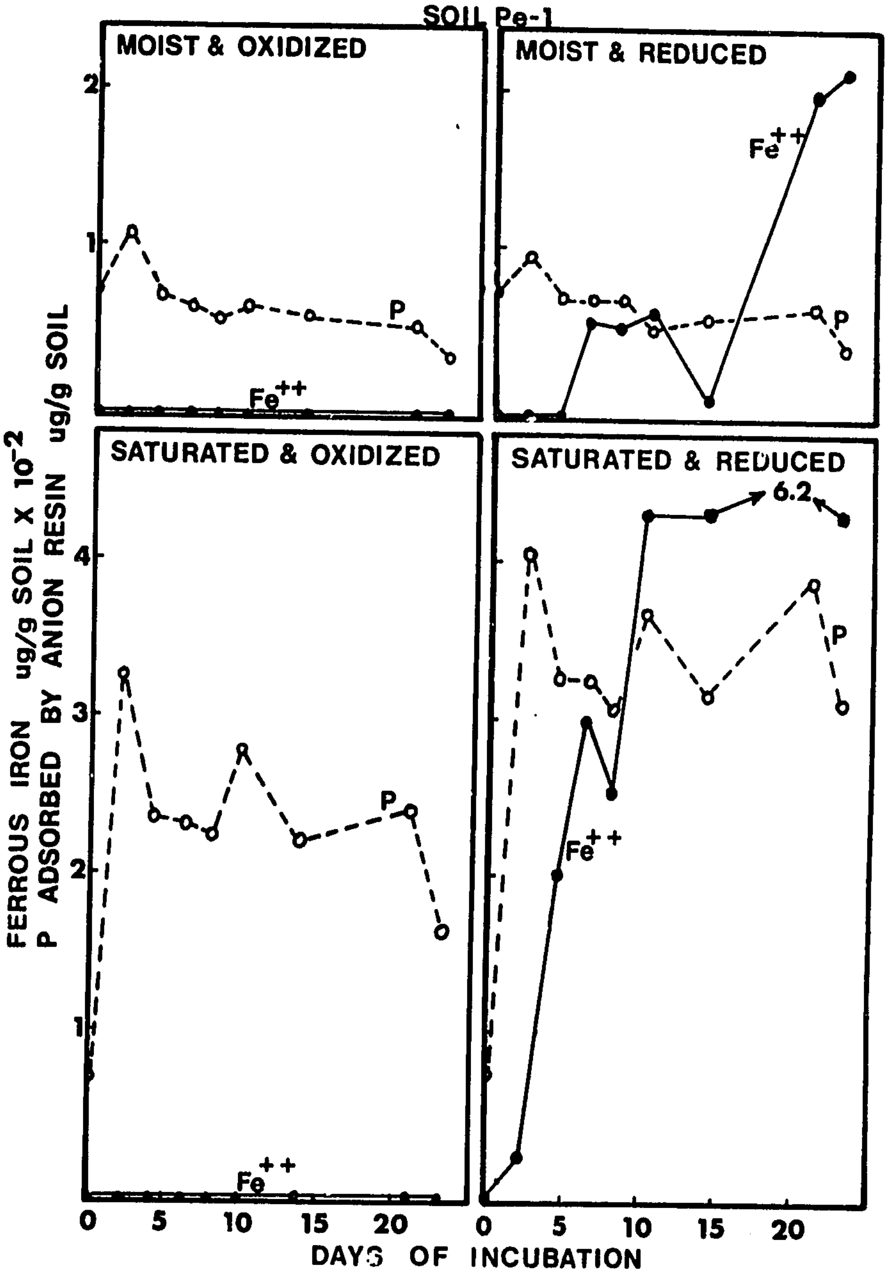


Figure 49. Effect of moisture and reducing conditions on anion resin absorbable P and ferrous iron in an alkaline Mollisol from Peru. Fertility-capability: Cgdb.

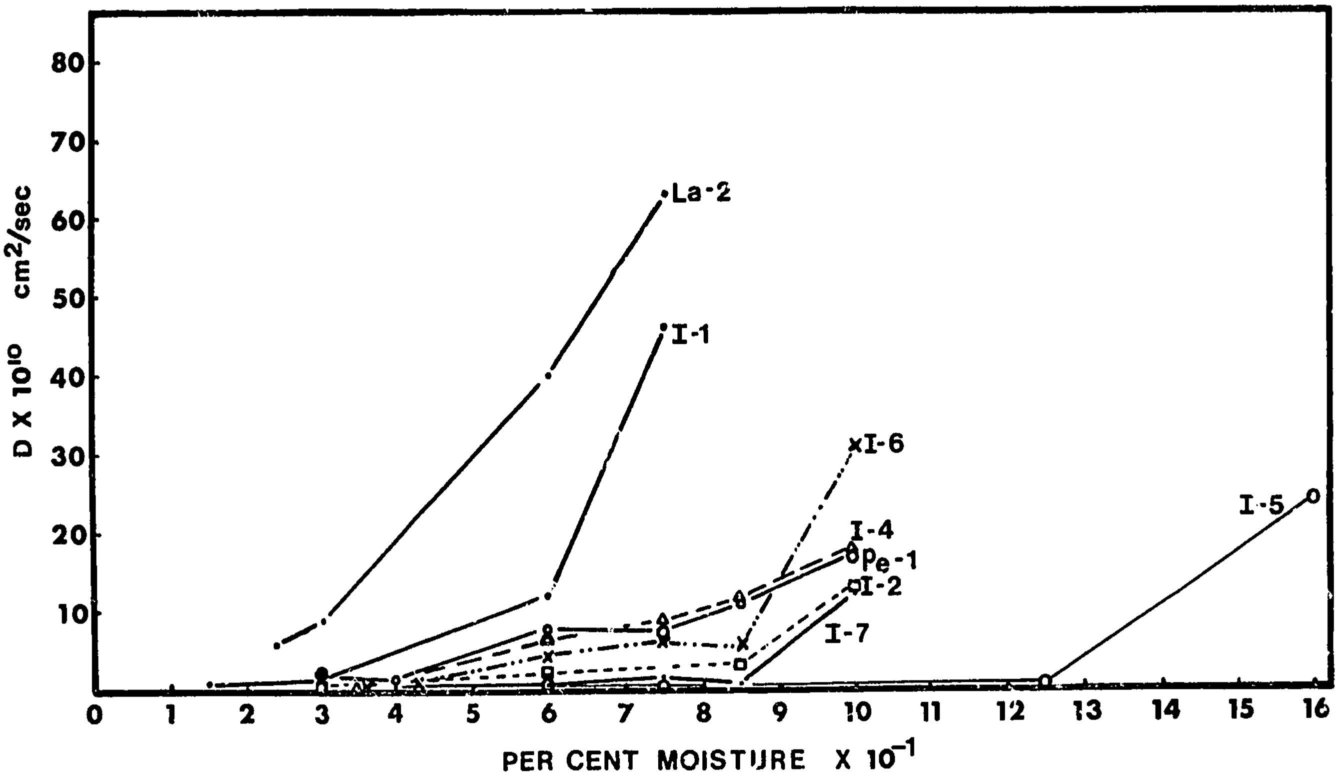


Figure 50. Effect of moisture on the diffusivity factor (D-values or ^{32}P self-diffusion coefficients). The final point on each curve represents D-values at water-saturation. I = Indian Vertisols, Pe = Peruvian Mollisol, La = Louisiana Mollisol.

instances, when increases in these three factors occurred, they were attributed to pH changes rather than anaerobiosis per se. Increases in the diffusivity factor, with moisture increases from near fifteen bar to water-saturation as measured by ^{32}P self-diffusion coefficients, were at least ten-fold in each soil. The fastest increases in phosphorus diffusion occurred as soil moisture increased from near one-third bar to water-saturation (Fig. 50). Thus, these data also indicate that increased soil phosphorus availability upon flooding is a result of the increase in the diffusivity factor.

Using a soil fertilized with phosphorus and a nutrient solution without phosphorus to nourish a split root system, rice-shoot growth and phosphorus uptake were determined as indicators of phosphorus availability. Further evidence was obtained to support the hypothesis that increased soil moisture increased phosphorus availability through an enhancement of phosphorus diffusion. When the P fertilized soil was replaced by phosphorus treated powdered cellulose, (having ^{32}P self-diffusion coefficients comparable to those found in soil), shoot growth and phosphorus uptake of rice plants increased with increasing moisture of the cellulose medium, when phosphorus was a limiting factor in plant growth. In the same experimental system, no plant growth differences occurred with moisture changes when the phosphorus solution concentration was sufficiently high so that even limited diffusion could supply adequate phosphorus (Table 62). In the phosphorus treated cellulose, as well as in the soil, maximum phosphorus uptake and shoot growth were obtained in the water-saturated treatment. These plant growth data are interpreted to indicate that all the increased phosphorus availability resulting from water-saturating the cellulose was due to increased phosphorus diffusion to root surfaces.

This study does not eliminate the possibility that reduction of iron or changes upon soil anaerobiosis may contribute to the increase in phosphorus availability in flooded rice soils. Nor does it eliminate the possibility that rice grown under flooded conditions has a lower functional phosphorus requirement or greater phosphorus absorption capacity. However, all three approaches employed in this study do suggest that increased phosphorus availability upon flooding is primarily due to the pronounced increase in phosphorus diffusion that occurs upon flooding.

Table 62. Effect of soil moisture on P availability in two soils as measured by shoot growth and P uptake of rice plants free of water-stress.

Moisture Treatments (centibars)	Dry Wt.[2] Tops (grams)	Shoot P Accumulation (ug P/pot)	P in Shoots (%)	Extractable Fe^{++} (ug/g)	Soil Moisture[3] (%)
Soil I-6. Vertisol, Rajendanagar, A. P., India. Fertility-capability: Cdvb.					
0[1]	4.73a[4]	1331	.08	50.0	63.0
5	4.35ab	1676	.09	0	43.0
15	3.78bc	410	.07	0	28.0
25	3.60bc	236	.07	0	25.0
35	3.43	-30	.07	0	26.0
Soil NC-6. Ultisol, Norfolk Series, North Carolina. Fertility-capability: LCea.					
0[1]	2.60a	1898	.08	2325.0	23.6
2	1.29b	463	.05	1.2	11.6
15	1.32b	578	.05	1.1	6.1

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[1] Water-saturated treatment

[2] Average of three replications (eight plants/replication)

[3] Moisture content at harvest

[4] Values followed by the same letter are not significantly different at the 5 per cent level of probability as tested by Duncan's multiple range test.

POTASSIUM RELEASE CHARACTERISTICS OF SELECTED SOILS FROM GUYANA AND NORTH CAROLINA

Objectives and Design

The study was undertaken by M. A. Granger and S. W. Buol to test the hypothesis that Ultisols of the mixed mineralogy family, relatively rich in potassium bearing feldspars would release, from fine and medium silt fractions, adequate amounts of potassium to sustain a crop during a cropping season. This has considerable bearing on the meaning of several soil tests for potassium.

It is believed that chemical weathering is more effective in these fractions. This causes a disruption of the crystalline structures with the concomitant release of the nutrient element. To measure the availability of this nutrient, pearl millet was used as the greenhouse test crop. The soils used were a Psammentic Tropudult and Typic Ochraquult from Guyana and two Typic Umbraquults from North Carolina. Chemical indices of potassium availability was also obtained by use of Beckett's Q/I ratio method, Hunter and Pratt's cold concentrated sulphuric acid method, and the North Carolina weak acid method of extraction.

Another aspect of the study involved the use of theoretical models to examine the soil-water solutions with respect to their mineral equilibria in an artificial environment simulating conditions as would be expected in a soil after a rain.

Results

The chemical indices used were poor indications of the actual availability of potassium as indicated by the uptake of the element by pearl millet seedlings. However, the available potassium by the North Carolina weak acid index was statistically superior to the other indices for relating chemically available potassium to plant uptake. The correlation obtained by the Q/I method was no better than that by the North Carolina method and the method itself proved too time consuming for use as a practical index of potassium availability.

One possible explanation for the poor correlation of the Q/I method with plant growth in these acid soils may be the interference of aluminum with the potassium relative to that of calcium, the chemical potential of aluminum or its effect on the activity ratio was not considered. Tinker has suggested that a better indication of the Q/I parameters as they relate to potassium uptake may be obtained by considering aluminum as an integral part of the activity ratio. However, when aluminum was used with calcium plus magnesium no better results were obtained.

Within the pedons, it was found that surface soil materials released more potassium for plant uptake during short-term cropping. It should be indicated that subsoil materials had higher capacities to supply potassium and would be expected to supply more for plant growth during long-term cropping than would the surface soils. Within the limits of the validity of attributing portions of the potassium taken up by the plant to exchangeable and non-exchangeable sources, it was found that significant amounts (40-100%) did come from non-exchangeable sources. The highest percentage from this source was in the very fine sand fraction and the lowest percentage from the fine silt fraction.

The mica content proved to be better related to plant uptake than did the potassium-bearing feldspar content. The implication here is that the feldspars contribute significantly to the soils capacity to supply potassium but their intensity is not as high as that of mica. A further implication is the concurrence with other evidence indicating a rapid initial potassium release from feldspars but requiring either a wet-dry or a freeze-thaw cycle for continued release during a growing season.

The fine silt was found to be contributing significantly to the plant available potassium. However, further attempts to rank the contributions to the labile pool by the various size separates would result in eroneous conclusions because of somewhat dissimilar mineralogies.

Examination of soil-water solutions with regard to mineral stability indicated that the surface horizon materials were more undersaturated than their corresponding subsoil materials where organic matter and free iron oxides were not removed. There was also some indication that the organic matter and free iron oxides tended to preserve existing minerals by forming a protective coating on them.

Within the mineralogical limits of the model used, the Hydrogen-Aluminum ratio (pH-1/3 pAl^{+3}) exerted a greater influence on controlling the mineral stability than did the hydrogen-potassium ratio relative to the solution levels of silica (pH_4SiO_4).

Conclusions

The simple North Carolina weak-acid extracting method remains a more practical and sensitive index for reflecting the availability of soil potassium for plant uptake. This method indicates that the Ultisols studied in the mixed mineralogy families released significant amounts of potassium for plant growth from the fine silt fractions.

The stability field diagrams indicate that the chemical composition of the soil water from these Ultisols at low tensions during relatively short soil-water contact periods, reflect a weathering rather than an orthogenic environment. The preservation of minerals such as montmorillonite in a high intensity weathering environment can occur if the minerals are coated with iron oxides.

RESEARCH UTILIZATION

A Salvadorean farmer using intensively fertilized forage sorghum as feed during the dry season.

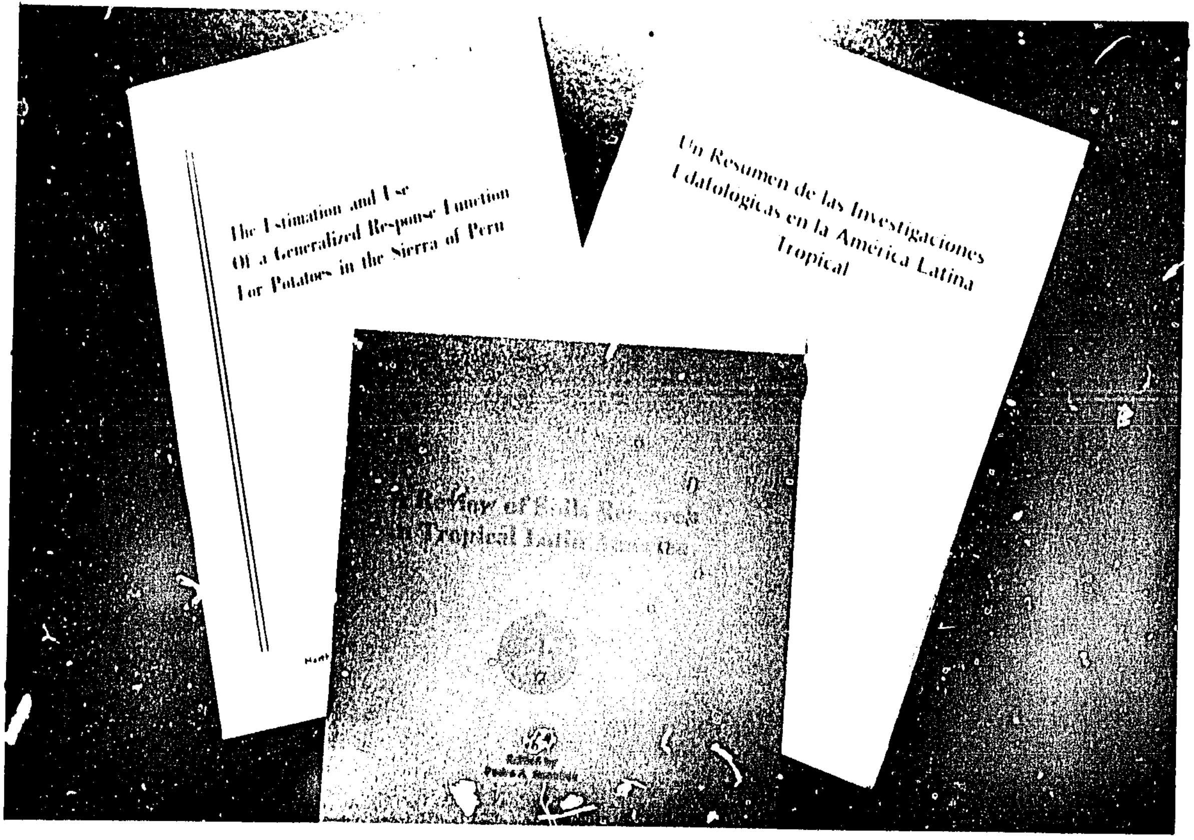
The effectiveness of this tropical soils research program should be measured by the generation of information not previously available to soil scientists in developing countries. As this information becomes available, the ultimate effect will be measured when farmers adopt the new recommended practices. Although most of the data generated so far is not sufficiently conclusive for making recommendations, concerted efforts have been made to disseminate as quickly and thoroughly as possible the available results to an audience of working soil scientists and key administrators. At the field stations, contacts have been made with nearby farmers, local research and extension agencies. Our scientists have participated actively in many national and international conferences. Some of the research projects have been mentioned in local radio broadcasts and in newspaper articles. Some farmers have adopted the new practices, particularly forage sorghum fertilization in El Salvador and to a limited degree around Brasilia.

PUBLICATIONS

The 1972 mimeographed version of the "Review of Soils Research in Tropical Latin America" consisting of 500 copies was quickly exhausted within a few months. Book reviews of this work appeared in the "Bulleting of the International Society of Soil Science," "Turrialba," and most recently in "Soil Science." The individual chapters have been abstracted in "Chemical Abstracts," "Soils and Fertilizers," "Fertilizer Abstracts," and "Tropical Abstracts." Due to the large number of requests from all parts of the world, the Review was reprinted as North Carolina Agricultural Experiment Station Technical Bulletin No. 219, with minor editorial modifications in late 1973. In order to make it more accessible to Latin American scientists, a Spanish translation was made. It is being presently printed in Turrialba, Costa Rica, and it is expected to be available in May, 1974. A total of 2000 copies will be available in each language. They will be sent free of charge to whomever requests them.

In order to accelerate the dissemination of this and other publications, the mailing list of working tropical soil scientists, key administrators, and libraries has been expanded during this year. At the time of writing, it consisted of 440 entries divided as follows: Latin America (279), United States (69), Asia (25), Europe (21), Africa (16) plus 30 on campus. All publications related to tropical soils produced by the Soil Science Department,

Miss Bertha Monar, Project Secretary (top) in the process of sending publications (such as below) to over 450 individuals and institutions included in our mailing list.



except theses, are sent to all these individuals. This includes additional publications written by the staff on contract time but not directly a result of Contract AID/csd 2806, as well as this Annual Report.

A considerable amount of feedback and scientist-to-scientist communications has evolved as a result of this publication exchange. In effect, as informal tropical soils "network" has been established with soil scientists working in Latin America.

The following articles and abstracts were published during 1973:

Bartholomew, W. V. 1973. Soil nitrogen in the tropics. pp. 68-69. In Sanchez (ed): A Review of Soil Research in Tropical Latin America. North Carolina Agr. Exp. Station Tech. Bull. 219.

Buol, S. W. 1973. Soil genesis, morphology and classification. pp 1-40. In Sanchez (ed): A Review of Soil Research in Tropical Latin America. North Carolina Agr. Exp. Station Tech. Bull. 219.

Cline, M. G. and S. W. Buol. 1973. Soils of the central plateau of Brazil. Agronomy Mimeo 73-13, Department of Agronomy, Cornell University.

Cox, F. R. 1973. Potassium. pp. 162-178. In Sanchez (ed): A Review of Soils Research in Tropical Latin America. North Carolina Agr. Exp. Station Tech. Bull. 219.

Cox, F. R. 1973. Micronutrients. pp. 182-197. In Sanchez (ed): A Review of Soils Research in Tropical Latin America. North Carolina Agr. Exp. Station Tech. Bull. 219.

Granger, M. A. 1973. Potassium characteristics, solution composition and mineral equilibria of selected soils from North Carolina and Guyana. Ph.D. Thesis, Soil Science Department North Carolina State University, 162 pp.

Kamprath, E. J. 1973. Soil acidity and liming. pp. 126-137. In Sanchez (ed): A Review of Soils Research in Tropical Latin America. North Carolina Agr. Exp. Station Tech. Bull. 219.

Kamprath, E. J. 1973. Phosphorus. pp. 138-161. In Sanchez (ed): A Review of Soils Research in Tropical Latin America. North Carolina Agr. Exp. Station Tech. Bull. 219.

Kamprath, E. J. 1973. Sulfur. pp. 179-182. In Sanchez (ed): A Review of Soils Research in Tropical Latin America. North Carolina Agr. Exp. Station Tech. Bull. 219.

Lutz, J. F. 1973. Soil physical properties. pp. 39-45. In Sanchez (ed): A Review of Soils Research in Tropical Latin America. North Carolina Agr. Exp. Station Tech. Bull. 219.

Lepsch, I. F. 1973. Genesis, morphology, and classification of soils in an Oxisol - Ultisol toposequence in São Paulo State, Brazil. M.S. Thesis, Soil Science Department, North Carolina State University, 89 pp.

Mendez-Lay, J. 1973. Effect of lime on phosphorus fixation and plant growth in various soils of Panama. M.S. Thesis, Soil Science Department, North Carolina State University, 90 pp.

Sanchez, P. A. 1973. Soil management under shifting cultivation. pp. 46-67. In Sanchez (ed): A Review of Soils Research in Tropical Latin America, North Carolina Agr. Exp. Station Tech. Bull. 219.

Sanchez, P. A. 1973. Nitrogen fertilization. pp. 90-125. In Sanchez (ed): A Review of Soils Research in Tropical Latin America, North Carolina Agr. Exp. Station Tech. Bull. 219.

Sanchez, P. A. 1973. Puddling tropical rice soils. I. Growth and nutrient aspects. II. Effects of water losses. Soil Science 115:145-157, 303-308.

Sanchez, P. A. and A. M. Briones. 1973. Phosphorus availability of some Philippine rice soils as affected by soil and water management practices. Agronomy Journal 65:226-228.

Sanchez, P. A., G. E. Raminez, and M. V. de Calderon. 1973. Rice responses to nitrogen under high solar radiation and intermittent flooding in Peru. Agronomy Journal 65:523-529.

Sanchez, P. A., A. Gavidia, G. E. Ramirez, R. Vergara, and F. Minguillo. 1973. Performance of sulfur-coated urea under intermittently flooded rice culture in Peru. Soil Science Society of America Proceedings. 37:789-792.

CONFERENCES AND RELATED TRAVEL

Dr. E. J. Kamprath participated in the third Soils Colloquium entitled "Chemical aspects and mineral forms of phosphorus in tropical regions" sponsored by the Colombian Society of Soil Science in Bogota on August 26 to 31. Messers. E. Gonzalez, R. S. Yost, and Dr. George Naderman attended the Brazilian Soil Science Congress at Santa Maria, Rio Grande de Sul in July. They presented some of their preliminary results in collaboration with Brasilian co-workers. Drs. S. W. Buol and M. A. Granger presented two papers at the American Society of Agronomy Annual Meetings in Las Vegas in November. Dr. P. A. Sanchez chaired a joint session between Divisions A-6 (International Agronomy) and S-4 (Soil Fertility and Plant Nutrition).

The following abstracts were also published from these conferences:

Granger, M. A. and S. W. Buol. Application of theoretical $K_2O - Al_2O_3 - SiO_2 - H_2O$ system to pedology. American Society of Agronomy Meetings. Las Vegas, Nevada. Agronomy Abstracts 1973:113.

Kamprath, E. J. Aspectos químicos y formas minerales de fósforo en suelos de zonas tropicales. III Coloquio de Suelos: "El Fósforo en Zonas Tropicales," Sociedad Colombiana de la Ciencia del Suelo, Bogotá, Agosto 26-31, 1973.

Soares, W., E. Zoborowsky, G. Naderman, E. Gonzalez, y R. Yost. Resultades preliminares de etudos com calcário e fósforo num Latosol Vermelho Escuro, textura argilosa, fase cerrado. Nota Prèvia, XIV Congresso Brasileiro de Ciencia do Solo, UFSM, Santa Maria, Rio Grande do Sul. Julho, 1973.

Campus-based staff travelled to Guatemala, El Salvador, Costa Rica, Panama, Colombia, Peru, and Brazil to consult with national and international institutions on matters pertaining to tropical soils research. Likewise, they have advised the Ford Foundation and the Tennessee Valley Authority on related subjects.

IMPACT ON FARM PRACTICES

The forage sorghum fertilization study in El Salvador, although in its first year has created keen interest among farmers in the area. Several farmers intend to apply the fertilizer recommendations to their next planting during the 1974 rainy season. To a lesser extent some of the practices being developed in Brasilia are being applied by some of the nearby farmers. Requests for on-farm testing have been received from other areas of the Cerrado and a government-owned cattle ranch near Yurimaguas in the Amazon.