AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
Batch #26

1. SUBJECT CLASSIFICATION

A. PRIMARY
Serials Y-AF20-0000-GG50

B. SECONDARY
Agriculture--Soil science--Tropics

2. TITLE AND SUBTITLE
Agronomic-economic research on tropical soils; annual report for 1974

3. AUTHOR(S)
(101) N.C.State Univ. Soil Science Dept.

4. DOCUMENT DATE
1975

5. NUMBER OF PAGES
233p.

6. ARC NUMBER
ARC LAT631.4072.N864

7. REFERENCE ORGANIZATION NAME AND ADDRESS
N.C.State

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*
(Research summary)

9. ABSTRACT†

10. CONTROL NUMBER
PN-RAB-513

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Latin America
Tropics

13. PROJECT NUMBER

14. CONTRACT NUMBER
CSD-2806 Res.

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

AGRONOMIC-ECONOMIC RESEARCH ON TROPICAL SOILS

ANNUAL REPORT FOR 1974

Soil Science Department

North Carolina State University

Raleigh, N. C. 27607

under

Contract AID/csd 2806

with the

U. S. Agency for International Development

CONTENTS

Page

INTRODUCTION

Highlights of the year 1
Personnel 5
Cooperating institutions and individuals 6

AMAZON JUNGLE OF PERU

Climate and soils 13
Changes in soil properties with clearing and cultivation 14
Crop performance in burned and bulldozed land clearing methods 22
Continuous cropping experiment 27
Pasture fertilization 42
Rice fertilization 48
Corn fertilization 50
Multiple cropping 52
Crop residue management 61
Secondary and micronutrient greenhouse studies 67
Towards an integrated management system 70

JOINT NSCU-CORNELL RESEARCH IN THE CERRADO OF BRAZIL

Crop weather 76
Residual effect of liming and depth of incorporation 78
Residual effect of broadcast and banded phosphorus applications 84
Phosphorus sources and rates for forage crops 92
Nitrogen fertilization 103
Zinc fertilization 106
Soil moisture studies 110
Crop physiology as affected by soil moisture and fertility 122
Resources for irrigation 125
Tolerance to aluminum and low available phosphorus 128
Extrapolation studies 143
Outreach study on properties of Cerrado Soils 148

CENTRAL AMERICA

Intensive multiple cropping systems 153
Nitrogen fertilization of various corn and bean combinations 167
Combining corn and soybeans 176
Competition studies with cassava 182

CONTENTS (Cont'd)

Page

Nitrogen management for upland rice 184
Copper toxicity in upland rice 190

SOIL CHARACTERIZATION AND MICROBIOLOGY

Yurimaguas Experiment Station in Eastern Peru 194
Occidental plateau of São Paulo State, Brazil 202
Llanos Orientales of Colombia 205
Maracaibo basin of Venezuela 206
Ultisols and Oxisols of Venezuela 206
Organic matter mineralization in Andepts 207

FERTILITY CAPABILITY CLASSIFICATION

Site classification of Brazilian experiments 214
Behavior of FCC units at different yield levels 214
Economic evaluation 221

COMMUNICATION OF RESULTS

Publications 226
Mailing list 227
Conferences and symposia 228

INTRODUCTION

This is the fourth 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 in small farms. The geographic emphasis is in Latin America, but the results are expected to be applicable to other tropical regions with similar environmental conditions.

The program continues to focus on developing economically-sound soil management practices for jungle areas presently under shifting cultivation, for acid Oxisol savannas and for volcanic highlands. Field research is based at representative locations. Additional research based on campus supplements field activities and attempts to devise means for extrapolating the results to other areas.

The activities during 1974 represent the second year of field operations at research stations in Yurimaguas, Peru, Brasília, Brazil and Turrialba, Costa Rica. The latter location serves as headquarters for studies throughout Central America. Supporting research was conducted on campus and with soils or data from Colombia, Venezuela, Peru and Brazil.

HIGHLIGHTS OF THE YEAR

Amazon Jungle.

Research in Yurimaguas showed that the fertility decline after land clearing is very fast in acid Ultisols. The slash and burn land clearing method however, slows the rate of fertility decline as compared with land clearing with a bulldozer. After burning, total exchangeable bases and available phosphorus increased severalfold. This reduced aluminum saturation to nearly acceptable levels. The pattern of organic matter depletion was retarded by six months with the traditional slash and burn system. Crop performance during two years showed that the average yields in bulldozed plots were 1/3 of those of the burned plots when no fertilizer was added, and that this difference gradually decreased with fertilization intensity. Economic interpretation shows that mechanized land clearing is unprofitable while the traditional slash and burn system was profitable at the small farm level.

Continuous cropping is agronomically and economically feasible with relatively modest fertilizer and lime inputs. After correcting the soil pH to 6 and adding a basal application

of 100 kg P/ha plus sulfur, boron and molybdenum, crop yields were maintained at a satisfactory level with 40 to 80 kg/ha of nitrogen and potassium additions per crop. The most promising cropping system appears to be a three-crop yearly rotation of rice, corn and soybeans which produced average grain yields between 2.5 and 3.5 ton/ha per crop.

Pasture fertilization experiments show that the establishment of Stylosanthes guyanensis produces as much as Guinea grass (Panicum maximum) dry matter per year as an application of 100 kg N/ha/yr as urea. Maximum yields were attained with 400 kg N/ha/yr as urea but the similar yields were obtained with 100 kg N/ha/yr of sulfur-coated urea, a slow release nitrogen source. The phosphorus requirements are lower than commonly assumed due to the low phosphorus fixation capacity of this soil. The Fosbayovar rock phosphate produced in the coast performed well when compared with the international rock phosphate standards. This low-cost source seems to offer real promise for Jungle Ultisols.

Multiple cropping experiments show that four crops (corn, soybeans, cassava and cowpea) can be produced in nine months and that the gross returns per hectare are considerably higher than that of monocultures. The response to both nitrogen and lime is higher in intercropped combinations than in monocultures. Incorporating Kudzu (Pueraria phaseoloides) tops increased drastically soybean yields and nodulation. This practice may reduce fertilizer costs and make good use of cheap, locally available material.

A preliminary model was developed for continuous cropping based on low-energy technology for small farms or cooperatives. Some of its components will require further testing.

Cerrado of Brazil.

The cooperative research project in Brasilia produced the first indication of the residual effects of lime, phosphorus and zinc applications. The superiority of deep lime incorporation as compared to shallow incorporation has remained consistent in three consecutive corn crops. The ability of corn roots to extract moisture and nutrients at greater depths in extremely acid Oxisol subsoils in which aluminum has been neutralized by liming is considered the main reason for the superior performance of deep lime incorporations. After three consecutive crops, the residual effect of 4 and 8 tons lime/ha is strong and is confirmed by profile chemical analysis.

The comparison of broadcast vs. banded superphosphate applications on four consecutive corn crops shows a different residual effect with time. Broadcast applications of 160 and

320 kg P_2O_5/ha failed to maintain adequate yield levels, while the very high level of 1280 kg P_2O_5/ha consistently produced high yields. Banded applications prior to each crop gradually increased in effectiveness. A tentative economic analysis of the first four crops shows that the most profitable strategy is to apply a relatively large initial broadcast application of 320 kg P_2O_5/ha plus a banded application of 80 kg P_2O_5/ha before each crop. The present cost:price ratio in Brazil makes these considerable investments profitable.

In search for cheaper sources of phosphorus, experiments with forage species show that the Termosfosfato (a thermal alteration of slowly soluble Araxã rock phosphate with magnesium silicate) produced initial forage crop responses similar to those of superphosphate. In addition, this source had a considerable liming effect on the soil. The residual effects are being investigated. The residual effects of the 3 kg Zn/ha applications were strong for the second crop.

The two year study of soil moisture properties with emphasis on dry spells ("veranicos") which occur during the rainy season was completed during this year. Analysis of long term rainfall records indicates that the probability of severe water stress for corn is high in most years. The available water storage capacity of a loamy-textured Oxisol was found to be 30% higher than a clayey textured Oxisol. The difference is attributed to the extremely strong aggregation of clay particles into sand-sized granules. Crop yields showed good agreement with the length of "veranicos." Probability analysis shows that long term rainy season corn yields will average 54% of the maximum yields due to "veranicos." The potential for irrigation and water impoundment was also determined.

Studies on varietal differences in tolerating high levels of aluminum and low levels of phosphorus were initiated. Culture solution studies show that these factors are interrelated and that significant differences exist among corn, rice and bean varieties. Field studies will follow.

The first extrapolation studies to other Cerrado soils were conducted this year. Work on the loamy Red-Yellow Latosol showed no response to depth of lime incorporation because subsoil aluminum saturation was below critical levels. A second experiment with beans on another soil underscored the importance of banding phosphorus for this crop. The study of a large number of topsoil samples throughout the Cerrado showed the very uniform low fertility parameters in the area. The natural vegetation gradient from campo limpo (pure grassland) to

deciduous forest through several intermediate steps was found to be directly associated with increasing soil pH, exchangeable calcium, magnesium, potassium, effective cation exchange capacity and available phosphorus, zinc and magnesium.

Central America.

Research on intensive multiple cropping systems in Costa Rica showed the superiority of intercropped systems as compared with monocultures at several fertility levels. A four crop combination of corn, bush beans, cassava and soybeans harvested in one year with a total fertilization of 212-144-132 kg N, P_2O_5, K_2O/ha on a Dystrandept produced maximum returns over fertilizer costs and a very high total edible energy and protein production. Nitrogen response was higher when corn and beans were intercropped than when the field was split in halves and planted with two monocultures. Economic interpretation of upland rice response to different nitrogen management alternatives shows a wide variety of profitable alternatives and the fact that more profit was made with the higher 1974 prices, when the cost of nitrogen tripled and the price of rice increased by 84 percent.

Soil Characterization Studies.

The map of the Yurimaguas Experiment Station was also completed during the year. Local variability of Ultisols, Alfisols, Inceptisols and Entisols is largely explained in terms of geomorphic surfaces. Variation in properties of the upland soils are directly related to clay content. Geomorphic relationships also explain local variability in a selected landscape in western São Paulo, Brazil. Oxisols, Ultisols, Alfisols and Mollisols occupy predictable positions in the landscape. Characterization studies were also made in the Llanos Orientales of Colombia, the Maracaibo basin of Venezuela and in the lowlands of that country. The slow mineralization rate of Andepts of Colombia is attributed to the low available phosphorus and nitrogen content of such soils.

Fertility-Capability Classification.

The analysis of the data set from Brazil affords an assessment of the potential of Fertility-Capability Classification System as a means of grouping soils with fertility management problems. The parameters for the type and substrata type categories appear to adequately define soils into broad but distinct classes that will warrant separate fertilizer management practices. The condition modifiers for low cation exchange capacity and aluminum

toxicity were useful in separating different yield responses. The "k" and "i" modifiers need redefinition in order to improve their ability to group soils with similar problems of potassium deficiency and phosphorus fixation by iron.

PERSONNEL

The following North Carolina State University faculty and staff participated in this research program:

C. B. McCants, Head of the Soil Science Department

P. A. Sanchez, Associate Professor and Program Leader

S. W. Buol, Professor, Soil Genesis and Classification

S. J. Chang, Research Assistant, Economics

A. Cordero, Graduate Student, Soil Fertility (Costa Rica)

F. R. Cox, Associate Professor, Soil Fertility

M. A. Granger, Research Associate, Fertility-Capability Classification

E. Gonzalez E., Research Assistant, Soil Fertility (Brazil)

E. J. Kamprath, Professor, Soil Fertility

I. F. Lepsch, Graduate Student, Soil Genesis (Brazil)

C. L. Langley, Research Technician III

A. S. Lopes, Graduate Student, Soil Fertility (Brazil)

C. E. López, Research Assistant, Soil Fertility (Peru)

R. E. McCollum, Associate Professor, Soil Fertility

D. M. McDonald, Bilingual Secretary II

L. Mejía, Graduate Student, Soil Genesis (Colombia)

G. S. Miner, Assistant Professor, Soil Fertility

B. I. Monar, Bilingual Secretary III

F. Munévar, Graduate Student, Soil Microbiology (Colombia)

G. C. Naderman, Jr., Extension Assistant Professor, Soil Management (effective Nov. 15, 1974). Previously Research Associate, Cornell University and Coordinator in Brazil

D. D. Oelsligle, Assistant Professor, Soil Fertility and Coordinator for Central America

J. R. Paredes, Graduate Student, Soil Genesis (Venezuela)

R. K. Perrin, Associate Professor, Economics

R. A. Pope, Research Assistant, Soil Genesis

J. G. Salinas, Research Assistant, Soil Fertility (Brazil)

R. Schargel, Graduate Student, Soil Genesis (Venezuela)

C. E. Seubert, Research Assistant, Soil Fertility (Peru)

T. J. Smyth, Research Assistant, Soil Fertility (Brazil)

E. J. Tyler, Research Assistant, Soil Genesis (Peru)

J. H. Villachica, Research Assistant, Soil Fertility (Peru)

M. K. Wade, Research Assistant, Soil Management (Peru)

A. G. Wollum II, Associate Professor, Soil Microbiology

R. S. Yost, Research Assistant, Soil Fertility (Brazil)

COOPERATING INSTITUTIONS AND INDIVIDUALS

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

In the Amazon Jungle, the field work is conducted in cooperation with the Dirección General de Investigaciones Agrarias of the Ministerio de Agricultura at the Yurimaguas Experiment Station which is part of the Centro Regional de Investigaciones Agrarias del Nor-Oriente. Supporting laboratory and greenhouse work was conducted at La Molina. The International Potato Center plays a major role in providing administrative and logistical support to this project.

In the Cerrado, the field work is conducted at the Brasília Experiment Station near Planaltina, 40 kms north of Brasília as a joint project with Cornell University and the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA). The AID Mission in Brasília has contributed substantially to this project by providing excellent logistical support.

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 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 Peruvian, Brazilian and Colombian scien-

tists. 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 Instituto Geográfico Agustín Codazzi, CIAT and the Ministerio de Obras Públicas of Venezuela. Soil samples for the microbiology studies were obtained in cooperation with the Instituto Colombiano Agropecuario.

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

Peru

Carlos Valverde, S., Project Coordinator for the Ministry of Agriculture

Marco A. Nureña, Head, Yurimaguas Experiment Station

David Anderson, Peace Corps Volunteer, Yurimaguas

Ruben Mesía P., Agronomist, Yurimaguas Experiment Station

Carmen Torres, Soils Department, La Molina Experiment Station

Mario Cano, Soils Department, La Molina Experiment Station

Brazil

K. Dale Ritchey, Research Associate, Cornell University and Joint Cornell-NCSU Project Coordinator (replaced Dr. Naderman as of Dec. 6, 1974)

James M. Wolf, Research Assistant, Cornell University

Dale E. Bandy, Research Assistant, Cornell University

Jan Pruntel, Research Assistant, Cornell University

Wilson V. Soares, Soil Scientist, Brasilia Experiment Station

Elcios Martins, Research Technician, Cornell-NCSU Project

Eduardo A. V. Morales, Agronomist, Fundação Zoobotânica do Distrito Federal and Agronomy Department Head, University of Brasilia.

Fernando F. Duque, Agronomist, Fundação Zoobotânica do Distrito Federal and University of Brasília

Costa Rica

Alvaro Cordero V., Head Soils Section, MAG, San José

Arnoldo Romero, Rice Specialist, MAG, Palmar Norte

John J. Nicholaides III, Regional Director, ISFEIP, San José

Antonio M. Pinchinat, Plant Breeder, CATIE, Turrialba

Rufo Bazán, Soil Scientist, CATIE, Turrialba

Nicolás Mateo, Agronomist, CATIE, Turrialba

Raúl Moreno, Plant Pathologist, CATIE, Turrialba

Gerardo Ramírez, Soils Research, MAG, San José

Rolando Gonzalez, Rice Program, MAG, Liberia

Roger Meneses, Agronomist, MAG, Los Diamantes

Fernando Rivera, Extension, MAG, San Isidro

Allen Yale, Peace Corps, San José

Fred Binder, Peace Crops, Liberia

El Salvador

José Antenor Romero, Livestock Extension, CENTA, Santa Tecla

Edmilda de Peña, Soils Investigation, CENTA, Santa Tecla

Julia de Menéndez, Soils Analysis, CENTA, Santa Tecla

Harry Brokish, Peace Corps, CENTA, Santa Tecla

Miguel Fuentes Velarde, Extension, CENTA, Olomega

José Elias Ventura, Extension, CENTA, San Francisco Gotera

Ralph Kramer, Peace Crops, San Francisco Gotera

Gary Larson, Peace Crops, Villa Dolores

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

Peru

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

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

José del Carmen Muro, Director de Investigaciones, Ministerio de Agricultura, 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 Agriculture Officer, USAID, Lima

Rollo Ehrich, Deputy Food and Agriculture Officer, USAID, Lima

Brazil

José Ireneu Cabral, President, EMBRAPA

Almiro Blumenschein, Director, EMBRAPA

Nathaniel Bloomfield, International Affairs, EMBRAPA

Wenceslau Goedert, Soils Specialist, Technical Scientific Department, EMBRAPA

Edson Lobato, Coordinator of Cerrado Research, EMBRAPA

Gilberto Páez, Head of the Data Processing Department, EMBRAPA

José M. Barcellos, Head of the Brasilia Experiment Station, EMBRAPA

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

Alphonse Chable, Deputy ARDO, USAID/Brasilia

Lawrence J. Able, USAID/Brasilia

John Young, USAID/Brasilia

Costa Rica

Manuel Elgueta, Director, CATIE, Turrialba.

Eladio Carmona, Director de Investigaciones, MAG, San José

Alberto Vargas, Subdirector de Investigaciones, MAG, San José

Jorge Soria, Jefe, Departamento de Suelos y Cultivos Tropicales, CATIE

Milton Lau, Agricultural Officer, USAID/San José

Carlos Gonzalez, MAG, Los Diamantes

José Miguel Méndez, Administrator, CATIE

Inés de Santiesteban, Executive Secretary, CATIE

El Salvador

Armando Alas, Director of Research, CENTA, Santa Tecla

José Perez Guerra, Director of Extension, CENTA, Santa Tecla

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

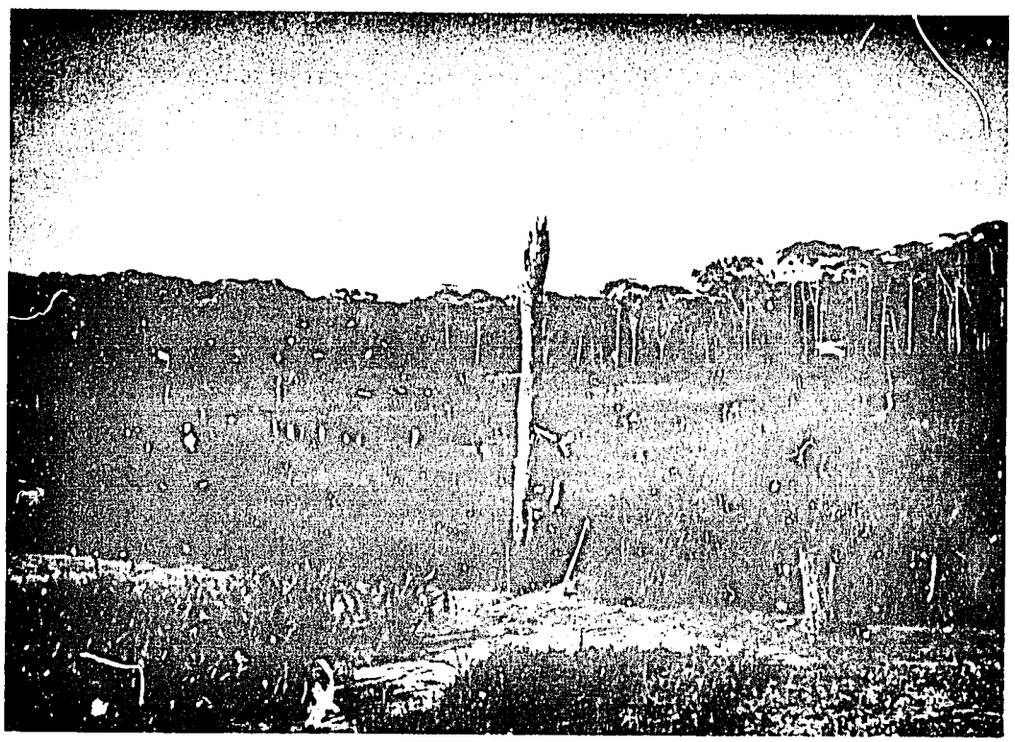
Francisco Rodriguez, Peace Corps Ag. Coord., San Salvador

Jack Morse, Food and Agriculture Officer, USAID/San Salvador

Julio A. Ringuelet, IICA Representative, San Salvador

A special note of thanks is due to Dr. J. L. Malcolm, the program monitor in AID, Washington and his associates for their backstopping and general support for the program.

AMAZON JUNGLE OF PERU



View of the Yurimaguas Experiment Station in the Jungle of Peru

Research at the Yurimaguas Experiment Station in the Jungle of Peru is aimed at developing economically-sound soil management practices to permit continuous cropping areas where population pressures dictate alternatives to shifting cultivation. The rationale for selecting Yurimaguas as a representative site was described in the 1972 Annual Report. The initial soil characterization studies, the design of the continuous cropping experiment and crop performance during the first 18 months are described in the 1973 Annual Report. The principal results were the recognition of Ultisols as the most extensive soils of the Amazon basin and the superiority of the traditional slash-and-burn land clearing system over mechanized clearing in several crops.

The experimental strategy consists of 1) determining the factors responsible for the marked decline in soil fertility after clearing, typical of shifting cultivation in acid soils, and 2) the development of corrective measures to enable continuous cultivation in small farming units with emphasis on low-energy technology options. A central experiment, called the continuous cropping experiment was designed to evaluate the feasibility of several cropping systems at selected soil fertility levels as a function of time after clearing. Several supplemental field experiments were established to determine the nutrient requirements of the principal food crops and pastures, to study means of increasing production in intercropped and multiple cropped systems and to manage crop residues. Greenhouse studies on secondary and micronutrient deficiencies were also conducted in Raleigh and La Molina. Plant and soil analyses were also conducted at these locations, until proper facilities are constructed in Yurimaguas.

This project is a joint effort with the Centro Regional de Investigaciones Agrarias del Nor-Oriente (CRIA III) and the Dirección General de Investigaciones Agrarias of the Ministry of Agriculture. Research reported during this period was conducted by Mr. Christopher E. Seubert on land clearing, Mr. E. J. Tyler on soil characterization, Mr. César E. Lopez on continuous cropping and pasture fertilization, Mr. Michael K. Wade on multiple cropping and residue management and Mr. David Anderson on fertilization of rice and corn. Greenhouse work was conducted in Raleigh by Mr. Hugo Villachica. Drs. P. A. Sanchez, C. Valverde, S. W. Buol, G. S. Miner, and Ings. M. Nureña and R. Mesía provided advice and supervision to the project.

CLIMATE AND SOILS

The monthly rainfall during 1974 is shown in Fig. 1, compared with the long-term average and recently calculated 20% probability limits. The pattern during this year was within these probability limits with the exception of unusually high precipitation during the month of July. The fluctuations encountered the previous year, a very wet June to August period and an unusually dry September to November weather were not duplicated this year.

Unless otherwise specified all field and greenhouse experiments were conducted on the Yurimaguas series, classified as a Typic Paleudult, fine loamy, siliceous, isohyperthermic. Its properties are described as Profile Y-17 in the 1973 Annual Report. It is a well drained, coarse textured soil with gradually increasing clay content with depth. Chemically it is very acid, low in phosphorus, bases and organic matter. Due to its coarse texture, its phosphorus fixation capacity is low.

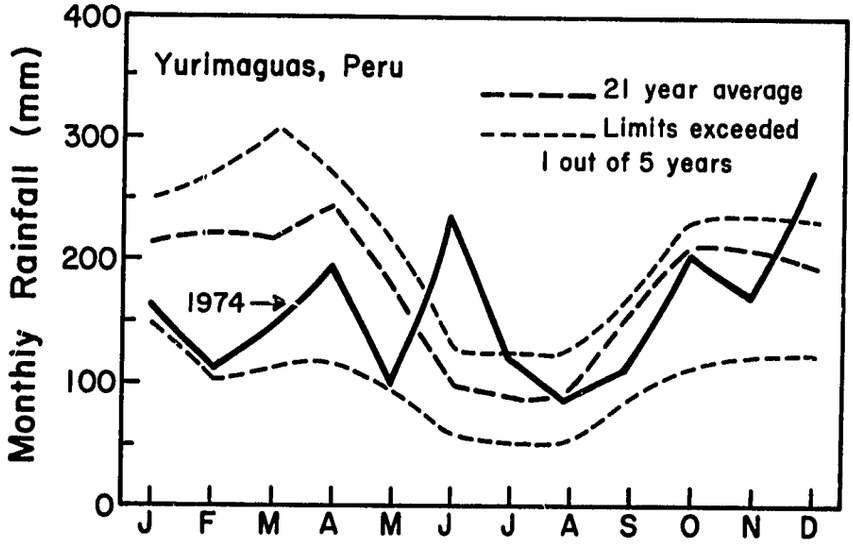


Fig. 1. Monthly rainfall pattern in Yurimaguas compared with long term averages and 20% probability limits.

CHANGES IN SOIL PROPERTIES WITH CLEARING AND CULTIVATION

The soil dynamics involved in the fertility decline process were monitored by periodic soil sampling in the 1972 clearing. Samples were taken before cutting (0 time) after burning (1 month after clearing), after the first rice harvest (6 months after clearing) and after the second rice harvest (10 months after clearing). The changes in measured properties are summarized in Figs. 2 to 6. They show the behavior of the 0-10cm layer in burned and bulldozed land clearing systems on the continuous rice cropping plots. Results are also available for 10-30cm and 30-50cm depth in Mr. Seubert's thesis.*

Burning markedly increased the base status of this Ultisol. The exchangeable calcium, magnesium and potassium contents approximately tripled after burning (Fig. 2). The exchangeable aluminim content dropped drastically, and the percent aluminum saturation decreased from 67% to 45% (Fig. 3). With time, exchangeable calcium and magnesium increased further but exchangeable potassium dropped to pre-burn levels. In plots cleared by bulldozer, exchangeable bases remained at their original low levels, except for potassium during the first month after clearing. The increase in potassium is believed to be caused by fast mineralization of the litter layer prior to bulldozing. Exchangeable acidity levels increased gradually with time which increased aluminum saturation from 58% to 73% in the bulldozed plots.

The increases in calcium and magnesium after burning are almost quantitatively accounted for by the calcium + magnesium content of the ash described in the 1973 Annual Report. In the case of potassium, the increases in the topsoil exceeded the ash contents. This suggests rapid mineralization and leaching of this element from the felled vegetation prior to burning or bulldozing. Burning increased soil test potassium from deficient to sufficient values according to the critical level of 0.2 meq K/100ml.

Effective cation exchange capacity, calculated by the sum of bases plus exchangeable acidity, increased gradually with time (Fig. 3). This is attributed to the pH-dependent charge of the clay minerals. In both burned and bulldozed clearings, soil pH increased from

---

*Seubert, C. E. 1975. Effects of land clearing methods on crop performance and changes in soil properties in an Ultisol of the Amazon Jungle of Peru. M.S. thesis, North Carolina State University.

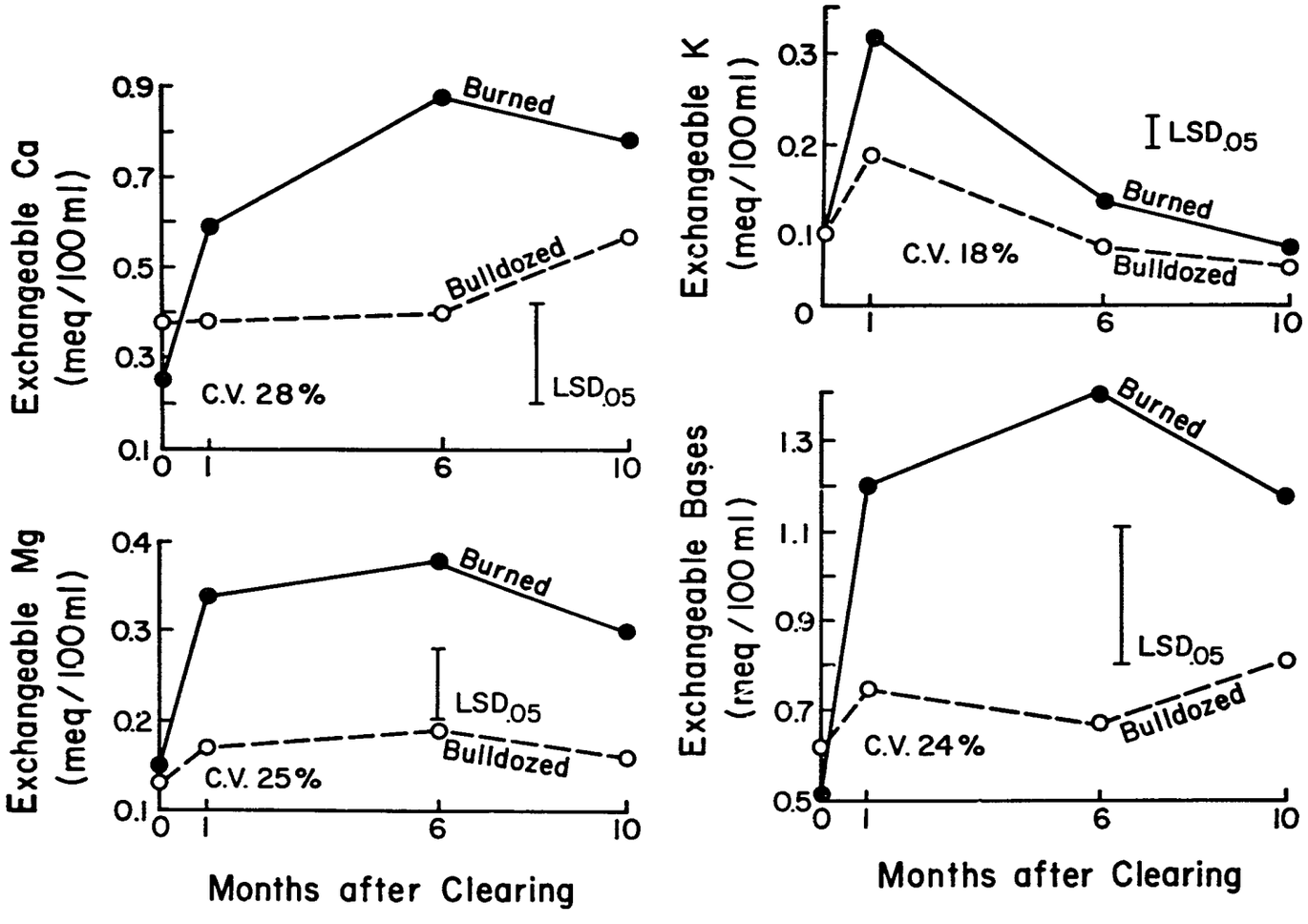


Fig. 2. Changes in exchangeable bases as a function of land clearing method and time after clearing. 0-10cm depth.

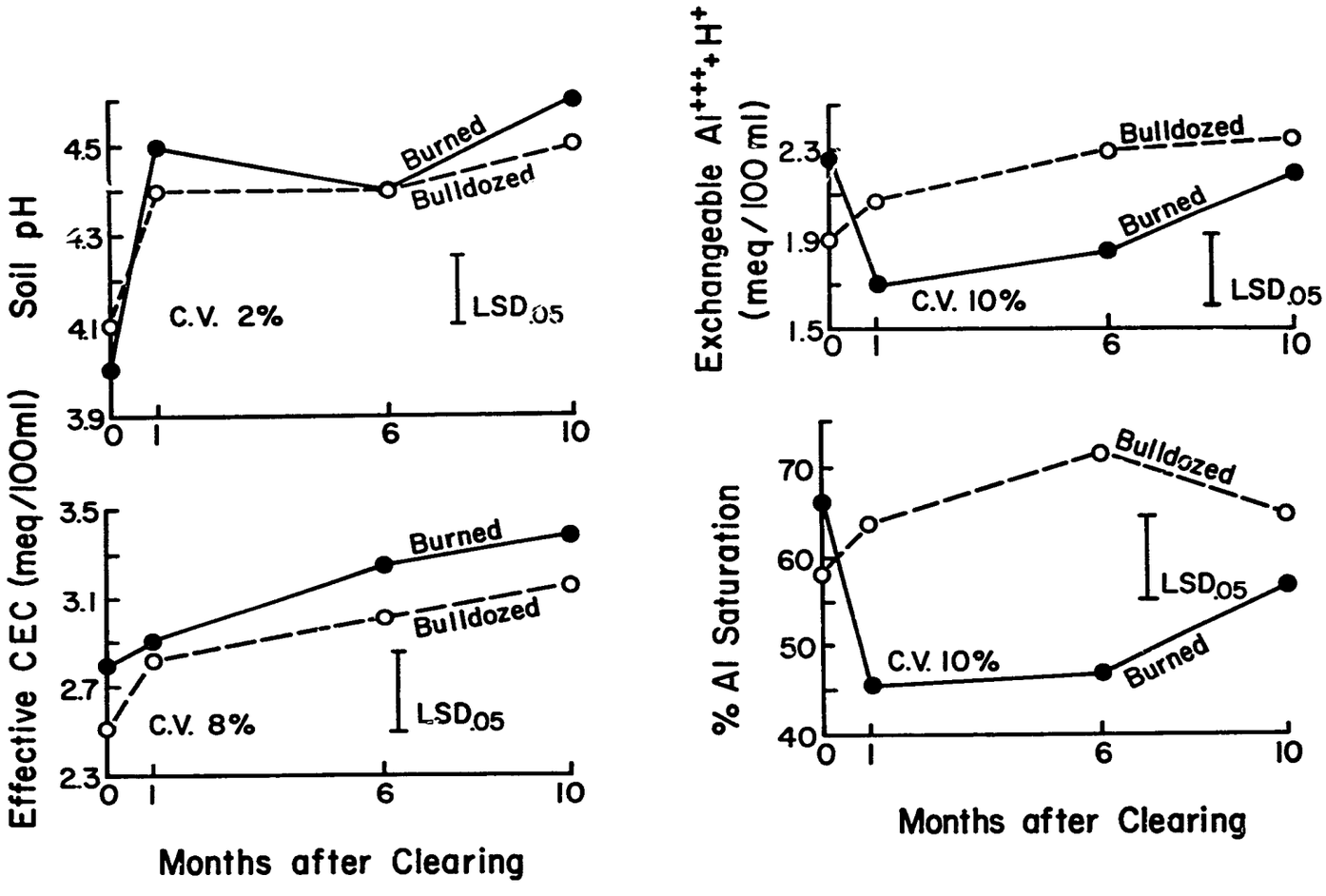


Fig. 3. Changes in pH, aluminum and effective cation exchange capacity in the top 10cms as a function of land clearing method and time after clearing.

4.0 to 4.5 within a month after clearing and remained stationary. Apparently the changes in bases and aluminum were not of sufficient magnitude to change the pH appreciably.

Available Phosphorus

Another advantage of burning was the dramatic increase in available phosphorus as determined by the Olsen method (Fig. 4). Burning raised the soil test value from 5 to 16 ppm P, which shifted from below to above the critical level of 12 ppm. Bulldozing did not change available phosphorus appreciably. At the tenth month after clearing, available phosphorus in the burned plots was similar to the bulldozed plots. The decline from the sixth to tenth month is almost quantitatively accounted for by crop uptake.

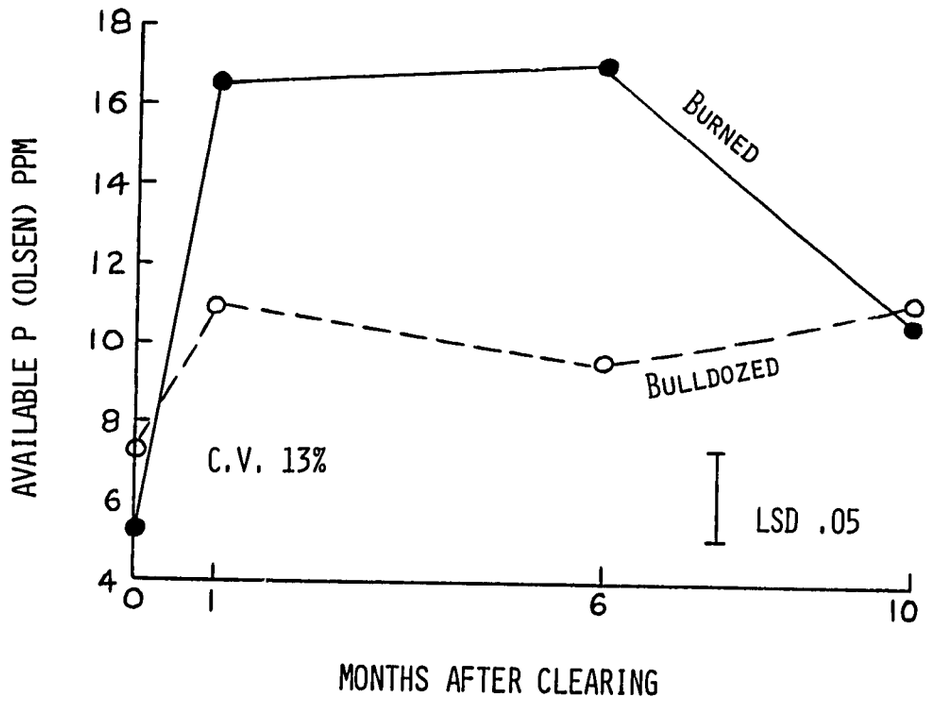


Fig. 4. Effects of land clearing methods upon available P as a function of time after clearing.

Organic Matter

Contrary to popular opinion, burning did not decrease the organic matter content of the soil (Fig. 5). The initial increase in organic carbon at one month after clearing is probably related to partially burned or charred material. After six months, organic carbon began to decline. In the bulldozed plots, organic carbon and nitrogen contents decreased immediately after clearing, presumably because of topsoil carried by the bulldozer blade. C/N ratio decreased in the burned plots and increased in the bulldozed plots. This is probably a consequence of higher soil temperature in the more exposed bulldozer plots which resulted in higher organic carbon mineralization rates. Burning, therefore, retarded the organic matter depletion process by six months.

Inorganic Nitrogen

Fig. 6 shows that the inorganic nitrogen content ($NH_4^+ + NO_3^-$) of the top 50cms increased significantly with clearing and decreased afterwards in both land clearing systems. This may be due to rapid mineralization of organic nitrogen upon clearing followed by leaching and crop uptake. It is interesting to note the rather large amounts of inorganic nitrogen present in the profile after clearing. Given the volume-weight relationships used in the analysis, 1 ppm of inorganic nitrogen is approximately equivalent to 1 kg N/ha. These values suggest that nitrogen deficiency is unlikely during the first crop after clearing in either burned or bulldozed crops.

A crude inorganic nitrogen balance sheet is shows in Table 1 for the first two consecutive rice crops. The inorganic nitrogen content of the top 50cm right before planting was very high (160 kg N/ha) in both land clearing systems. After the first rice harvest, which produced low yields due to drought, most of the nitrogen was accounted for by crop uptake or remained in the soil profile. Apparently the drought prevented any significant losses. After the second crop which grew under normal weather conditions, the inorganic nitrogen supply in the soil was depleted by crop uptake and other losses. At higher fertility levels, crop uptake increased and nitrogen losses decreased. These losses are a balance between leaching plus denitrification minus organic matter mineralization. Given the heavy rainfall and the well-drained nature of the soil, leaching is presumed to be the main loss mechanism.

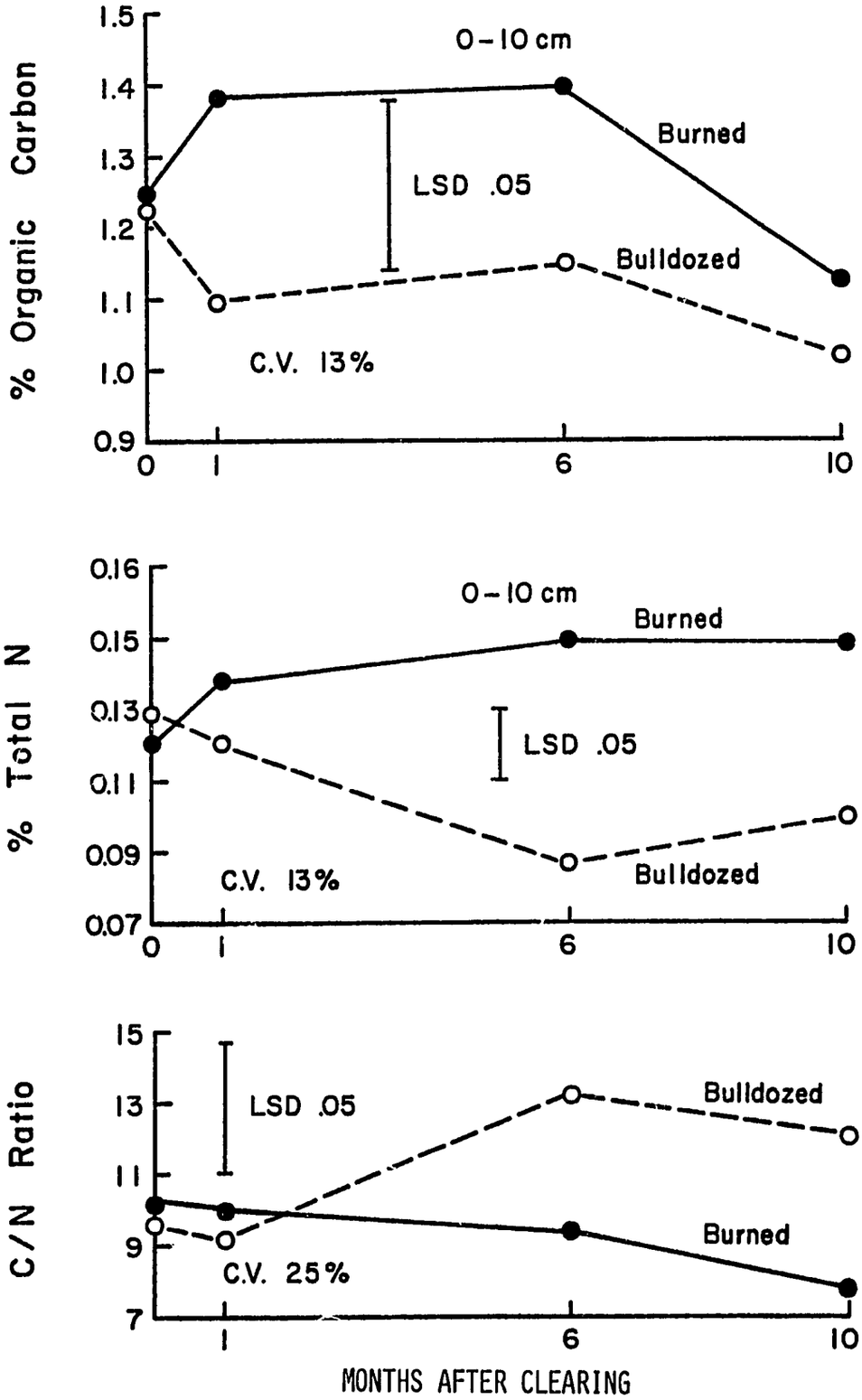


Fig. 5. Changes in soil organic carbon, organic nitrogen and C/N ratios in the top 10cm as a function of time after clearing.

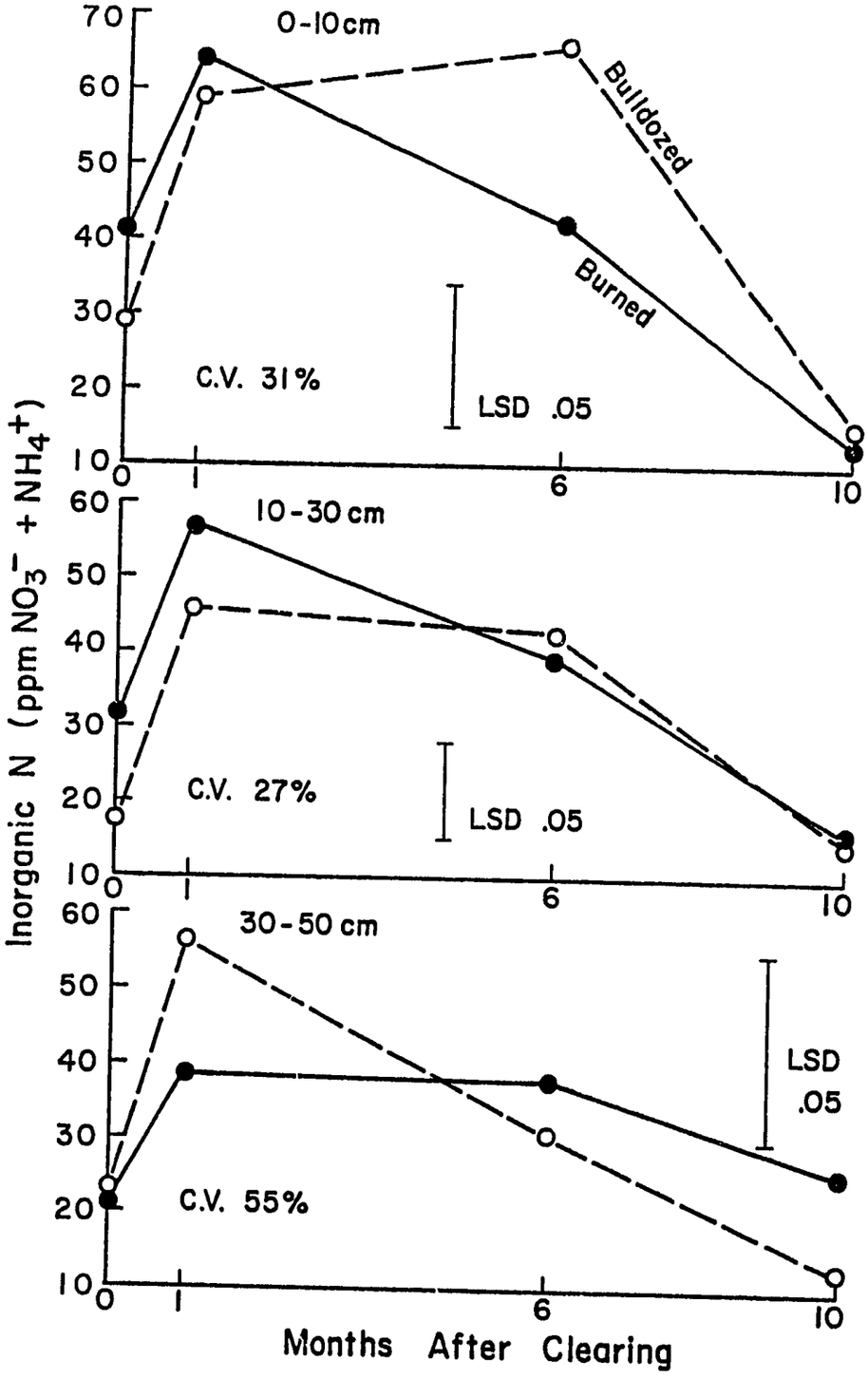


Fig. 6. Effects of land clearing methods upon inorganic N as a function of time after clearing.

Table 1. Summary of nitrogen changes during the first two consecutive upland rice crops.

Clearing method and parameters	Check	Fertilizer applied to 2nd. crop		
		50-0-40	50-172-40	50-172-40 + 4 tons/lime
	kg N/ha			
BURNED PLOTS				
Soil inorg. N at first planting	160	160	160	160
Crop uptake, first planting	38	38	38	38
Soil inorg. N at first harvest	120	120	120	120
Net gain or (loss), 1-6 months	(2)	(2)	(2)	(2)
Fertilizer N applied	0	50	50	50
Crop uptake, second planting	36	49	62	69
Soil inorg. N at second harvest	55	41	36	55
Net gain or (loss), 6-10 months	(29)	(80)	(72)	(46)
BULLDOZED PLOTS				
Soil inorg. N at first planting	163	163	163	163
Crop uptake, first planting	29	29	29	29
Soil inorg. N at first harvest	140	140	140	140
Net gain or (loss), 1-6 months	(4)	(4)	(4)	(4)
Fertilizer N applied	0	50	50	50
Crop uptake, second planting	28	34	39	87
Soil inorg. N at second harvest	43	53	55	53
Net gain or (loss), 6-10 months	(69)	(103)	(96)	(50)

CROP PERFORMANCE IN BURNED AND BULLDOZED LAND CLEARING METHODS

The previous section suggests that the pattern of fertility decline is more rapid in land cleared mechanically than with the traditional slash-and-burn technique. Crop growth during the past two years confirms this supposition.

Yields

The overall effect of land clearing methods on crop performance is illustrated in Table 2 where the average of eight crop harvests and six forage cuttings are shown at three fertility levels. In unfertilized plots, bulldozing reduced yields to about 1/3 of the burned plots. When nitrogen, phosphorus and potassium were applied, bulldozing reduced yields to approximately 1/2 of the burned plots. In plots receiving these fertilizers and lime, bulldozing reduced yields to about 8/10 of the burned plots.

The detrimental effects of bulldozing therefore, were partially compensated by fertilization, but the yield levels, with the exception of cassava, were never equivalent to the burned plots yields. The grain crops (rice, corn and soybeans) were most sensitive to the detrimental effects of bulldozing. Cassava and Guinea grass (*Panicum maximum*) were the least sensitive.

Fertilizer Efficiency

The initial results with rice also indicate that fertilizer efficiency was lower in the bulldozed clearings. Table 3 shows that the apparent recovery of fertilizer nitrogen, calculated by nutrient uptake differences was consistently higher in the slash-and-burn system. Fertilizer nitrogen recovery increased drastically with phosphorus and lime applications, due to better rice growth. The nitrogen recovery values in plots fertilized with phosphorus and limed are very high for upland rice.

Economic and Social Implications

The results of this two-year study strongly favors the traditional slash-and-burn system of land clearing. In addition to the agronomic disadvantages, bulldozer clearing has some economic and social disadvantages for this area. Mechanized land clearing costs from two to three times as much per hectare as manual land clearing (1973 Annual Report). This difference does not include transportation and maintenance costs of the machines.

Table 2. Summary of effects of land clearing methods on crop yields, 1973-1974. Yields are the average of the number of crops indicated.

Crop	No. of harvests	Fertility level*	Burned	Bulldozed	Bulldozed / Burned
			------tons/ha ------		%
Rice (grain)	3	0	1.33	0.70	53
		NPK	3.00	1.47	49
		NPKL	2.90	2.33	80
Corn (grain)	1	0	0.10	0.00	0
		NPK	0.44	0.04	10
		NPKL	3.11	2.36	76
Soybeans (grain)	2	0	0.70	0.15	24
		NPK	0.95	0.30	34
		NPKL	2.65	1.80	67
Cassava (roots)	2	0	15.4	6.4	42
		NPK	18.9	14.9	78
		NPKL	25.6	24.9	97
Guinea grass (dry matter per year)	6	0	12.3	8.3	68
		NPK	25.2	17.2	68
		NPKL	32.2	24.2	75
Mean relative yields		0	-	-	37
		NPK	-	-	47
		NPKL	-	-	78

*50 kg N/ha, 172 kg P/ha, 40 kg K/ha, 4 tons of lime.

Table 3. Apparent fertilizer nitrogen recovery by rice during the second consecutive crop. N rate = 50 kg N/ha. K rate = 40 kg K/ha.

P	Lime	Burned	Bulldozed
kg/ha	tons/ha	---------- % recovery ----------	
0	0	26	12
172	0	52	22
172	4	66	58

Comparative production costs for the first three consecutive rice crops as affected by land clearing methods and fertilization are shown in Table 4. They are very preliminary estimates because the first crop's rice yields were extremely low due to drought, fertilizers and lime were applied after the first crop, the cost of labor, fertilizers and and transportation are likely to vary widely. Also the investment in both land clearing and fertilization should not be applied to the first three crops only. In addition, the labor costs charged for land clearing, cultural practices, harvesting, threshing and transporting the crop to the rice mill are non-monetary costs to these farmers, because family is used exclusively. In spite of all these limitations, Table 4 clearly shows that the slash-and-burn technique was profitable at all fertility levels while the bulldozed land clearing was unprofitable. It is interesting to note that despite the fact that transportation costs of fertilizers and lime equal their purchase cost, and the low rice yield levels, fertilization was profitable, particularly in the treatment which received no phosphorus or lime.

It is possible that other types of mechanized land clearing are likely to do less damage to soil physical properties than the one used. The highly important free fertilizer of the ash is lost unless the vegetation is burned. A combination of burning and bulldozing has been attempted in Pucallpa, using tree crushers to fell the vegetation, followed by burning and by log and stump removal with a root rake. Two machine operations, however, increase costs significantly. It is also possible that the agronomic disadvantages can be minimized in soils with better physical properties and higher native fertility. Unfortunately, this combination is rarely found in the Amazon Jungle although it may be present in parts of Africa with high-base status Oxisols.

The traditional slash-and-burn method has some social and logistical advantages. It can be done during the period of least rainfall when people are not very busy. It can also be done at a large scale, even in relatively unpopulated areas. A 700 hectare jungle area was cleared successfully by hand at the Granja Yurimaguas (Km 17) last year, planted to Guinea grass and is producing good pasture.

An additional advantage is that the transition from shifting to continuous cultivation by small farmers can be accomplished gradually by clearing small amounts of land every year. When large areas are cleared mechanically, the logistical problems of delayed fertilizer

Table 4. Comparative production costs and income from the first three consecutive upland rice crops grown within 17 months after clearing (preliminary estimates due to residual effects of future crops).

Parameter	Burned			Bulldozed		
	0	NK*	NPK-Lime*	0	NK*	NPK-Lime*
	S/. /ha					
INCOME						
Rice yields in 3 crops (tons/ha)	4.55	6.97	7.98	3.03	5.00	7.26
Rice value	27,300	41,820	48,880	18,180	30,000	43,560
Firewood (100 m^3/ha)	3,000	3,000	3,000	0	0	0
Gross Income	30,300	44,820	50,880	18,180	30,000	43,560
EXPENDITURES:						
Land clearing and preparation	3,500	3,500	3,500	17,000	17,000	17,000
Cultural practices	5,400	5,400	5,400	5,400	5,400	5,400
Harvesting and threshing	4,368	6,691	7,600	2,908	4,800	6,969
Crop transportation to the mill	1,820	2,788	3,192	1,212	2,000	2,904
Fertilizers and lime	0	1,045	8,045	0	1,045	8,045
Fertilizers and lime transportation	0	1,250	8,361	0	1,250	8,361
Total Costs	15,088	20,674	36,158	26,520	31,495	36,674
Profit or (loss)	15,212	24,146	14,722	(8,340)	(2,505)	(5,119)

Prices: (July 1974). Rice: S/.6,000/ton. Firewood: S/.30/m^3. Man-day of labor: S/.60. Crop transportation to the rice mill S/.400/ton. Urea: S/.3,300/ton. Ordinary superphosphate: S/.2,100/ton. KCl: S/.5,000/ton. Lime from Juanjui: S/.1,200/ton. Transportation of fertilizers from Lima by land/river barge: S/.3,800/ton. Lime from Juanjui: S/.1000/ton. Exchange rate: 1U.S.$ = S/.43.38.

*50 kg N/ha, 172 kg P/ha, 40 kg K/ha, 4 tons lime/ha.

shipments, vigorous jungle regrowth and lack of labor at harvest time can become severe.

The decision is finally one of economics and policy. Our results strongly suggest continued use of the traditional slash-and-burn system, as an appropriate low-energy-technology component of soil management.

Table 5. Clearing, burning and first planting dates of the three clearing chacras in the continuous cropping experiments.

Chacra (Clearing)	Cutting	Burning	First Planting
I	September 8, 1972	September 26, 1972	October 5, 1972
II	June 15, 1973	August 15, 1973	October 26, 1973
III	June 25, 1974	August 14, 1974	September 16, 1974

CONTINUOUS CROPPING EXPERIMENT

The long-term continuous cropping experiment increased in size this year with the opening of the third yearly clearing. In this fashion the same crops are grown in the same soil and fertility levels subject to a time of clearing variable. The clearing dates of the three "chacras" are shown in Table 5. Chacras II and III were cleared by the slash-and-burn method. The burned portion of Chacra I was continued in this experiment. Due to size and time limitations, the experiment now consists of four cropping systems: continuous upland rice, rice-cassava-plantains, rice-corn-soybeans and rice-Guinea grass pasture. The cropping sequences are illustrated in Fig. 7. Details on varieties and cultural practices are the same as those described in the 1973 Annual Report.

Seven treatments, each comprising a fertilization strategy were superimposed on the cropping systems. The original treatments in Chacra I were modified to conform with these in July 1973. A description of each treatment follows:

1. Untilled: No fertilization or tillage

2. Control: No fertilization, rototilled as Treatments 3 to 7

3. Maintenance: An attempt to give back to the soil what the plants removed. A rate of 40 kg N/ha, 20 kg P/ha and 30 kg K/ha was used per crop. Half of that amount was applied after each pasture cutting every two months. A basal application of 32 kg S/ha and 0.5 kg B/ha was added to the first crop.

4. Complete: Fertilization and liming according to soil test recommendations. A corrective basal application of 80 kg N/ha, 100 kg P/ha, 80 kg K/ha, 0.5 kg/ha of B and Mo plus 3.5 tons/ha of lime to raise the pH to 5.5 was broadcast and incorporated before the first crop. Subsequent crops received 80-20-80 and subsequent pasture cuttings 50-0-50 of N, P, K. In pastures a second application of 60 kg P/ha was added at the beginning of the second year. The pH will be corrected annually to 5.5. In two years this has not been necessary. A second boron application was added at the beginning of the second year at the same rate.

5. Complete-P: Same as 4 except no further phosphorus applications will be added in order to evaluate the residual effect.

6. Complete-K: Same as 4 except for no further potassium applications

7. Half Complete: Half the rate of Treatment 4

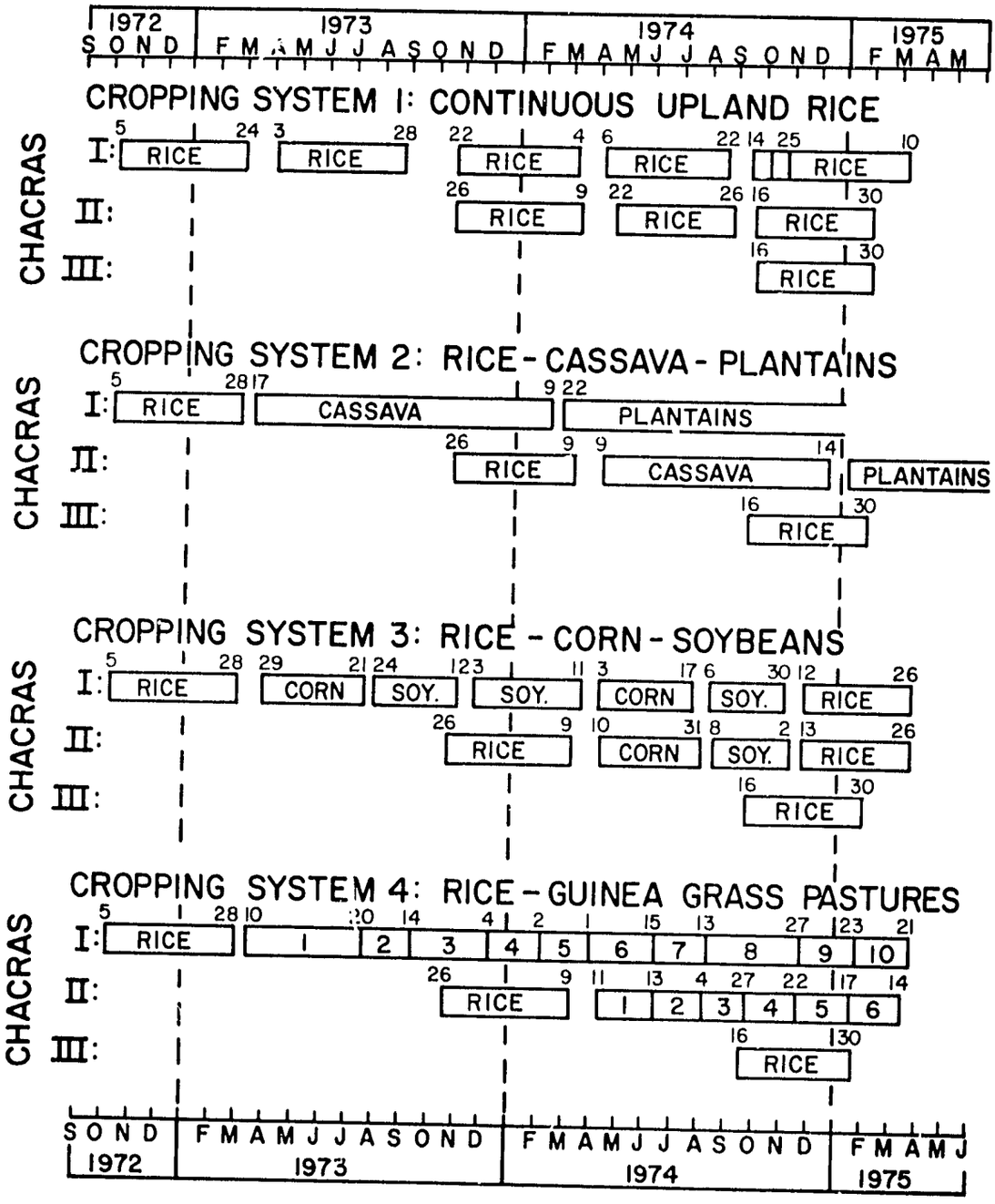
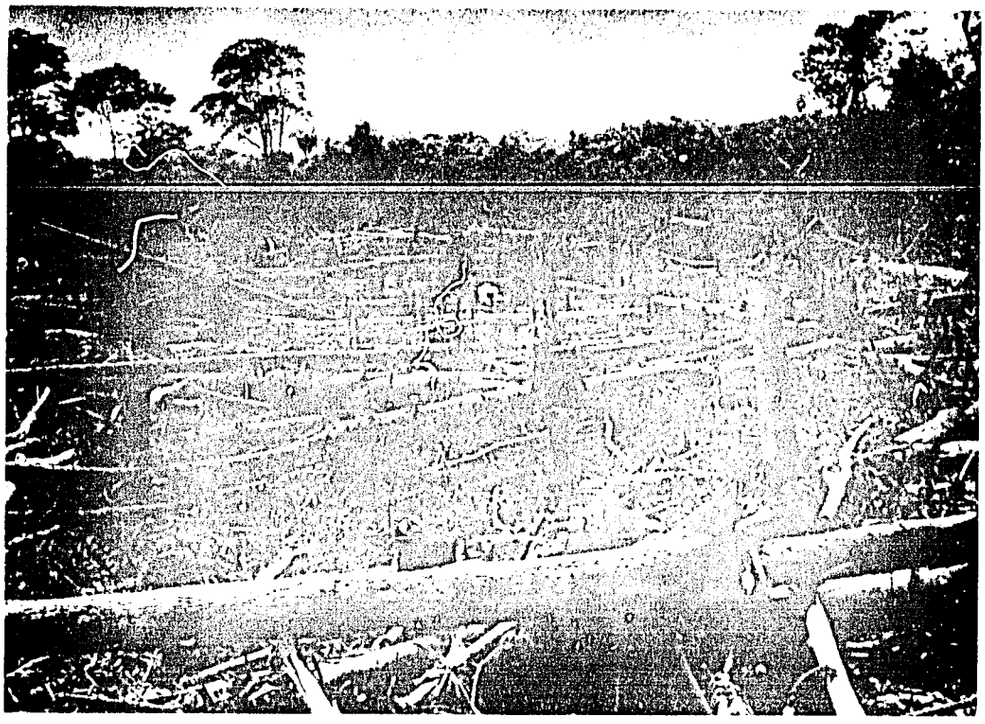
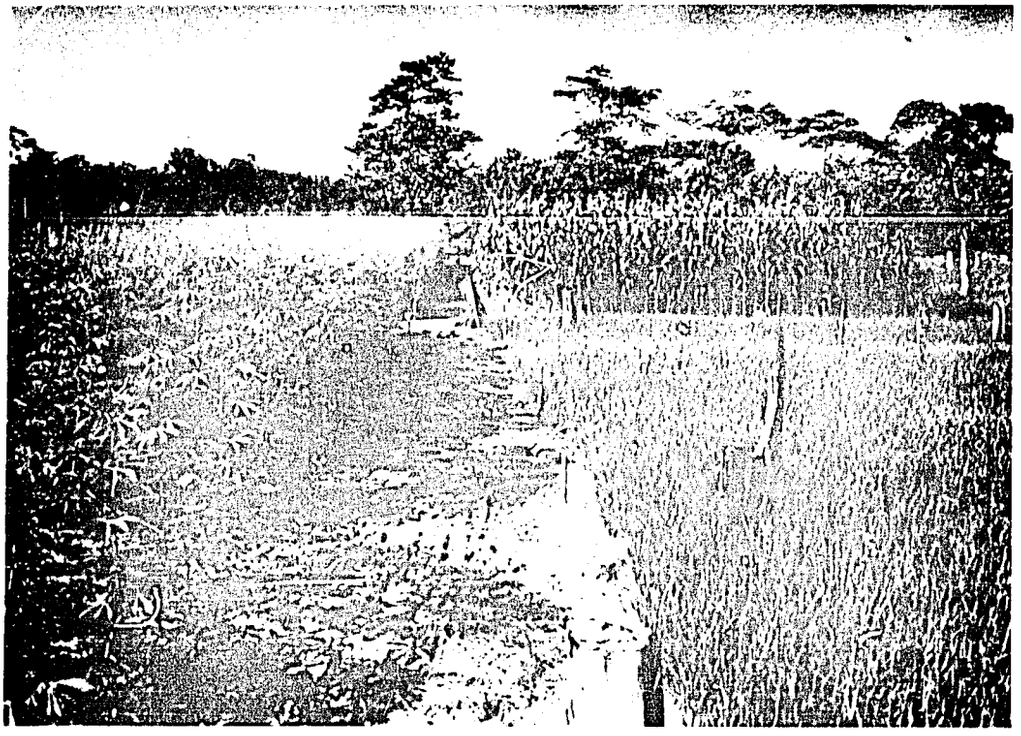


Fig. 7. Cropping scheme used in the continuous cropping experiments. Numbers in the corner of the rectangles refer to planting and harvesting dates.



View of Chacra III after hand clearing (top) and during burning (bottom).



Above: The four continuous cropping systems growing on Chacra II in July 1974. Bottom left: cassava in System 2. Bottom right: continuous rice in System 1. Top left: Guinea grass in System 4. Top right: corn in System 3.

Below: Incorporating lime by rotovation with a hand tractor.

Treatments 2 to 7 were rototilled with a 6 hp. Kubota hand tractor to incorporate the basal lime and phosphorus applications to a depth of 10cm. Urea, KCl, S flower, and borax were applied broadcast at appropriate times. Rice and soybean seeds were treated with a solution of ammonium molybdate to provide an annual rate of 0.5 kg Mo/ha.

Continuous Rice System

Rice yields during the second continuous year of Chacra I and the first full year of Chacra II are presented in Table 6. Yields declined rapidly without fertilization but averaged an annual production of 6 tons/ha with the complete treatments in both chacras. The pattern of rapid yield declines with time is shown in Table 7 where the yields of the September 1974 planting are shown in land cleared 0, 1 and 2 years ago. The overall trends with time are shown in Fig. 8. Without fertilization, rice yields were maintained between 1.0 and 1.5 tons/ha during the first three consecutive crops of Chacra I. They dropped to near zero in the fourth and fifth consecutive crops. With maintenance fertilization, rice yields remained steady at 2.5 tons/ha in the second and third crops but declined afterwards. With the complete fertilizer and lime rate yields peaked at 3.7 tons/ha in the third crop but declined drastically in the fourth and fifth crops. Yield declines in rice planted in April are expected because of the more frequent water stress. A further yield decline in the September 1974 planting was not expected. Problems in germination and initial stand were encountered. These plots had to be replanted three times as shown by broken lines in Fig. 7.

It was hoped that the complete treatments would maintain a yield level fluctuating between 2.5 and 3.5 tons/ha per crop. This is what happened in Chacra II as shown in Fig. 8. Both complete and maintenance treatments fluctuated within this range while yields in the control plots dropped rapidly after the first crop. No germination or initial stand problems were observed in plots cleared in 1974.

No yield differences were observed between the complete and complete-P treatments implying a satisfactory residual effect of the basal 100 kg P/ha application. The cumulative yields of three crops in the first and second chacras were almost identical in these two treatments. Suspending further potassium applications caused a steep yield decline in the fifth consecutive rice crop in Chacra I as shown in Table 7. This effect was not observed in the first three crops of Chacra II. Reducing the complete rate to 1/2 did de-

Table 6. Upland rice yield performance during the second year of Chacra I and the first year of Chacra II.

Treatment	Chacra I (second year)			Chacra II (first year)		
	Oct. 73 (3rd crop)	April 74 (4th crop)	Annual yield	Oct. 73 (1st crop)	April 74 (4th crop)	Annual yield
	Tons/ha					
Untilled	1.29	0.30	2.59	3.73	1.17	4.90
Control	1.36	0.77	2.13	2.79	1.73	4.52
Maintenance	2.52	1.71	4.23	3.33	2.43	5.76
Complete	3.86	2.42	6.28	3.49	2.89	6.38
Complete - P	3.53	2.00	5.53	3.59	2.75	6.34
Complete - K	3.41	1.21	4.62	3.59	2.58	6.17
1/2 Complete	3.10	1.48	4.58	3.54	2.32	5.86

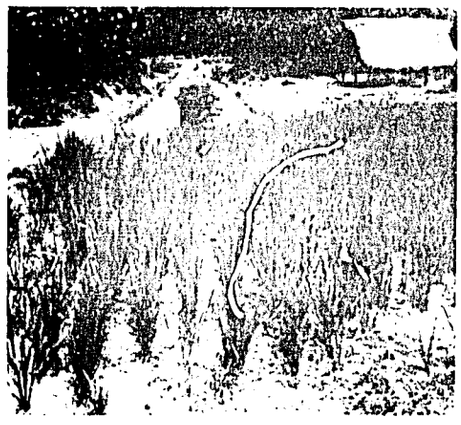
Table 7. Effect of time after clearing on upland rice yields planted in September.

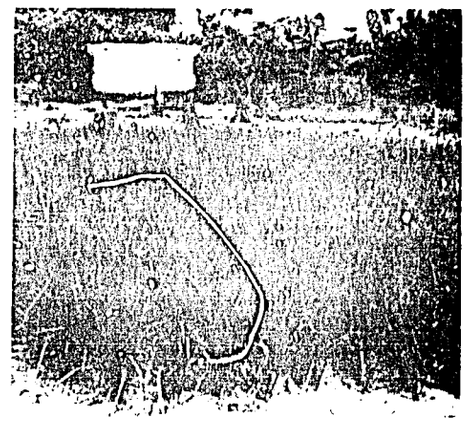
Treatment	Chacra I (1972) 5th crop	Chacra II (1973) 3rd crop	Chacra III (1974) 1st crop
	tons/ha		
Untilled	0.42	1.21	3.77
Control	0.35	1.47	2.69*
Maintenance	0.82	3.10	3.86
Complete	1.32	3.72	4.37
Complete - P	1.41	3.92	4.21
Complete - K	0.50	4.06	3.84
1/2 Complete	1.28	3.28	3.98

*Ash removed.

Unfertilized Complete

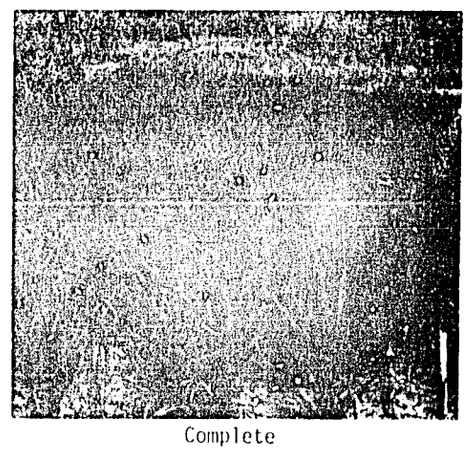
First Crop after Clearing (Chacra III)





Unfertilized Complete

Third Crop after Clearing (Chacra II)



Unfertilized Complete

Fifth Crop after Clearing (Chacra I)

Rice growth showing the yield decline pattern in unfertilized plots and the effect of complete fertilization in maintaining continuous cropping. All crops planted in September 1974.

crease yields somewhat. The cumulative yield of three crops decreased from 7.6 to 5.9 tons/ha in Chacra I and from 11.1 to 9.1 tons/ha in Chacra II when the "complete" rate was decreased in half.

Rice-Corn-Soybeans Rotation

The results of the fourth to seventh consecutive crops in Chacra I are shown in Table 8. The yields of the first to fourth crops in Chacra II appear in Table 9. The overall trend is shown in Fig. 8. The behavior of the unfertilized treatments was very similar to the continuous rice system. Yields decreased to almost zero after one year of cropping in the 1972 clearing. Yields also followed the same sharp decline pattern as continuous rice in the 1973 clearing. The maintenance treatments, however were less successful than in the continuous rice system. Corn and soybeans are more sensitive to high aluminum saturation levels than rice.

The complete treatment was successful in maintaining relatively high yield levels in this system. Rice, corn, and soybean yields were maintained at a level between 2.5 and 3.0 tons/ha each. Although these are good yields for rice and soybeans, they are still mediocre for corn. We suspect that this is a genetic effect and that no adequate corn varieties or hybrids are available. Also the pest and disease problems are most serious with corn. We have yet to obtain an excellent corn yield in Yurimaguas.

The excellent performance of the last rice crop with the complete treatment sharply contrasts the poor performance of the same planting in the continuous rice system. Although the dates of planting are different, the dates of harvest were the same because of the reseeding problems in the continuous rice system. This suggests a beneficial effect of the rice-corn-soybean rotation which permits good rice growth and prevents the germination and initial stand problems encountered with continuous rice. The reasons for these differences are being investigated.

Rice-Cassava-Plantains-Fallow

The plantain crop planted in the 1972 clearing was lost to disease. These plots have been allowed to go back to fallow. The cassava yield in the 1973 clearing are shown in Table 10. They are compared with a cassava crop planted at the same time in extra plots of the 1972 clearing which were previously grown to grain sorghum, beans, soybeans, and soy-

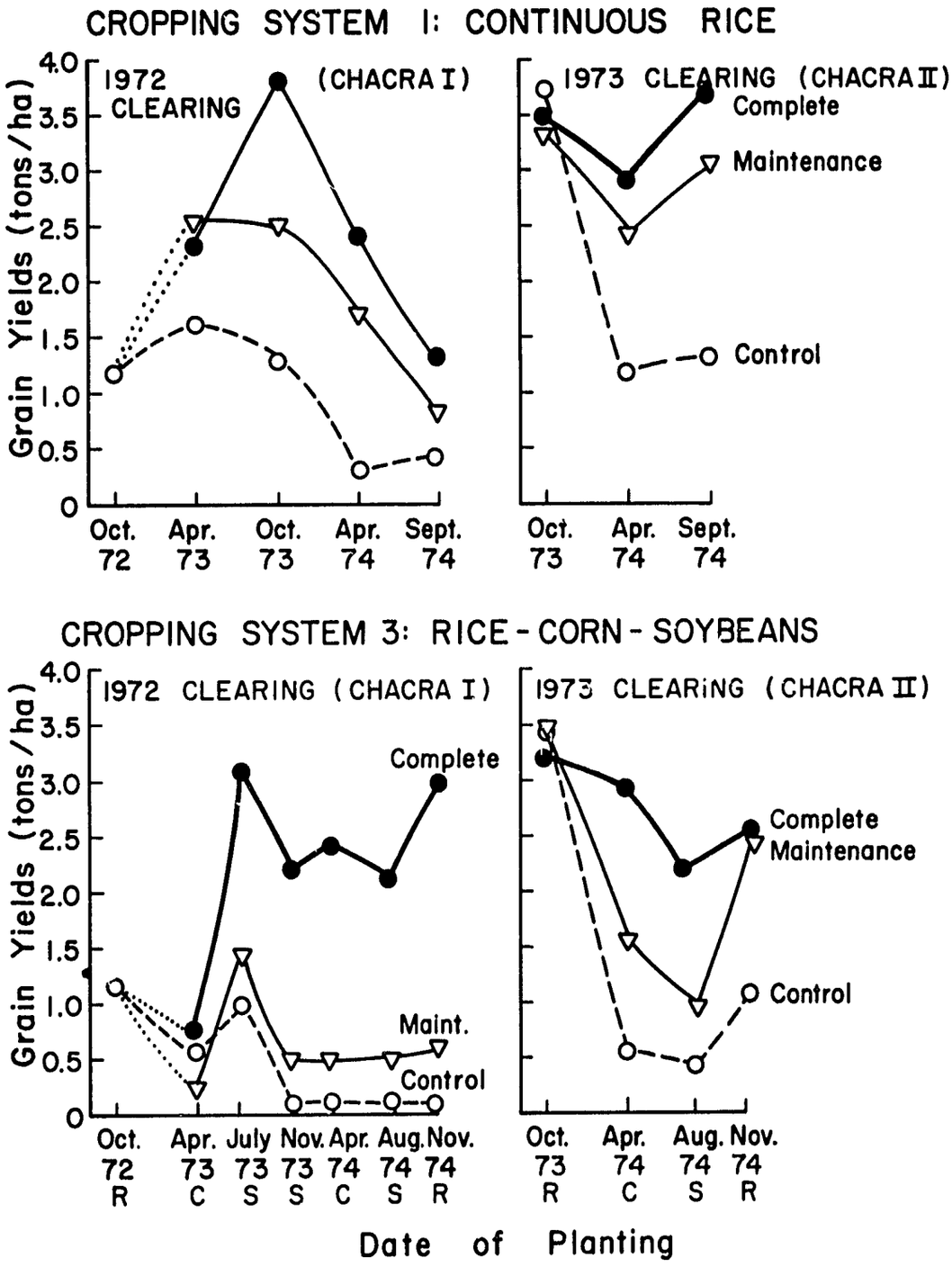


Fig. 8. Yields of continuous rice and rice-corn-soybean systems as a function of time after clearing and fertilization. R = rice, C = corn, S = soybeans.

Table 8. Grain yields of the rice-corn-soybean system in the 1972 clearing. Fourth to seventh consecutive crops in Chacra I.

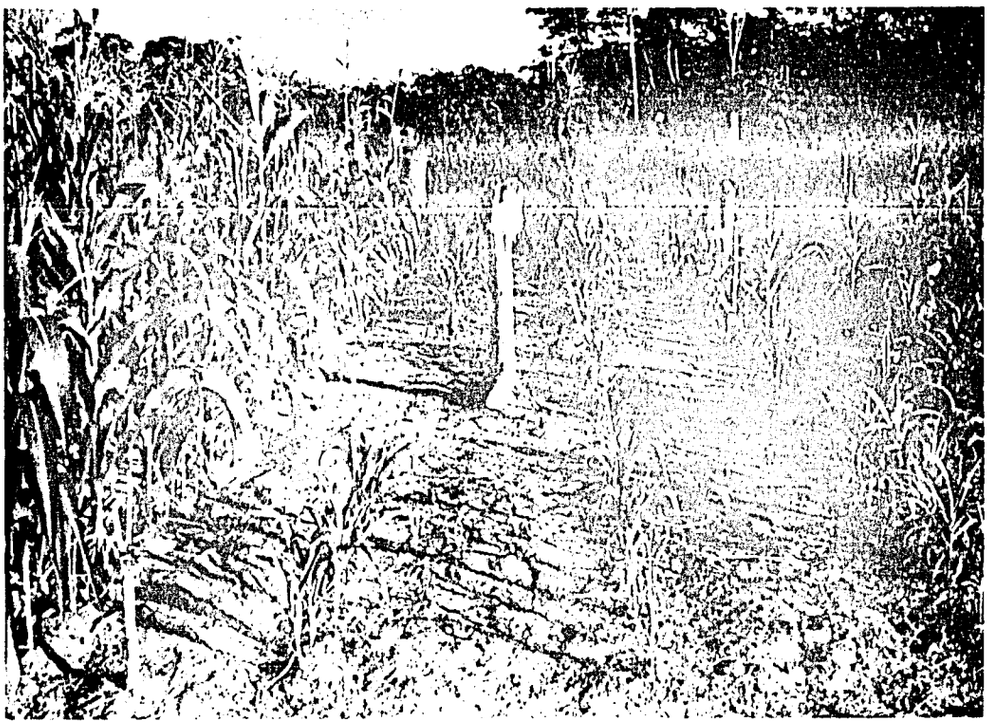
Treatment	4th Soybeans Nov. 73	5th Corn Apr. 74	6th Soybeans Aug. 74	7th Rice Nov. 74
	tons/ha			
Untilled	0.08	0.10	0.13	0.16
Control	0.27	0.09	0.32	0.51
Maintenance	0.49	0.44	0.50	0.66
Complete	1.61	3.11	2.09	3.01
Complete - P	2.19	2.42	2.03	2.95
Complete - K	1.66	2.21	1.27	1.31
1/2 Complete	1.47	1.72	1.41	1.42

Table 9. Grain yields of the rice-corn-soybean system in the 1973 clearing. First to fourth consecutive crops in Chacra II.

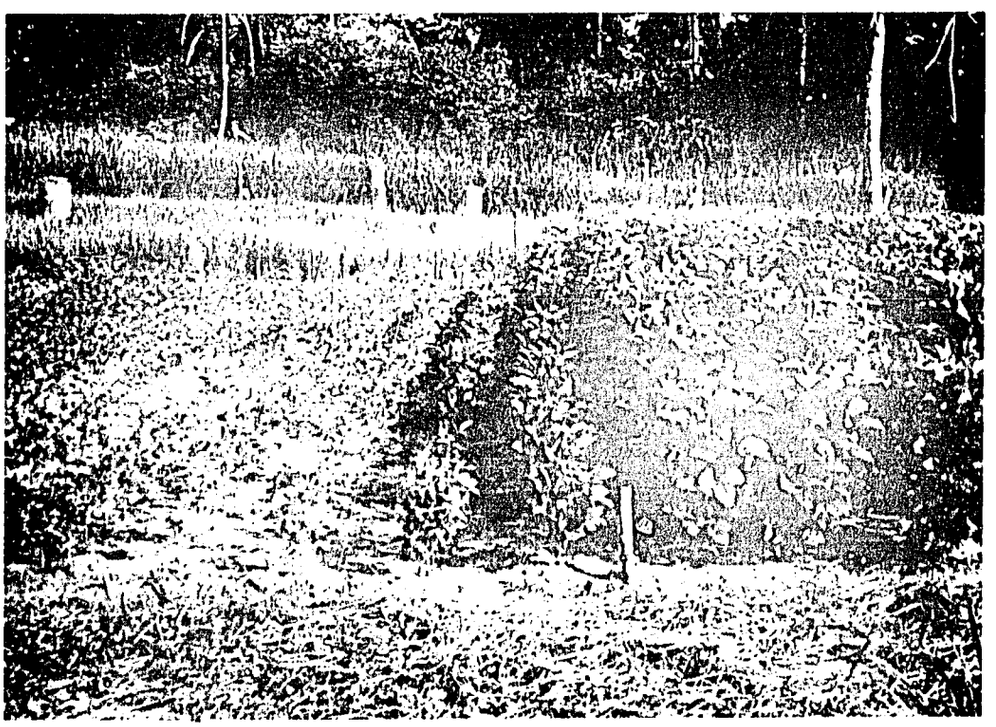
Treatment	1st Rice Oct. 73	2nd Corn Apr. 74	3rd Soybeans Aug. 74	4th Rice Nov. 74
	tons/ha			
Untilled	3.46	0.60	0.42	1.10
Control	3.36	0.63	0.65	1.37
Maintenance	3.48	1.56	0.93	2.47
Ideal	3.21	2.96	2.19	2.54
Complete - P	3.18	2.29	1.75	2.94
Complete - K	3.16	2.72	1.61	2.39
1/2 Complete	3.32	2.51	1.35	2.76

Table 10. Effects of time after clearing on cassava production planted in April 1974.

Treatment	Chacra I 5th crop	Chacra II 2nd crop
	tons/ha of roots	
Untilled	9.4	13.6
Control	8.3	11.1
Maintenance	8.8	15.2
Complete	17.0	20.1
Complete - P	17.1	20.4
Complete - K	18.4	20.7
1/2 Complete	18.6	20.3



The rice-corn-soybeans system requires the complete fertilization in order to be fully productive. Top: unfertilized corn in the center vs. complete on far left. Bottom: unfertilized soybeans at the left, complete fertilization on the right.



beans. In this fashion, the effects of time after clearing could be compared. Yields were consistently lower in the 1972 clearing particularly in the control and maintenance treatments. Cassava responded strongly to the complete fertilization and liming of the complete and 1/2 complete treatments in both clearing systems. This substantiates the observations made in the 1973 Annual Report on the response of cassava to relatively high fertilizer inputs. The 1/2 complete treatment however, seems the most promising, since it produced similar yields.

Rice-Guinea-Grass Pasture

The rice-Guinea grass (*Panicum maximum*) system is of immediate interest to the region because many farmers are actually practicing it. Table 11 summarized the annual dry matter production during the first and second years of Chacra I and the first year of Chacra II. Annual dry matter production was relatively low, about 10 tons/ha for the first year in unfertilized plots, and decreased in the second year to a very low figure of 6 tons/ha. With maintenance fertilization, annual dry matter production doubled in all cases. This indicates that *Panicum maximum* is tolerant to high aluminum saturation since liming was not included in the maintenance treatment. The complete treatments increased production further, but probably to a degree not justifiable by the extra investment in lime and fertilizer.

Fig. 9 illustrates the yields over time. Dry matter production responses to fertilization were sharp in the second half of 1973, but during 1974, all treatments tended to produce stable yields in both clearings. This suggests superior weather conditions during 1973, and not an effect of age of clearing.

Dry matter production is only one component of forages. The nutritional and quality components are being determined but are not available at the time of this writing. Nevertheless, the trend suggests that continuous forage production can be maintained at a high yield level with a maintenance application.

Economic Implications

A preliminary analysis of the economics of fertilization during the first 15 to 17 months of Chacra II has been prepared for each cropping system at the maintenance, complete and 1/2 complete fertilization levels. The results shown in Table 12 are based

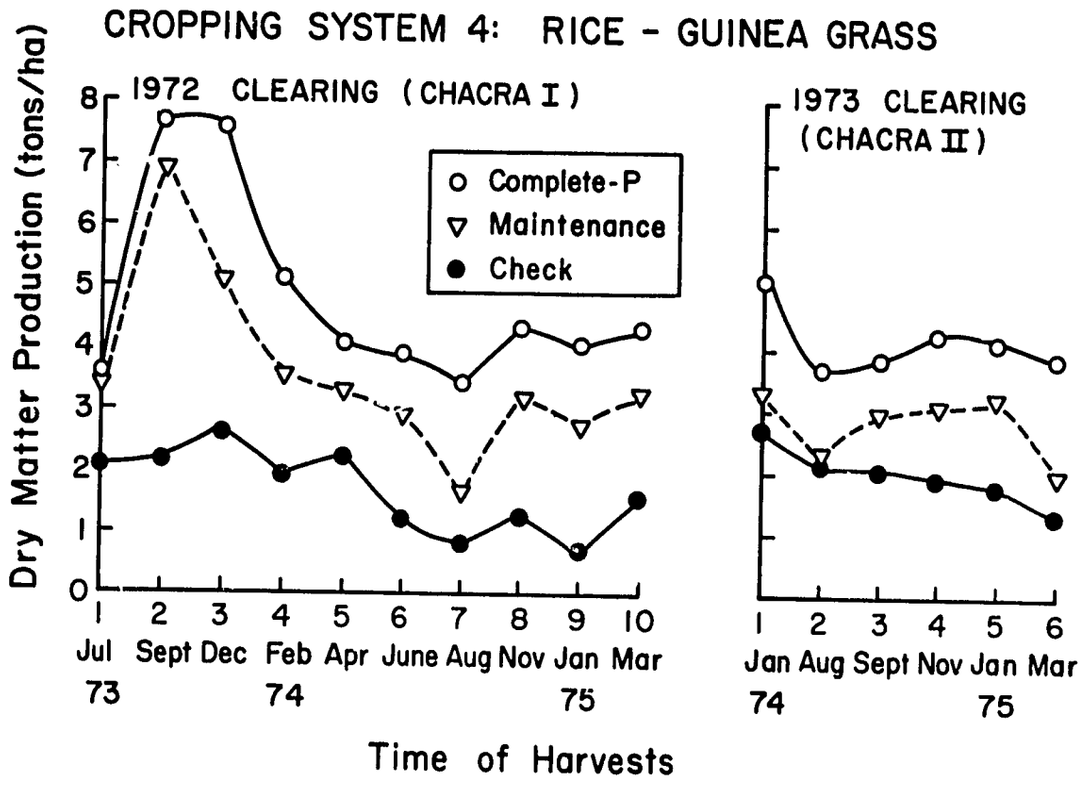


Fig. 9. Effects of time after clearing and fertilization on Guinea grass dry matter production in the continuous cropping experiment.

Table 11. Annual dry matter production of Panicum maximum in the Rice-Guinea grass cropping system. Sum of cuttings at 2 months intervals. Period of April 1974 to March 1975.

Treatment	1972 clearing		1973 clearing
	1st to 5th cuts March 73-April 74	6th-10th cuts April 74-March 75	1st to 6th cuts April 74-March 75
	ton/ha of dry matter		
Untilled	10.9	6.3	10.1
Control	11.0	5.8	12.2
Maintenance	22.3	13.8	20.1
Complete*	-	17.7	20.0
Complete - P	28.2	13.7	24.3
Complete - K*	-	12.4	19.8
1/2 Complete*	-	12.4	22.7

*Lime and P basal rates incorporated June 1974.

on the newly subsidized fertilizer prices put in effect in Peru in 1975. Transportation costs are not considered. As in the previous economic analysis, this is tentative because of the expected residual effects of lime and phosphorus applications. Table 12 shows that the maintenance treatment produced approximately 3 soles per sol invested in fertilizer and lime in the continuous upland rice. The 1/2 complete treatment, however, produced the highest profit. For the rice-cassava system the 1/2 complete produced the highest return on investment and the highest profit as well. In the rice-corn-soybean system the complete treatment produced the highest overall return to fertilization of the experiment (about US $796/ha). This is equivalent to 2.6 soles per sol invested in fertilizers and lime. The value of the Guinea grass forage, according to estimates of Ing. G. Carrasco of the Universidad Nacional Agraria was set at S.1,500/tons of dry matter. With these prices the rice-Guinea grass system produced the highest profit and return per sol invested in fertilizers at the 1/2 complete level.

The prices around Yurimaguas are fluctuating widely, so these figures can be considered only tentative. In spite of its limitations, this analysis shows that continuous cropping can be profitable at the fertilizer subsidy prices.

The critical issue is the transportation costs of fertilizers. At present fertilizers can only be obtained from Lima via road and river barge at a cost of approximately US$80 per ton. This extremely high cost reduces the profit margins to marginal levels. There are however, cheaper ways to transport fertilizers into the area. Imported fertilizers can arrive in transatlantic steamers to Iquitos via the Amazon from Europe, Venezuela or the United States. National production of urea and rock phosphates from the Bayovar complex in the Coast could be transported when the new road which connects the coast to Yurimaguas is opened next year.

Table 12. Preliminary response to fertilization during the first 15-17 months of crop production in Chacra II.

Cropping System	Fertilization Strategy		
	Maintenance	"Complete"	1/2 "Complete"
1. Continuous Rice: 3 crops, 15 months:			
Total fertilizer added (kg NPK, tons Lime/ha	120-60-90-0	240-140-240-3.5	120-70-120-1.7
Add value of yield response over control[1/] (S/. /ha)	17,720	30,660	18,900
Cost of fertilizer + lime[2/] (S/. /ha)	5,960	17,434	8,715
Profit or (loss) (S/. /ha)	11,760	13,226	10,185
S/. of added crop value per S/. invested in fertilizer and lime	2.97	1.76	2.17
2. Rice-Cassava: 2 crops, 14 months:			
Total fertilizer added (kg NPK, tons lime/ha)	80-40-60-0	160-120-160+3.5	80-70-80-1.7
Add value of yield response over control (S/. /ha)	7,060	17,572	19,540
Cost of fertilizers + lime (S/. /ha)	3,974	13,903	7,292
Profit or (loss)	3,086	3,669	12,248
S/. of added crop value per S/. invested in fertilizer and lime	1.78	1.26	2.68
3. Rice-Corn-Soybeans-Rice: 4 crops 17 months:			
Total fertilizer added (kg NPK, tons lime/ha)	160-80-120-0	320-160-320-3.5	160-110-160-1.7
Added value of yield response over control (S/./ha)	5,750	55,840	31,710
Cost of fertilizer + lime (S/. /ha)	7,895	21,295	11,508
Profit or (loss)	(2,145)	34,575	20,202
S/. of added crop value per S/. invested in fertilizer and lime	0.72	2.62	2.76
4. Rice-Guinea grass pasture: 1 crop, 6 cuts, 17 months:			
Total fertilizer added (kg NPK tons lime/ha)	160-80-120-0	380-160-380-3.5	190-80 + 90-1.7
Added value of yield response over control (S/. /ha)	9,870	13,980	15,330
Cost of fertilizers + lime (S/./ha)	7,895	23,164	11,522
Profit or (loss) (S/. /ha)	1,975	(9,184)	3,808
S/. of added crop value per S/. invested in fertilizer and lime	1.25	0.60	1.33

[1/] Estimated crop prices (1974): Rice S/. 6,000/ton (US$138); Cassava S/. 2,000/ton fresh roots (US$46); Corn S/.5,000/ton (US$115); Soybeans S/.10,000/ton (US$230); Guinea grass cut forage S/.1,500/ton dry matter (US$34).

[2/] Subsidized fertilizer prices (1975): Urea S/.23.6/kg N (US$0.54); Single superphosphate S/.15/kg P_2O_5 (US$0.34); KCl S/.10/kg K_2O (US$0.23); Lime from Juanjui S/.1,200/ton (US$27).

PASTURE FERTILIZATION

The first series of satellite experiments to determine optimum fertilizer rates and sources was initiated in October, 1973 with Panicum maximum, the most commonly used grass pasture species in the area. The objectives and experimental procedures are described in the 1973 Annual Report. The studies include experiments on nitrogen, phosphorus-lime and an evaluation of the Fosbayovar rock phosphate. Guinea grass was cut as forage every 60 days in all experiments. The initial soil properties, not previously reported, are shown in Table 13.

Nitrogen Experiment

The annual dry matter yield of Panicum maximum is shown in Table 14. Without fertilization annual dry matter production was 13 tons/ha. When Stylosanthes guyanensis was seeded as a source of nitrogen, and the soil received phosphorus, potassium and lime, annual yields increased to 18 tons/ha. In terms of dry matter production, Stylosanthes performed similarly to urea at an annual rate of 100 kg N/ha urea. The amount of Stylosanthes in the sixth cut, the first time it was sufficient to be measured, increased with liming, phosphorus and potassium applications.

When urea was used as the source of nitrogen, a maximum yield of 25 tons/ha was attained with an annual rate of 400 kg N/ha. When sulfur-coated urea (SCU), a slow release nitrogen source was used, a maximum yield of 22 tons/ha was obtained with 100 kg N/ha/yr. This suggests that the slow release properties of SCU can reduce the fertilizer nitrogen rate to 1/4 of that needed by urea in soils like this Ultisol where nitrogen leaching losses are suspected to be high.

The effect of these treatments on forage quality are being determined. Judging from dry matter production alone, the use of a legume adapted to these conditions such as Stylosanthes guyanensis seems promising provided that the pasture is adequately fertilized and limed to pH 5.5. The nutritional reasons for the need of liming are not yet determined. Stylosanthes is very tolerant to aluminum toxicity, and consequently the lime response was not expected. Chemical analysis might answer this question, but straight calcium deficiency is suspected. In mixed grass-legume pastures, the relationships are more complex than in pure legume stands.

Table 13. Topsoil properties of the two pasture fertilization experiments at planting time (October 1973).

Experiment	pH	Organic C	Avail. P (Olsen)	Exchangeable Al	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Effective CEC	Al Satn.
		%	ppm	---------- meq/100 cc ----------					%
Nitrogen	4.6	2.0	2.3	1.87	1.60	0.30	0.01	3.78	49
P - lime	4.7	2.2	2.7	1.93	1.60	0.30	0.01	3.84	50

Table 14. Annual dry matter production of Panicum maximum forage cut every two months. Sum of 6 cuts every two months[1/].

Nitrogen source	Annual N rate	Application of P, K, Lime[1/]	Total Dry Matter	Stylo in 6th cut: Composition	Stylo in 6th cut: Dry Matter
	kg/ha		(tons/ha)	%	kg/ha
0	0	0	13.3	-	-
	0	L	15.5	-	-
Stylo	20[2/]	0	9.8	27	220
	20	PK	13.0	2	28
	20	L	15.4	22	245
	20	PKL	18.2	38	690
Urea	100	PKL	17.7	-	
	200	PKL	19.6	-	
	400	PKL	25.1	-	
	800	PKL	25.6	-	
SCU	100	PKL	22.0	-	
	200	PKL	22.1	-	

[1/] Basal application of 3.5 tons lime/ha, and 50 kg P/ha. Topdressed applications of 30 kg K/ha per cut. The entire experiment received a blanket application of 30 kg S/ha.

[2/] Starter application.

The performance of the inorganic fertilizer, particularly the 100 kg N/ha rate as sulfur-coated urea, produced higher annual dry matter yields than the leguminous source. The rate of urea which produced maximum yields (400 kg N/ha) is most likely uneconomical due to its high cost. The 100 kg N/ha rate as SCU is promising. The experiment is continuing for a second year. The longer term effects may determine whether Stylosanthes or SCU are the best alternatives.

Lime-Phosphorus Experiment

The second pasture experiment aims at determining the optimum lime and phosphorus rates for *Panixum maximum* and to compare the behavior of a 200 kg P/ha basal rate of different rock phosphate sources with several rates of ordinary superphosphate. The experimental design was described in the 1973 Annual Report. The results for the first full year are shown in Fig. 10.

There was a strong response to superphosphate, a lesser one to lime applications and an interaction between the two. Without lime, an annual application of 50 kg P/ha seems to be the optimum, with a total dry matter production of 20 tons/ha. When lime was applied in the absence of superphosphate, dry matter production increased to 19 tons/ha. When lime was applied at either 2 or 3.5 tons/ha and superphosphate at 25 kg P/ha, maximum dry matter production of 25 tons/ha was reached. Higher rates of superphosphate tended to increase yields in the limed treatments.

The most promising combination seems to be 2 tons/ha of lime and 25 kg P/ha/yr as superphosphate. The phosphorus levels are lower than normally expected for highly weathered Amazon soils, which are supposed to have a high phosphorus fixation capacity. The sandy texture of this topsoil prevented a high phosphorus fixation capacity, as was shown in the phosphorus fixation isotherms presented in the 1973 Annual Report. The optimum levels between 25 and 50 kg P/ha correspond closely to the level of 25 ppm P needed to supply the desired concentration of 0.2 ppm P in the soil solution according to the fixation isotherm.

The behavior of the rock phosphate sources applied without lime is also promising, as Table 15 shows. Dry matter production levels ranged from 20.4 tons/ha for Fosbayovar rock phosphate to 22.7 tons/ha for the Morocco rock. This is the first field test of the Fosbayovar rock in the Amazon Jungle. Its behavior indicates that it compares well with the three international standards and that it is a high reactivity rock in spite of a somewhat coarser

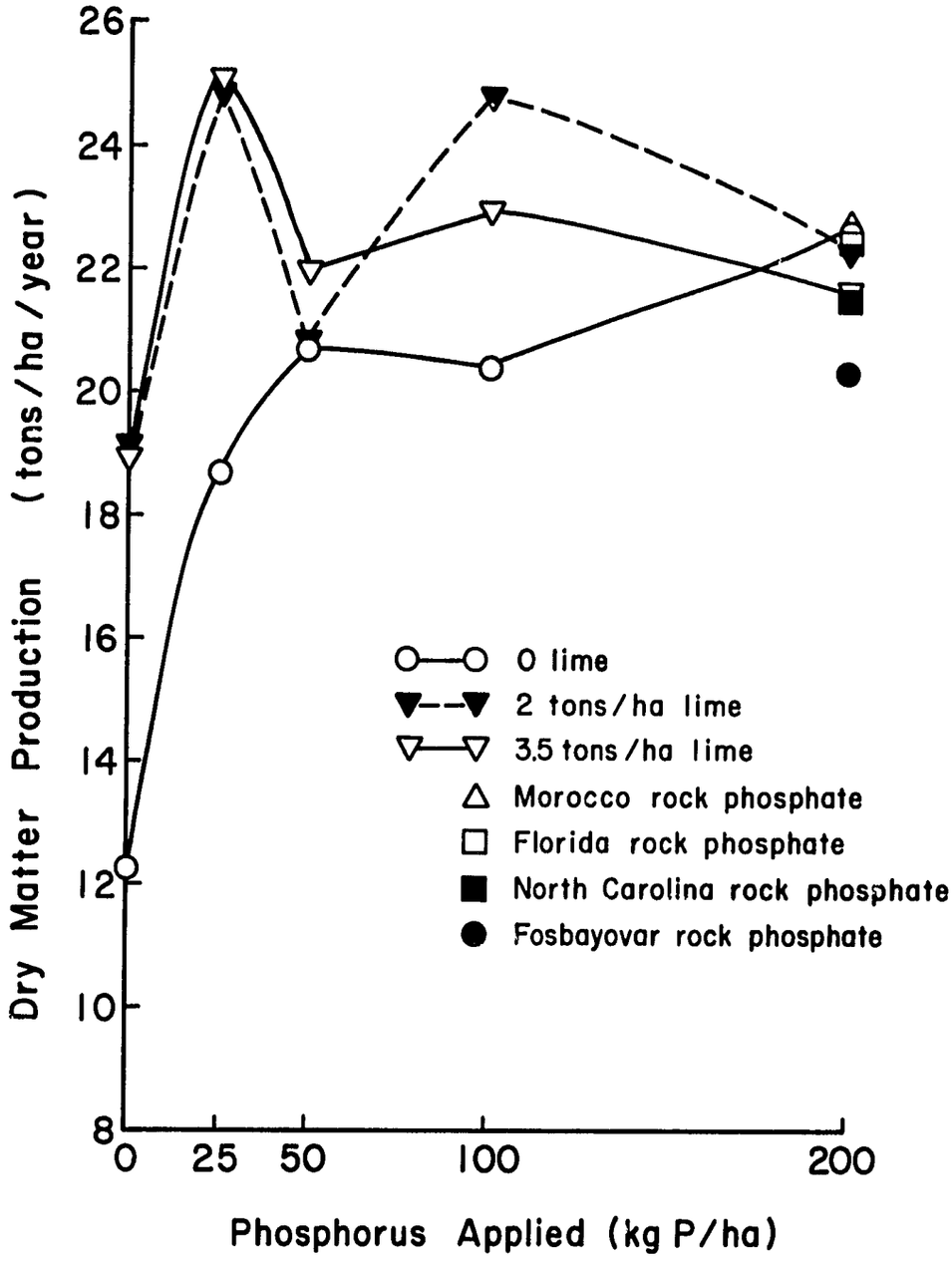


Fig. 10. Effect of phosphorus and lime on the annual dry matter production of Panicum maximum planted Oct. 17, 1973. Sum of 6 cuts on Dec. 21, 1973, Feb. 22, Apr. 19, June 6, Aug. 1 and Sept. 27, 1974.

particle size. Dry matter production with Fosbayovar was 91% of the average of the three TVA standards and ordinary superphosphate. The potential of this new phosphate deposit is supported by this test.

One year is inadequate time to test the residual effect of superphosphate and the rock phosphates. The experiment is being continued to provide this information. Plant nutrient content and changes in soil properties are also being determined.

Fosbayovar Rock Phosphate

A third pasture experiment was established on June 22, 1974 to evaluate this promising source further. Five rates of phosphorus were tested at 0, 1, and 2 tons/ha of lime. The experiment was installed in burned plots of the 1972 clearing which were grown to rice and Guinea grass-Kudzu since October 1972 without fertilization. Rock phosphate and lime were broadcast and incorporated with a rototiller and Guinea grass then replanted. Other fertilization was similar to the previous two experiments.

The results of the first three cuts are shown in Fig. 11. Lime applications increased the response to Fosbayovar. Higher initial yields were obtained at the rate of 100 kg P/ha with two tons of lime. This information is much too preliminary to establish firm conclusions. The long-term effect of these sources is the main objective of the work.

Table 15. Comparison of different sources of phosphorous on annual dry matter production of *Panicum maximum* during its first year of growth. P rate = 200 kg P/ha*.

Source	Total P_2O_5	Citrate-soluble	Citrate-soluble of total P	Annual dry matter production
	%	%	%	tons/ha
Simple superphosphate	20.0	100.0	100.0	22.7
Fosbayovar rock	30.9	7.8	25.2	20.4
North Carolina rock (PR-3)	29.9	7.8	26.1	21.7
North Florida rock (PR-4)	32.4	6.6	20.4	22.2
Moroc o rock (PR-8)	33.3	5.1	15.3	22.7

* Chemical composition provided by Dr. E. C. Doll, Tennessee Valley Authority.

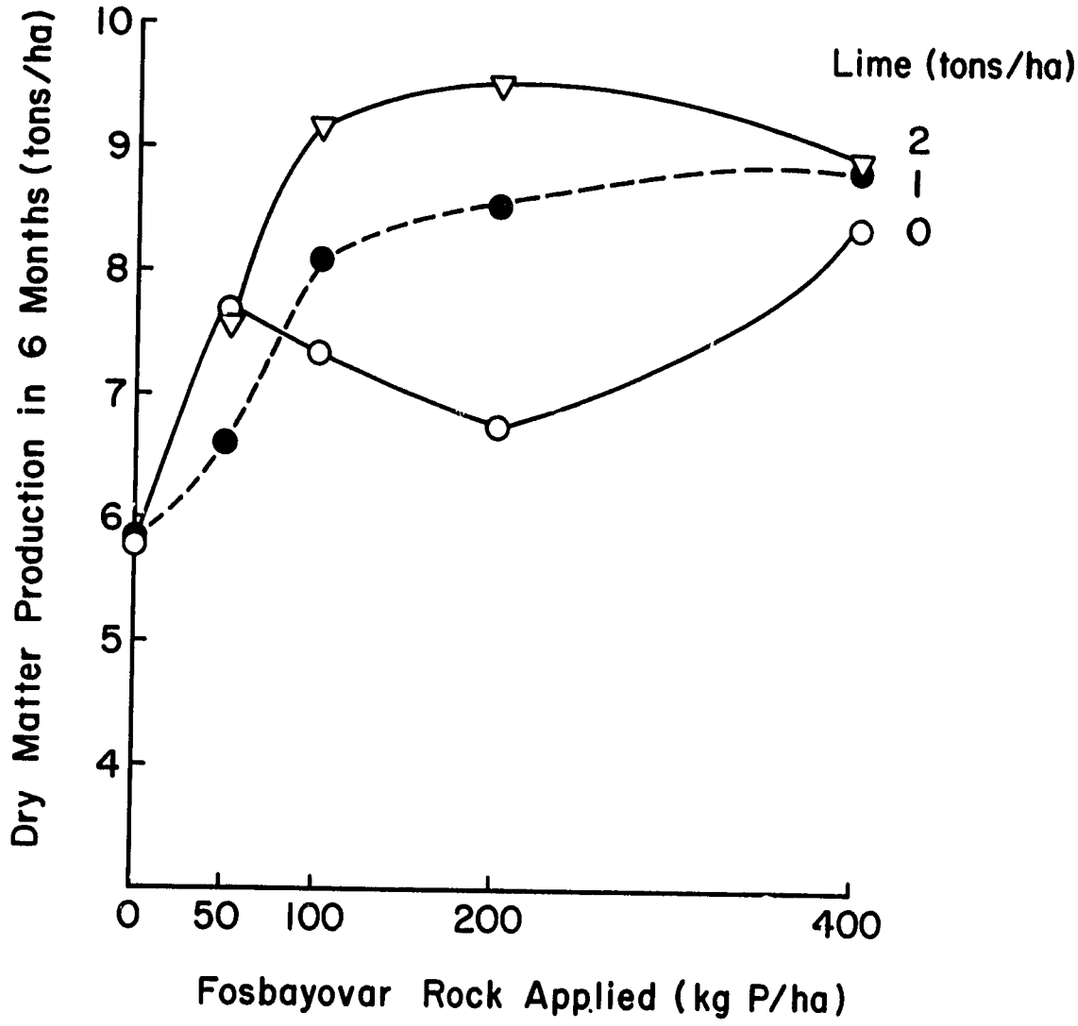


Fig. 11. Response of Panicum maximum to Fosbayovar rock phosphate and lime applications. Planted June 22, 1973. Sum of 3 cuts (Aug. 16, Oct. 11 and Dec. 5, 1974).

RICE FERTILIZATION

A field experiment was planted in an old Andropogon pasture with a pH of 4.9. It consisted of a NPK factorial arranged in the "Guadalupe" centroid design with extra treatments for lime and micronutrients. The IR-4 variety was planted on September 16, 1974 in 25cm rows at a seed density of 50 kg/ha. Two rows were skipped every two meters where cassava was interplanted 45 days later. The 2 x 3mm rice plots in the center permitted the rice harvest as a monoculture devoid of intercropping effects. The main effects are shown in Fig. 12. Grain yield levels of approximately 3.5 tons/ha were obtained with about 60 kg/ha of N, P_2O_5 and K_2O and 2 tons of lime. Tables 16 and 17 show that there was no response to boron or a beneficial effect of sulfur-coated urea over the commercial urea. A significant response to molybdenum was observed, confirming previous observations.

Table 16. Effects of lime, boron and molybdenum on upland rice yields.

Treatment			Rice yields
N	P_2O_5	K_2O	
kg/ha			tons/ha
0	0	0	1.54
90	120	120	3.56
90	120	120-Lime	2.64
90	120	120-B	3.27
90	120	120-Mo	2.70

Table 17. Effects of nitrogen source on upland rice yields.

N rate	Urea	SCU
kg/ha	Rice yields (tons/ha)	
90	3.56	3.29
180	3.52	3.23

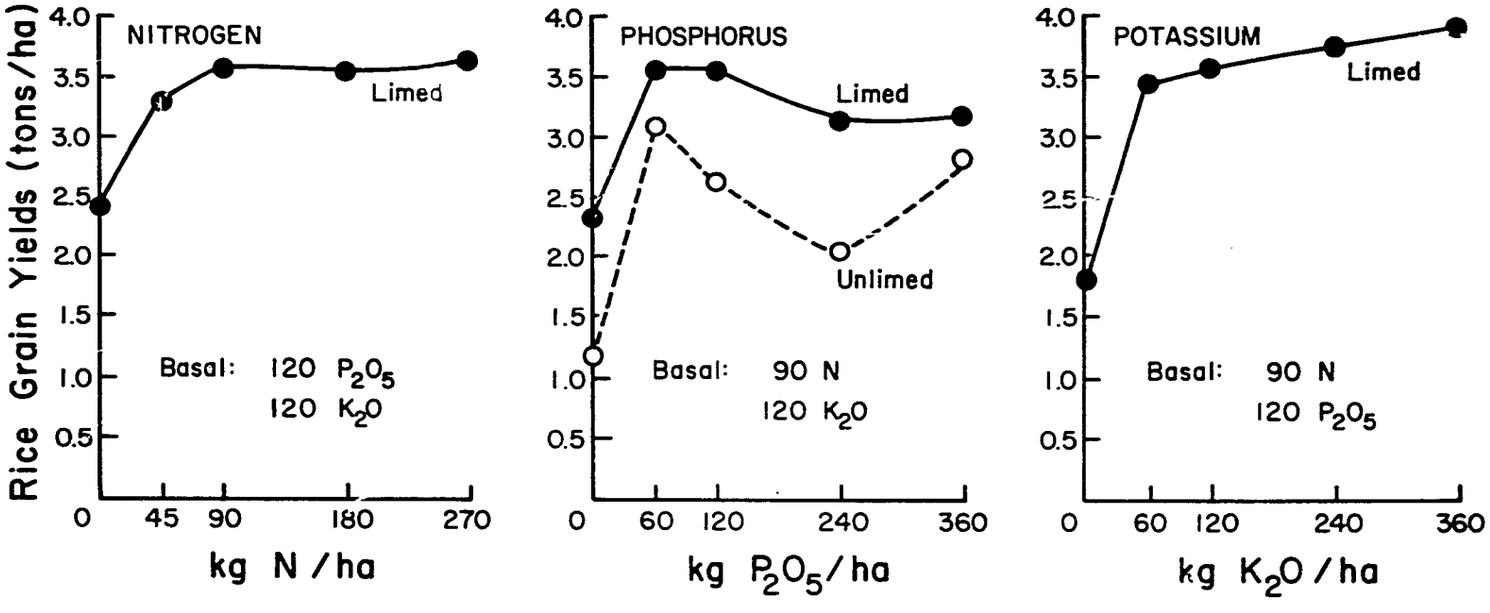


Fig. 12. Rice response to nitrogen, phosphorus and potassium.

CORN FERTILIZATION

A similar experiment was also installed with a local (Cuban Yellow) variety of corn in the same field. It consisted of a P-K-Zn factorial arranged in the "Guadalupe" composite design with extra lime and nitrogen source treatments. No nitrogen rates were included because a subsequent experiment was planted by Mr. Wade for this purpose. Rates were determined according to soil tests.

The yield responses are shown in Fig. 13. The optimum levels seem to be in the order of 50 kg P_2O_5/ha (22 kg P/ha) and 160 kg K_2O/ha (133 kg K/ha). No zinc response was observed. The maximum yield of about 3.2 tons/ha (50 bu/acre) was reached, which is mediocre for corn.

Table 18 shows that there was no response to boron and molybdenum. When lime was omitted, yields were the same as the check plots. Two extra nitrogen treatments shown in Table 19, indicate a substantial yield drop when the nitrogen rate was reduced to 75 kg N/ha, but that this effect was totally compensated for when kudzu was incorporated. The reasons for the beneficial effects of kudzu are not known.

Table 18. Effects of lime, boron and molybdenum on corn yields.

Treatment			Corn grain yields
P_2O_5	K_2O	Zn	
kg/ha			tons/ha
0	0	0	0.96
105	105	2	3.03
105	105	2-Lime	0.92
105	105	2-B	3.29
105	105	2-Mo	3.44

Table 19. Effect of nitrogen sources and rates on corn yields.

N rate	Corn grain yields
kg/ha	tons/ha
75	2.56
150	3.03
75 + Kudzu incorporated	3.15

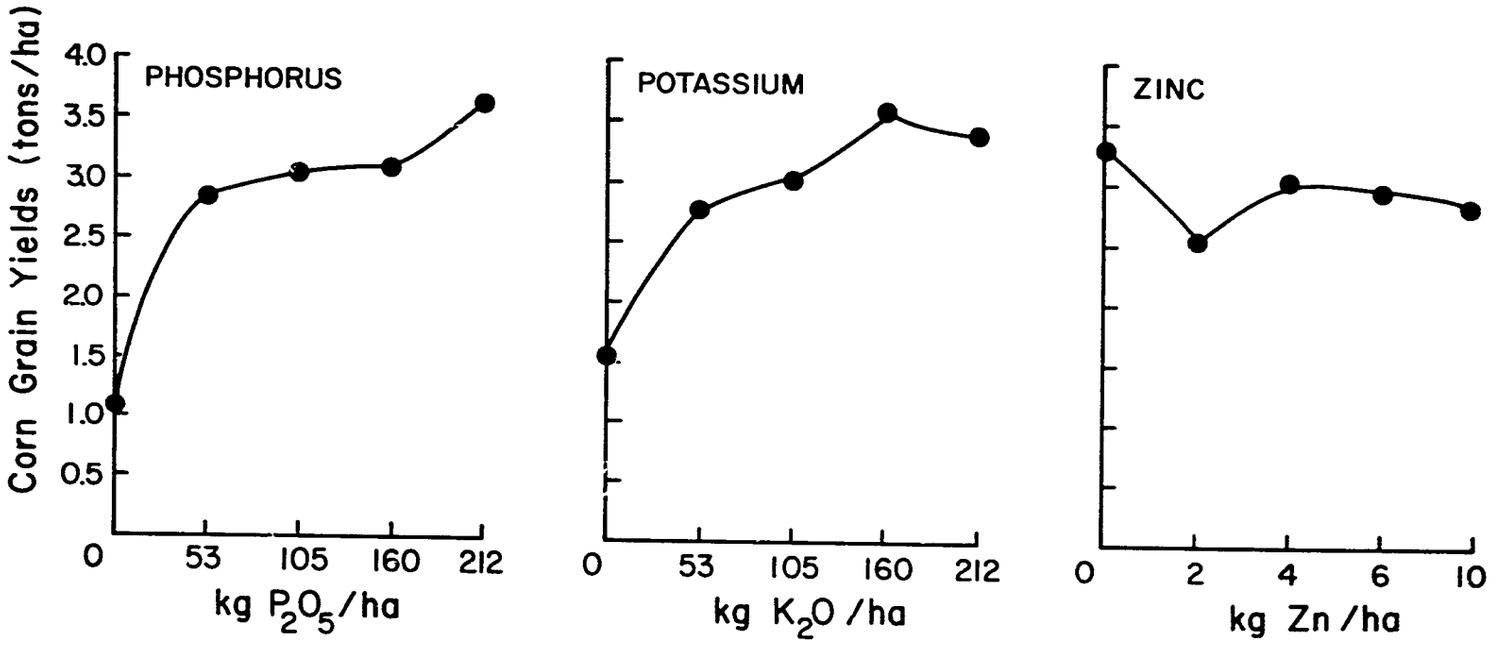


Fig. 13. Corn yield response to phosphorus, potassium and zinc.

MULTIPLE CROPPING

Most farmers in the Yurimaguas region practice multiple cropping. This gives them variety in their diet and provides protection against complete crop failures. The exception of this case is rice production which is the only crop currently exported from the region. All other crops are grown for family consumption and limited sale to the marked in various intercropped combinations. This is not done systematically nor is there a typical local practice.

A series of studies were initiated in 1974 to determine if intercropping could be improved with crop and soil management practices and thus be incorporated into the continuous cropping objective of the Program. These studies also intend to find if multiple cropping systems use fertilizer more efficiently than monocultures. Three experiments were installed: nitrogen-spacing, liming, and maximum crop intensification. The results of the first two experiments are presented in this section.

Nitrogen-Spacing Experiment

The first experiment studies the effect of two major parameters, nitrogen and row spacing, in an intercropped system composed of four crops a year, in comparison with individual monocultures. The experiment was located in an area cleared in July, 1973 by the traditional slash-and-burn system, and planted to rice for seed production purposes without fertilization. The soil had a pH of 5.0 at planting time. The intercropped planting scheme shown in Fig. 14 involves a tall-statured and a short-statured plant grown at the same time. Corn and soybeans were planted simultaneously. Corn was planted in rows spaced at 1, 2 and 3m with a synthetic "Mezcla Amarillo Planta Baja x Varios Amarillos" provided by the National Corn Program. Soybeans (Improved Pelican variety) were planted in 50cm rows regardless of corn spacing. Monoculture plots of each were planted at the same time with corn in 75cm rows and soybeans in 50cm rows.

Cassava sprigs (Huallaguina variety) were planted in the corn rows 45 days later. After the harvest of both corn and soybeans, cowpeas (*Vigna sinensis*, variety vs. Moh from Turrialba) were planted in 50cm rows between the cassava. Monoculture checks of cassava spaced at 75cm and cowpeas spaced at 50cm were planted at the same dates. The cropping pattern is shown in Fig. 14.

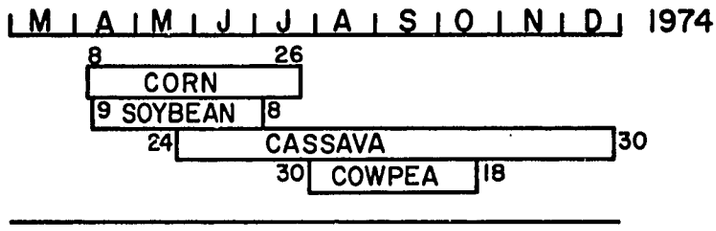
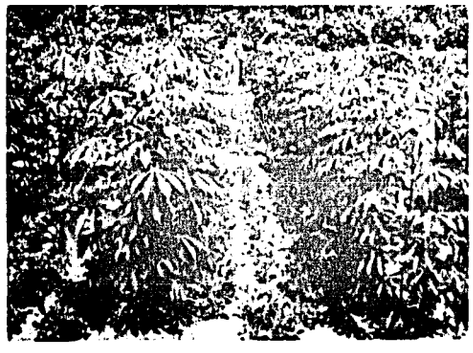


Fig. 14. Cropping pattern used in the Nitrogen-spacing experiment.

1

2



3

A promising multiple cropping system for Yurimaguas. 1: corn and soybeans growing in May. 2: after the soybean harvest, cassava is beginning to develop in the corn row (July). 3: cassava and cowpeas growing together in September.

The experiment was arranged in a split-plot design with four replications. Four levels (0, 45, 90, 180 kg N/ha were the main plots with 1, 2 and 3m spacing in the subplots. Nitrogen applications were split as follows: 1/3 at planting, 1/3 60 days later and 1/3 after the corn and soybeans harvest. Thus, the rates for the corn-soybeans combination were 0, 30, 60 and 120 kg N/ha.

The following basal application was added to all treatments. Dolomitic lime at 0.9 ton/ha to raise the pH to 5.5; simple superphosphate at 50 P/ha, 10 kg S/ha, 0.5 kg B/ha/ and 0.53 kg Mo/ha. A total of 120 kg K/ha was in split applications with nitrogen. The experiment thus provides information of corn and soybeans as companion crops, and cassava and cowpeas as companion crops. Also the 4-crop system as a whole can be compared with monoculture crops.

Fig. 15 shows the response of corn and soybeans to the nitrogen applications. As the rows became wider, corn responded less to added nitrogen. The soybeans showed a strong response to nitrogen which is probably due to the fact that soybeans were not inoculated by natural or artificial sources. However, when grown beneath 1m corn, the soybeans did not respond to nitrogen due to strong plant competition from the taller corn. As the corn rows were made wider, corn yields dropped accordingly. Conversely, with less competition, the soybeans grew more vigorously and their yields increased as corn rows widened.

Fig. 15 also shows the response of cassava and cowpeas to nitrogen. The cowpeas, which nodulated from natural sources showed no response. Also cassava shows very little response. Fig. 15 suggests that the cowpeas were quite responsive to the cassava shading. Yields of the cassava monoculture and cassava intercropped in 1m rows were essentially equal. This indicated that the first 75 days of grown beneath the maturing corn did not adversely affect cassava growth. There seemed to be very little difference in visual appearance at corn harvest between the 1m cassava and the cassava monoculture. However, because the populations of the two were not equal (20,000 vs. 15,000 plants/ha) there is a possibility that the monoculture cassava was <u>too</u> close and therefore, too high a population for optimum growth. This will be tested next year as when the monoculture will be planted at 1m x 67cm. Cassava yields of the 2m and 3m intercropped spacings dropped according to population.

The yield of the four crops and the Land Equivalent Ratios (LER) of the three intercropped systems are shown in Table 20. LER values reflect the relative advantage or dis-

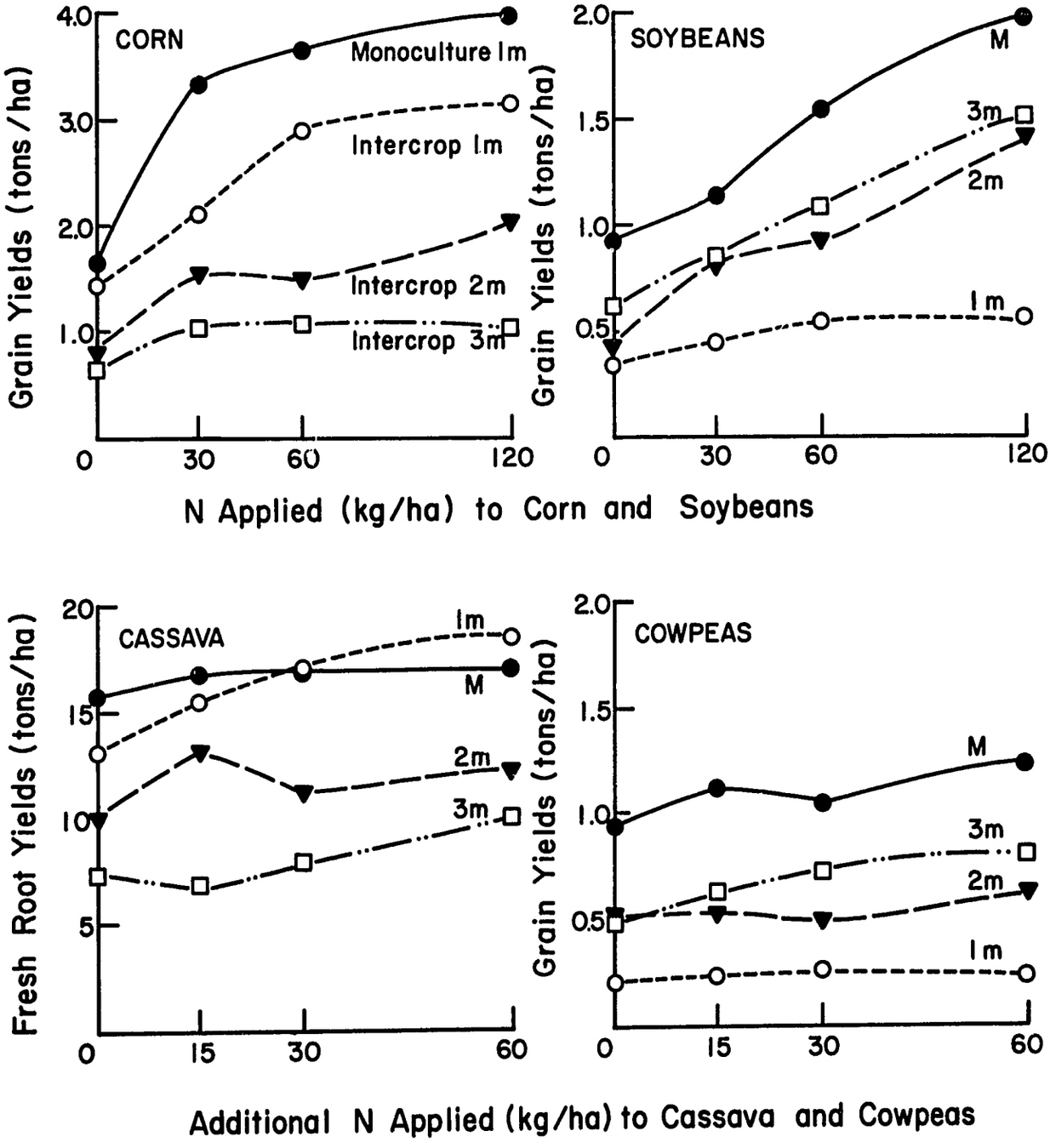


Fig. 15. Effects of nitrogen and row spacing on yields of a corn-soybean-cassava-cowpeas intercropped system in comparison with monocultures.

advantage of intercropping one hectare as opposed to growing two monocultures in 1/2 hectare lots. LER values greater than 1 indicate the superiority of intercropping and the first two decimals the percent differences. In the corn-soybeans comparison LER values averaged 1.12, 1.09 and 1.04 for the 1, 2 and 3m row spacing. The highest values were observed at the zero nitrogen level and 1m spacing, and at the 180 kg N/ha level with 2m spacing. These values indicate that mixing these two crops improved total production by a relatively modest level of 2% to 25%. The 3m row spacing was the poorest. In the case of the cassava-cowpea comparison the 1m row spacing was superior reaching LER values of 1.27. Table 20 shows some instances in which intercropping was detrimental, as indicated by LER values lower than 1.

A comparison can also be made of the intercropping system of the four crops with their monocultures. A meaningful way to do this would be to assess them according to calories and grams of protein produced per day. However, this must wait for laboratory analyses that will be done at a later time. We can evaluate these economically according to the value of the crops at local market prices. This is also present in Table 20. Total crop value reached a maximum of S/.63,160/ha in the 1m row spacing with the highest nitrogen rate. A total of 266 days, almost nine months of crop growth, therefore, produced a rather large return. To compare it with the monocultures the crop value of 1 hectare divided in two, 1/2 ha plots and grown to the monocultures was calculated in Table 21. This table shows that the maximum value attained by a hectare of monocultures at the 180 kg N/ha rate was approximately 1/2 of that attained by one intercropped hectare at the same level of fertilizer investment. The compatibility among these four species increases the return to fertilization by a significant margin.

The results indicate that row spacings of 1m and 2m are more profitable than the 3m spacing and the monocultures. The slight yield increases as indicated in Table 20 plus the 75 days saved by relay planting the cassava are responsible for the superiority. One might wonder why the 3m spacing is less efficient than the 1 or 2m spacings. At the harvest of the cowpeas in October, there was a complete canopy of cassava leaves in the 1m rows. The 2m rows also made a full canopy, although less dense than the 1m rows. Therefore, even though more than two months remained before the cassava harvest, it would probably have produced little if another crop were planted in these same plots. This was not the case for the 3m row plots. Plenty of unused light fell between these wide rows (also water and nutrients

Table 20. Effects of nitrogen and spacing on yields, land equivalent ratios and total market value of different intercropped combinations.

Cropping System	Total N rate	Corn yields	Soybean yields	LER[1/]	Cassava root yields	Cowpea yields	LER	Total market value[2/]
	kg N/ha	--- tons/ha ---			--- tons/ha ----			S/./ha
Intercrop	0	1.48	0.34	1.25	13.32	0.21	1.07	40,590
1m rows	45	2.11	0.44	1.02	15.25	0.23	1.11	48,900
	90	2.91	0.54	1.14	16.89	0.25	1.25	57,480
	180	3.15	0.72	1.08	18.08	0.27	1.27	63,160
	Mean	2.41	0.74	1.12	15.88	0.24	1.18	52,532
Intercrop	0	0.80	0.43	0.94	8.49	0.54	1.10	32,290
2m rows	45	1.54	0.83	1.18	11.68	0.54	1.18	47,460
	90	1.50	0.94	1.01	8.90	0.50	1.01	42,200
	180	2.02	1.42	1.23	10.60	0.62	1.12	54,800
	Mean	1.46	0.90	1.09	9.91	0.55	1.10	44,437
Intercrop	0	0.64	0.63	1.06	7.46	0.52	1.02	32,270
3m rows	45	1.03	0.85	1.06	7.18	0.62	0.98	37,310
	90	1.08	1.11	1.00	8.31	0.73	1.19	44,070
	180	1.06	1.52	1.04	10.42	0.79	1.75	53,190
	Mean	0.95	1.03	1.04	8.34	0.66	1.11	41,710

1/ LER: Land Equivalent Ratio = $\frac{\text{Yield/ha of Crop A intercrop.}}{\text{Yield/ha of Crop B monoculture}} + \frac{\text{Yield/ha of Crop B intercrop.}}{\text{Yield/ha of Crop B monocult.}}$

2/ Same corn, cassava and soybean prices as in Table 12. Price of cowpeas: S/.15,000/ton (US$346).

Table 21. Yield of the four monoculture crops and calculated market value if grown separately in two 1/2 ha systems: 1/2 ha corn and 1/2 ha soybean, followed by 1/2 ha cassava and 1/2 ha cowpea.

Nitrogen added	Corn	Soybeans	Cassava	Cowpeas	Total market value of 4 monocultures
(kg N/ha)	----------tons/ha ----------				S/.ha
0	1.65	0.85	16.2	0.90	31,324
45	3.35	1.15	16.8	1.15	39,550
90	3.65	1.15	16.8	1.05	41,550
180	3.98	1.95	16.8	1.20	45,300
Mean	3.16	1.37	16.6	1.08	39,410

out of reach of the cassava roots were unused). There was time and space for another short term crop such as early maturing beans to be planted and harvested prior to by harvesting the cassava crop. Had this been done, the economics of the 3m spacing would likely have been approximately equal with the 1m and 2m spacing. This is another change that will be made next year in an attempt to test this hypothesis.

This experiment is being repeated for a second year with upland rice replacing soybeans. Soil and plant samples have been taken to determine the effect of intercropping on soil properties, nutrient, crop nutritive value and efficiency of fertilizer utilization. The first year results, although preliminary, show that a significant amount of both carbohydrate and protein can be produced in nine months with intensive intercropped systems.

Liming Experiment

The second multiple cropping experiment is one of liming rates and methods of applications. These soils are generally quite acid, power equipment is practically non-existant, and certainly not available to the average farmer. This experiment has five rates of lime (0, 1, 2, 3, and 4 tons/ha). The rates are lime as it came from the quarry in Juanjui, which only 67% passed a 100 mesh sieve. Thus, by U. S. standards, the liming rates are actually 0, 0.67, 1.33, 2.0, 2.67 tons/ha. The experiment also included four methods of application: the rototiller for optimum incorporation; the hoe, which is the tool the farmer has; broadcast to the surface and merely raked lightly, which has little labor requirement, and a small amount of lime broadcast and raked with each crop to test the idea that small quantities of lime can be leached into the soil over a period of time without heavy labor input. It is thought that the ash fall from a burning chacra, which is not incorporated, provides sufficient fertility and liming affect for one or two crops, so possibly this can be duplicated to some extent by this last treatment. Corn, which is very sensitive to aluminum toxicity was the tall-statured test crop. It was intercropped with short-statured cowpeas under these same treatments. Both crops were also grown as monocultures subject to the same treatments.

The experiment was established on Chacra I plots which was cut and burned in September 1972 and grown to unfertilized pastures. The corn selection PD(MS)6 was planted in 1.5m rows and the cowpeas (variety Floricream from CATIE) was planted at 50cm spacing on June 21 and June 27, 1974 respectively. The corn monoculture was planted in 75cm rows. All treat-

ments received a basal application of 75 kg N/ha as ammonium sulfate, 50 kg P/ha as simple superphosphate, 50 kg K/ha as K_2SO_4, 30 kg S/ha as sulfur flower and 0.5 B/ha as BoroPeru. Three months after liming the soil pH was 4.6 in the unlimed plots and 5.8 in the 4 ton/ha incorporated treatment.

The responses of the first harvest are shown in Fig. 16. The intercropping effect is shown in Table 22. The optimum amount of lime required is 2 tons/ha which is relatively low, although the corn showed a tremendous response to the first level of lime. Low corn yields were due to the disease attacks, and possibly the low yield potential of variety used. The LER values show a disadvantage of intercropping at the 0, 1 and 2 ton/lime/ha levels incorporated with a rototiller, and at the 3 ton/ha rate when raked in. Surprisingly high LER values of 1.34 to 1.37 were achieved at the 3 ton/ha rate either incorporated with a rototiller or a hoe, and at the 0.6 ton/ha broadcast but the latter at a very low yield level.

Table 22 shows the comparison of the different methods of application of lime. The rototiller is superior, but incorporation with a hoe is comparable. The cowpeas, being less sensitive to aluminum, did not decline in yields as much as corn, due to the less efficient methods of application. The method of broadcast and raking is considerably below the rototiller, as would be expected for the first crop. Only time will tell whether this treatment can give a favorable response.

This experiment will continue for several plantings to test the residual effect of the lime as well as test the incorporation methods. Corn will be grown continuously, but the companion crop will change with each planting. For example, currently growing is corn and peanuts.

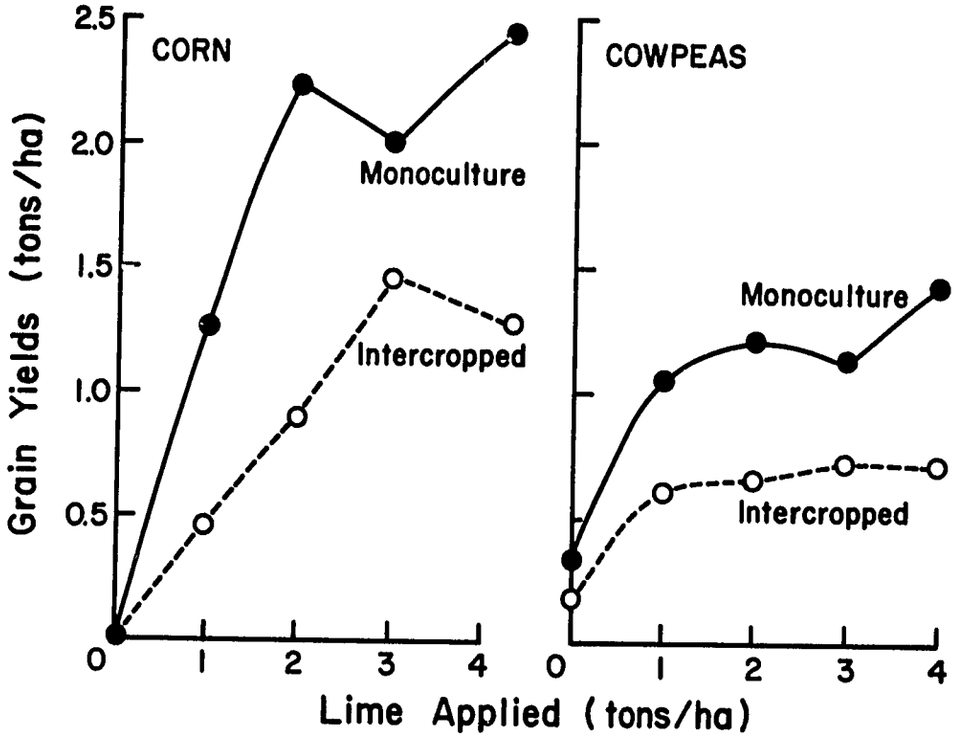


Fig. 16. Corn and cowpeas response to lime in monoculture and while intercropped.

Table 22. Results of the first harvest of the intercropped lime experiment. September 1974.

Lime Rate	Incorporation Method	Corn Mono-culture	Corn Inter-crop	Corn % of Mono.	Cowpeas Mono-culture	Cowpeas Inter-crop	Cowpeas % of Mono.	Land Equiv Ratio
tons/ha		---------- Grain yields (tons/ha) ----------						(LER)
0	---	0.02	0.01	44	0.36	0.17	49	0.93
1	Rototiller (10cm)	1.26	0.47	37	1.07	0.63	59	0.96
2	Rototiller (10cm)	2.24	0.89	40	1.20	0.69	52	0.92
3	Rototiller (10cm)	1.99	1.47	74	1.16	0.73	63	1.37
4	Rototiller (10cm)	2.41	1.28	53	1.40	0.72	58	1.11
3	Shovel (10cm)	1.53	1.03	67	1.12	0.74	65	1.32
3	Broadcast & raked	1.41	0.48	34	0.85	0.52	61	0.95
0.6	Broadcast & raked	0.63	0.29	46	0.67	0.59	88	1.34
Means		1.43	0.74	52	0.98	0.60	61	1.13

Corn responds strongly to lime in these acid Ultisols. Left: No lime, pH 4.6. Right: 3 tons lime/ha, incorporated at 10cm, pH 5.8.

CROP RESIDUE MANAGEMENT

Objectives and Design

Under intensive continuous cropping it is necessary to conserve as much of the existing resources as possible in order to minimize high fertilizer costs. In the system of slash-and-burn agriculture the initial conditions are excellent. Fertility is relatively high, soil physical properties are excellent and thus general growth and production are good. But, after the first one or two crops there is a rather rapid decline. An experiment was designed to determine what residue management practices could best maintain yields, retain nutrients and good physical conditions of a soil that is continuously cropped.

A portion of Chacra II, which was cleared and burned in August 1973 was used for this purpose. No crop had been grown since the clearing, and therefore, there were no existing residues. Thus, an even application of rice straw was spread to the entire field to serve as a residue. The experiment consisted of a factorial design of four residue management treatments and four fertility levels. The residue management treatments were: removed, burned, mulched, incorporated, and kudzu (*Pueraria phaseoloides*) material taken from an adjacent area and incorporated in with a hoe. A total of approximately 2 tons/ha of kudzu

dry matter, containing about 50 kg N/ha was incorporated. All incorporation was accomplished with a hoe.

The latter treatment was included in view of the abundant growth of kudzu in the area, which in cases covers the jungle vegetation. The four fertility levels were 1) no fertility. 2) 2 tons lime/ha and 400 kg P/ha as Fosbayovar rock phosphate. 3) a "maintenance" level of 1 ton lime/ha, 80 kg N/ha/crop as urea, 25 kg P/ha/yr as simple superphosphate, 40 kg K/ha/crop as KCl, 10 kg S/ha, 0.5 kg B/ha and 0.1 kg Mo/ha 4) a "complete" treatment of twice the quantity of lime, nitrogen, phosphorus and potassium plus the same amount of sulfur boron and molybdenum. The soybeans were inoculated with Nitragin Rhizobium obtained from CIAT.

The first planting consisted of intercropping corn (PD (MS) 5 selection) sown in 1m rows with two rows of Improved Pelikan soybeans planted in between. The soybeans were planted two weeks prior to the corn in order to allow the soybeans to develop somewhat ahead of the corn and prevent the shading observed in the nitrogen-spacing multiple cropping experiment. The soybeans were planted on May 18 and harvested August 16, 1974; the corn was planted June 1 and harvested on September 25, 1974.

Results

Fig. 17 shows the results of the soybean harvest. The yields with the kudzu incorporated treatment at the lower fertility levels were as good as that obtained with "complete" fertilization. In sharp contrast, there was a marked response to increasing fertility levels in the other residue management treatments. The superior performance of the soybeans in the plots with kudzu incorporated was visible throughout the growth of the crop. At about three weeks before harvesting, 10 plants were sampled at random and the numbers of nodules counted. The results appear in Table 22a. Kudzu incorporation caused a remarkable increase in nodulation. Many of these nodules were pink inside. The reasons for the superiority of the kudzu incorporation are not known at this time. One speculation is that green material of the kudzu enabled the Rhizobium inoculum to multiply sufficiently to infest the roots, while the others lacked an adequate supply of organic material. It appears that the responses to the residue treatments were primarily due to increased availability nutrients and not by physical properties, as adding fertilizers alone ("complete" residue removed) equalled the yield of any combination of treatments. Soil and plant analysis, in-

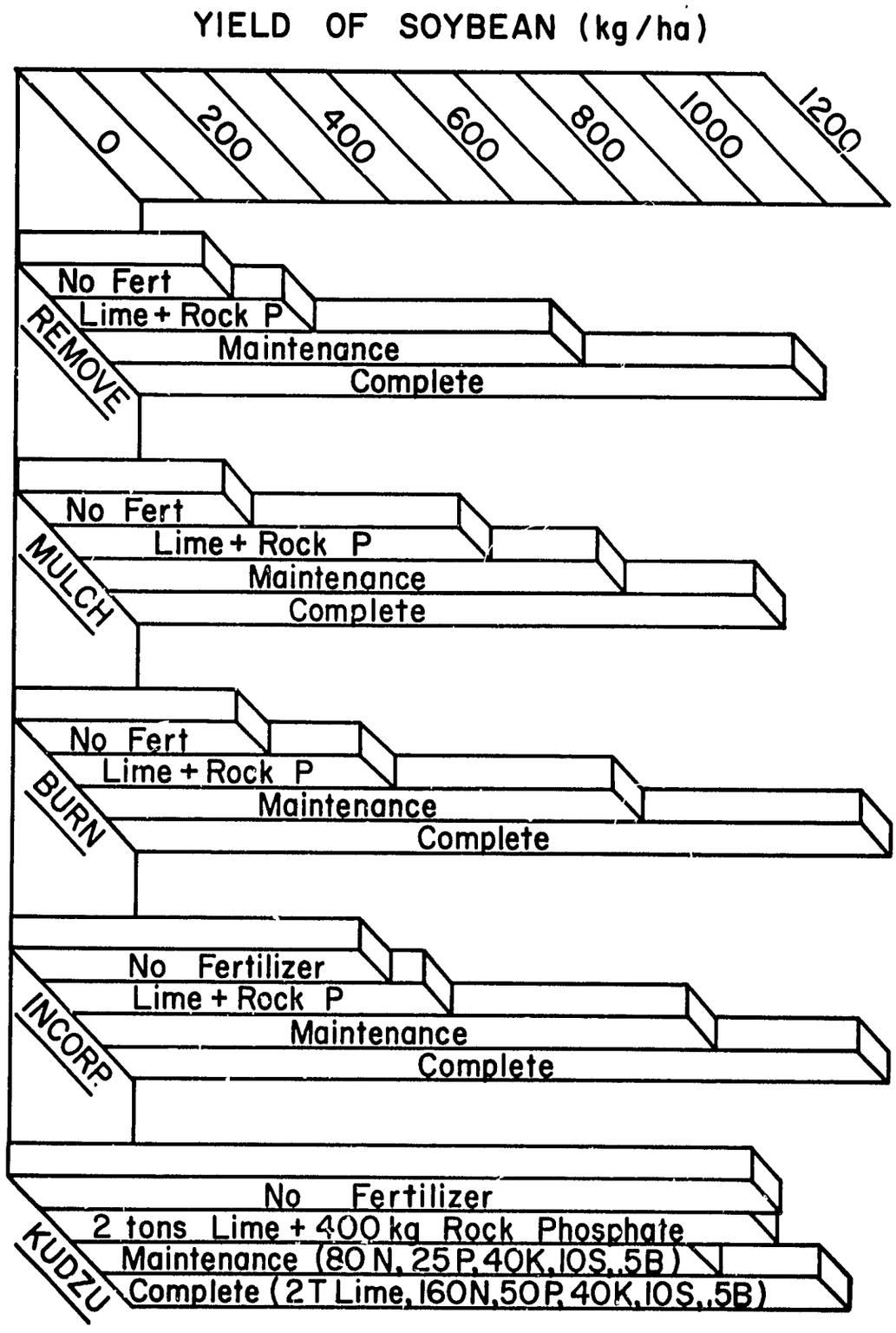


Fig. 17. Effect of residue management and fertility levels on soybean grain yields.

Table 22a. Effects of residue treatments and fertility levels on soybean nodulation.

Fertility level	Rice Straw				Kudzu Incorporated
	Removed	Mulched	Burned	Incorporated	
	Nodules/10 plants				
Check	18	8	9	27	91
Lime + Rock Phosphate	1	24	6	2	66
Maintenance	7	18	21	4	60
Complete	3	33	3	40	70
Means	7	21	10	18	72

Table 22b. Effects of residue management and fertility levels of corn grain yields intercropped with soybeans.

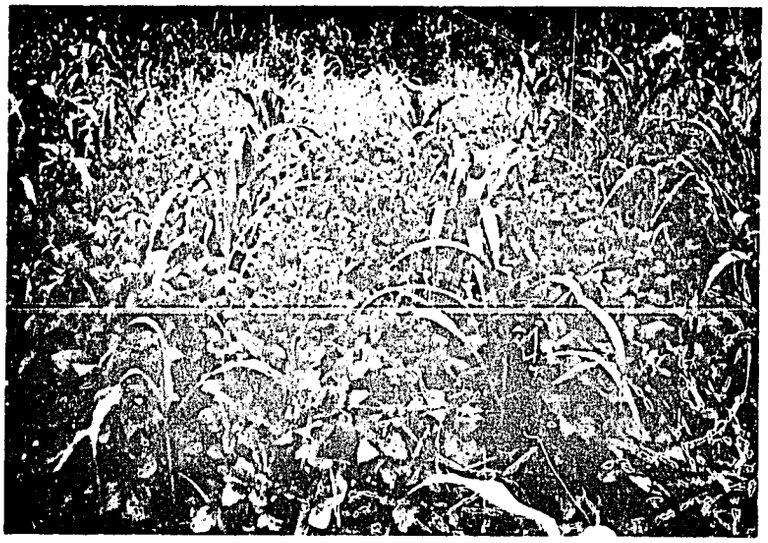
Fertility level	Rice Straw				Kudzu Incorporated
	Removed	Mulched	Burned	Incorporated	
	Grain Yields (tons/ha)				
Check	0.67	1.00	0.78	0.84	0.79
Lime + Rock Phosphate	0.41	0.59	0.94	1.26	0.94
Maintenance	0.93	0.92	1.37	0.97	1.05
Complete	1.06	1.02	1.29	1.21	1.44
Means	0.77	0.88	1.09	1.07	1.06

cluding the nutrient composition of the crop residues are being conducted in order to obtain an adequate explanation.

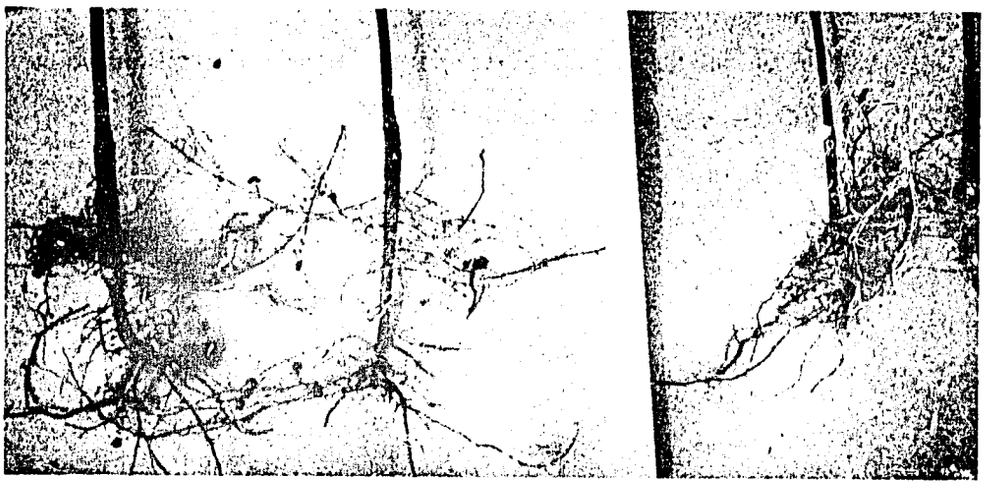
The performance of the intercropped corn was very poor, as the yields in Table 22b show. There appears to be little response to any residue treatment. This would strengthen the thought that the kudzu increased soybean yields by augmenting nodulation and therefore, did not affect corn. However, Table 22b shows little response to even the "complete" fertility application. We know that corn should respond to fertilizers, at least at these low yields. Therefore, other factors apparently over-shadowed any response to fertility or residue treatments. The corn was practically overgrown by the soybeans with their two week headstart. It was severely infested with a leaf disease and also a stalk insect. These outside factors prevented a response to any of the treatments. Thus, only with subsequent crops will the real effect of kudzu on non-leguminous crops be shown.

These early responses to kudzu used as a green manure are very exciting. If indeed the increased nodulation plus nutrients released from the decomposing material can produce yields equal to large fertilizer applications, it will be a very promising crop for this fertilizer-poor region. Even if its affect is limited to legumes, it still could be a powerful fertilizer. Kudzu grows vigorously in unfertilized regions and can be found growing wild in many abandoned pastures of the region. It would cost practically nothing for a farmer to harvest substantial quantities of the vine, either from wild areas or it could be propagated in a "tired" and abandoned farm plot.

The experiment is being continued with monocultures of corn and peanuts in order to separate the effects in grass vs. legume species.



Soybeans growing vigorously in unfertilized plots where kudzu was incorporated while intercropped corn is doing poorly.



Left: Two soybean roots from the treatment in which kudzu was incorporated. Right: lack of nodulation in the plots from which residues were removed.

SECONDARY AND MICRONUTRIENT GREENHOUSE STUDIES

Objectives and Design

As it was pointed out in the 1973 Annual Report, sulfur, boron, and molybdenum deficiencies were detected at Yurimaguas. It was necessary to quantify these possible deficiencies in the soil and their effect on plant growth. Greenhouse from two soils of the Yurimaguas station were carried to Raleigh in order to: a) identify the limiting nutrient elements in these two soils, using the missing element technique, and, b) evaluate corn responses to five levels of lime, phosphorus, sulfur, copper and zinc applied to one of these soils, using a central composite rotatable design.

Two sets of experiments were conducted. In each one, dry matter yield and nutrient uptake was measured. All the techniques for soil preparation and plant growth were the standard ones for greenhouse studies using small soil volumes. Plants were harvested at 14 and 21 days after seeding.

Results

The first experiment was done with two Paleudults differing in their chemical properties, and using the missing element technique. Corn (variety Pioneer 3369A) was used as a test crop.

The results obtained from this experiment indicated that in the very acid soil (pH 4.5, 1.6 meq Al/100 gms, 50% Al saturation) the main problems were aluminum toxicity and nitrogen deficiency. When the soil was limed, using amounts equivalent to that of the extractable aluminum, copper deficiency became a serious problem, and responses to phosphorus, sulfur and potassium began to be evident. In the second soil (pH 5.5 and 0.5 meq Al/100, 20% Al saturation and high in available P) there were no lime, phosphorus or potassium responses, but there was a sharp response to nitrogen and sulfur. Determination of nutrient adsorption rates indicated that sulfur deficiency in plants was enhanced with time (14 to 21 days) and it also showed that some of the poor growth of the plants was associated to a lack of translocation of iron from roots to shoots.

From this set of experiments it is concluded that limiting factors of soils of the area are not only aluminum toxicity and nitrogen, phosphorus and potassium deficiencies, but that sulfur and copper deficiencies can be limiting for plant growth.

A second experiment was done on samples of plots burned in 1972 (Chacra I), which have been cropped once with rice, without fertilizer application. The soil had pH 4,4. 55% Al saturation, 3.66% organic carbon, 0.45% total N, 12 ppm P, 10 ppm S, and 1.0 and 1.2 ppm of Cu and Zn. Thus, it was low in P, S, Cu and Zn. Five levels of lime, phosphorus (as 10% acidulated Fosbayovar rock), sulfur, copper and zinc were studied. The results showed that the most limiting nutrients for corn growth were phosphorus and copper as it can be appreciated in Fig. 17. This result compared well with the low levels of these nutrients in the soil. Responses to the 10% acidulated Peruvian rock phosphate suggested a good possibility in its use in these acid Ultisols.

A response to lime and sulfur was also observed in this experiment, but it was of lower magnitude than that of phosphorus or copper. It is suspected that the response to liming was decreased by the application of 150 ppm P from the rock phosphate (32% P_2O_5 citrate soluble) which has a basic reaction and could be a calcium source (33% Ca). Nevertheless, it should be pointed out that this source does not carry sulfur, as the simple superphosphate does, which is a limiting factor in these soils. As it can be also appreciated in Fig. 17, no response to zinc was found in this experiment. When the residual effect of the former treatments was studied it was found that the main response was that to the sulfur fertilizer, which confirmed that sulfur deficiency increases as the soil is cropped. Only a slight residual effect of lime and rock phosphate was observed. No response to the residual copper was observed.

These results suggest the necessity to study sulfur and copper responses in the field, as well as its interactions with lime, nitrogen, phosphorus and potassium applications. It also indicates the need to apply sulfur, copper and other micronutrients to these soils in order to get good yields.

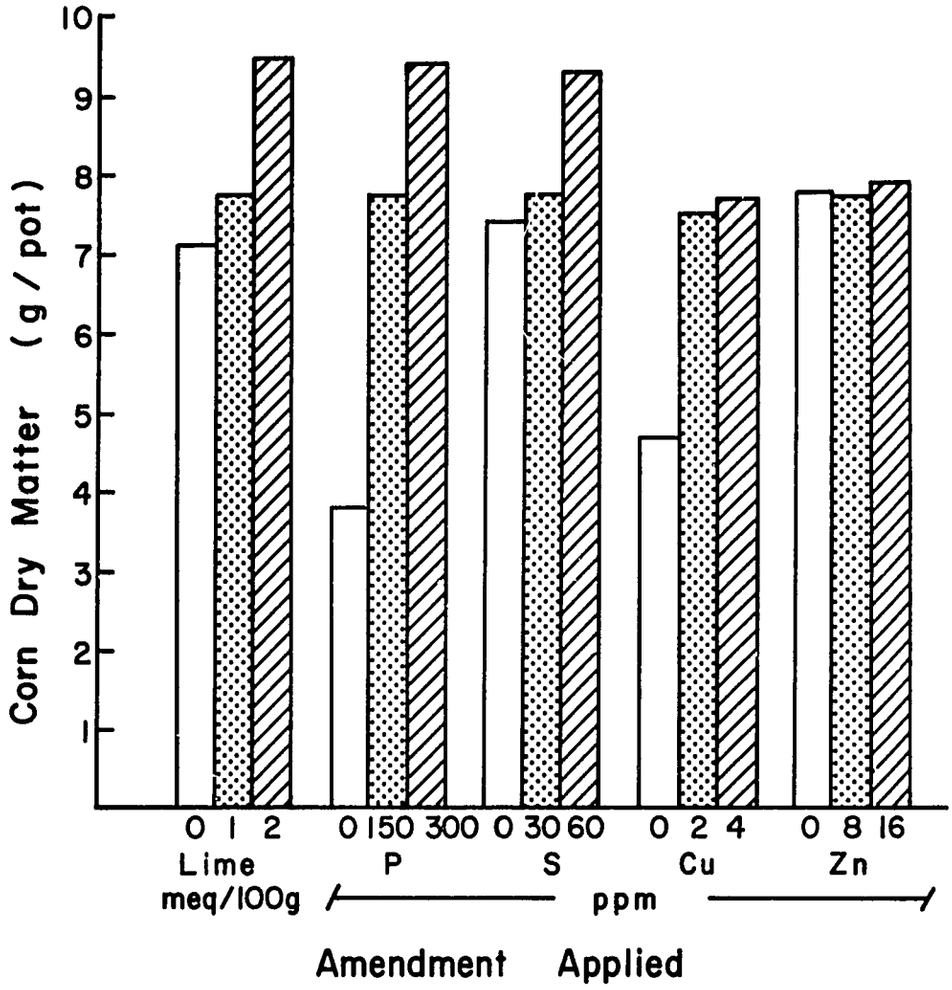


Fig. 18. Effect of lime, rock phosphate, S, Cu and Zn applications on corn dry matter yield in Yurimaguas soil.

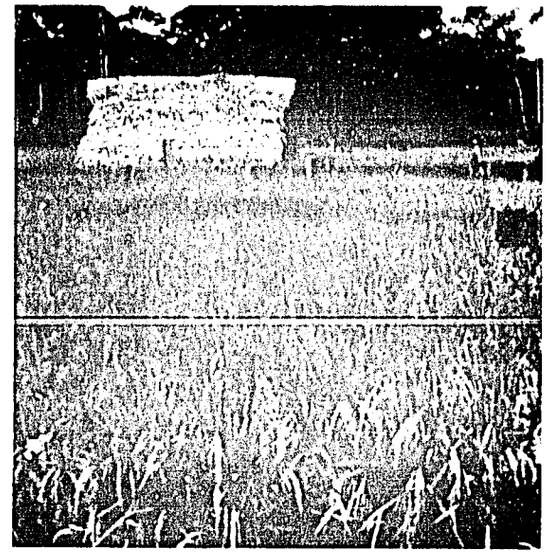
TOWARDS AN INTEGRATED SOIL MANAGEMENT SCHEME

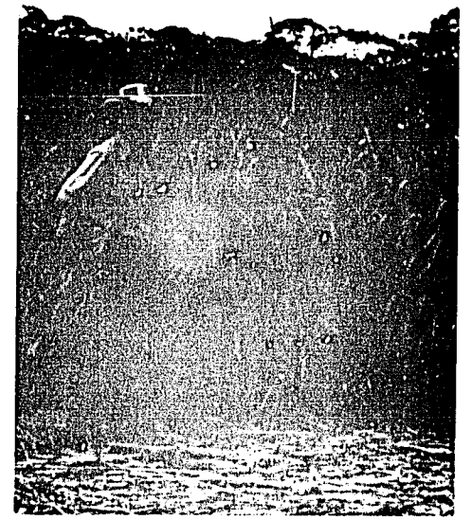
Due to the heavy population inlfux into the Yurimaguas area and the implementation of the land reform program, the traditional shifting cultivation system is beginning to degenerate around Yurimaguas. Continuous cropping schemes are urgently needed both by individual farmers and by the new cooperatives that are in the process of being formed. As data is gathered, some components of a possible soil management system begin to emerge. A minimum-energy model has gradually developed and it is presented as follows. A family is used as the unit, but it can be adapted to cooperatives by multiplying the area by the number of farming members.

Each farmer would clear a two-hectare tract every year by the traditional slash-and-burn method. The tree trunks and branches will be cut after burning with an ax or chainsaw and sold as firewood in town. This is the first harvest and will compensate for the additional cutting costs as well as provide some cash. It leaves the soil relatively free of trunks but not stumps. Immediately afterwards, the entire area will be planted to rice, soybeans or corn, depending on market demands. No fertilizers will be added except on extremely poor sandy soils, or when the burn has been of poor quality, or when a young secondary forest (1 to 4 years old) has been cleared. Under normal conditions, the ash is expected to supply the additional nutrients for the first crop.

After the harvest, 80% of the area will be planted to a grass-legume pasture, (such as Guinea grass-kudzu) with a light NPK and micronutrient applications, and followed by periodic potassium applications. The remaining 20% chosen to be in the best land, will be rototilled and sufficient quantities of fertilizer and lime will be added. The farmer might use an ox-drawn plow instead of a rototiller to incorporate the phosphorus and lime. This area will be planted to intercropped food crops such as rice, corn, cowpeas, soybeans, cassava and plantains in successful cropping schemes such as the corn-soybean-cassava-cowpea combination. Mulching, possibly kudzu, will be used in order to prevent the excessive soil compaction. The fertility of this intensively managed area will be best monitored by a soil testing program.

The same operation will be repeated every year until 20 to 50 hectares have been cleared and 80% is in pastures and 20% in food crops. The gradual growth of the pastures will enable the farmer to build his herd gradually. Although no research has been done with





Some components of a possible management system: Top left; planting rice after slash-and-burn land clearing. Top right; a rice crop is planted on the entire clearing. Lower left; intensive intercropping on 20% of the land. Lower right; pasture production in 80% of the land.

permanent crops, it seems feasible that crops such as oranges, oil palm, and other fruits such as pijuayo (pejibaye) can be planted into the pastures at a later date.

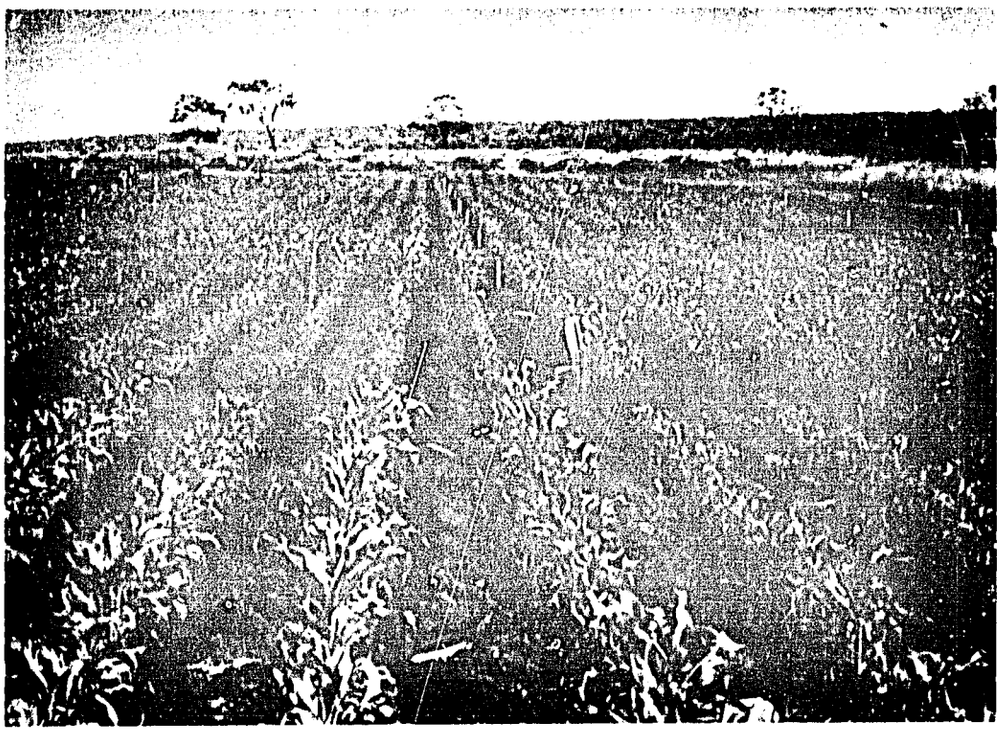
At this rate a cooperative of 50 families may have 1000 to 2500 hectares under production in about 10 years. If capital is available at the beginning, the rate of annual land clearing can increase.

This model has several conceptual advantages: 1) The change from shifting to continuous cultivation is gradual, 2) the investment in fertilizers and lime is the minimum possible since the ash is used to start production, legumes as a source of nitrogen in pastures, and intensive fertilization is used in only 20% of the area, 3) the increases in production are gradual in order not to saturate the markets at a certain time, 4) income would come from a series of products such as meat, milk, cereals, beans, cassava and plantains. This insures against violent price fluctuations or crop failures, 5) the nutritional level of the farmers and their families would be superior to the actual one. This model is based on Ultisols of low native fertility. In alluvial terraces close to the rivers, which normally have a higher base status, production could be more intensive.

This model needs to be tested at the farm level and arrangements to do so are being made between the Ministry and the Cooperativa San Ramón in Yurimaguas.

The plan aims at utilizing to the largest possible extent local resources. This model assumes that farmers will be able to purchase fertilizers at the 1975 subsidy prices in Yurimaguas and similar towns. As mentioned before, transportation costs of fertilizers by land and river from Lima essentially double the price. This makes most of these results uneconomical. The opening of the road to the north coastal cities of Piura and Chiclayo along the oil pipeline is expected to significantly reduce transportation costs of the urea to be manufactured there along with Fosbayovar rock phosphate from the coast. Other fertilizers currently imported can be shipped in transatlantic steamers into Iquitos via the Amazon and by river to other towns, thus essentially eliminating the high transportation costs of crossing the Andes.

JOINT NCSU - CORNELL
RESEARCH IN THE CERRADO OF BRAZIL



Experiments measuring soil fertility and moisture variables at the Brasilia Experiment Station.

The research activities initiated at Brasilia in 1972 continued and expanded during this year. The project continued to function as a joint effort with Cornell University in collaboration with the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) and USAID Brazil. The overall objective is to develop economical methods of managing acid, infertile Oxisols such as those associated with the Cerrado, in order to increase agricultural productivity of these tropical savannas.

Emphasis was given to determine the residual effects of lime, phosphorus and zinc fertilization in these soils. Many of the amendments last for several years in such soils. The evaluation of the residual effects in agronomic and economic terms is one of the fundamental aspects of this project. Studies on soil moisture as a limiting factor continued evaluation of water resources for irrigation and soil characteristics for pond and canal construction were also conducted. Research on varietal and species tolerance to high exchangeable aluminum and low available phosphorus was initiated at the greenhouse level. The outreach study of topsoil properties of the Cerrado region was completed. Two extrapolation-type experiments were also initiated in different soils around Brasilia.

Work reported during this period was conducted by the following staff stationed in Brasilia: Dr. George C. Naderman, Jr., (Cornell) was project coordinator, and responsible for the nitrogen and zinc experiments and the extrapolation study at Agua Limpa. Dr. Naderman was transferred to Raleigh on November 15, 1974 to accept new responsibilities at North Carolina State University. Dr. K. Dale Ritchey (Cornell) replaced Dr. Naderman as project coordinator on December 6, 1974. Mr. Enrique Gonzalez (NCSU) conducted the liming study. He returned to Raleigh on June 11, 1974 to complete his requirements for the Ph.D. degree. Mr. José G. Salinas (NCSU) arrived in Brasilia on September 16, 1974 and took over Mr. Gonzalez's experiments which were modified to fit his studies on varietal tolerances. Prior to arrival in Brasilia, Mr. Salinas conducted greenhouse experiments on this subject. Mr. Russell S. Yost (NCSU) was responsible for the phosphorus studies and one outreach experiment in Brasilia. Mr. James M. Wolf (Cornell) completed his studies on soil water relation and returned to Ithaca in June to complete his doctoral dissertation. Mr. Dale E. Bandy (Cornell) arrived in February 1974 to conduct studies on the physiological effects of dry periods. Mr. Jan Pruntel (Cornell) was stationed temporarily in Brasilia from June through August 1974 to conduct the evaluation of water availability and irrigation. Mr.

Alfredo S. Lopes (NCSU) completed his outreach studies on properties of Cerrado soils on-campus. Mr. Elcios Martins (Cornell) had operational responsibilities for routine experimental work and management of the field labor staff.

The following faculty members of both universities provided backstopping and supervision through short term visits to Brazil or on-campus work. Drs. M. Drosdoff (Cornell), P. A. Sanchez (NCSU), E. J. Kamprath (NCSU), C. O. Grogan (Cornell), S. W. Buol (NCSU), F. R. Cox (NCSU), R. B. Musgrave (Cornell), P. J. Zwerman (Cornell), G. E. Levine (Cornell), M. G. Wright (Cornell) and C. B. McCants (NCSU).

A new cooperative agreement was signed between the two Universities and EMBRAPA on December 3, 1974 in order to formalize the working relationships with this new institution. This agreement made the project an integral part of EMBRAPA's operation in the Cerrado. Assistance was requested by EMBRAPA in developing a proposal for the formation of the Cerrado Research Center. Such a proposal was prepared by Dr. P. A. Sanchez, Mr. A. S. Lopes and Dr. S. W. Buol and presented to EMBRAPA in September 1974.

CROP WEATHER

This report covers the work conducted during the period of October 1973 to September 1974 which comprises the 1973-1974 rainy season and the 1974 dry season. It also covers trials conducted independently of these seasons. The rainfall regime is illustrated in Fig. 19. The rainy season started about one month early this year. The total rainfall in September 1973 was the second highest in 47 years of records. Rainfall during the rainy season was unusually well distributed. There was only one mild "veranico" from December 5 to 14, 1973. The 506mm recorded during March 1974 was the highest in 45 years of records. Rain fell every day, sometimes accompanied by winds. The heavy rains during September and March resulted in much lower solar radiation levels during these two months as Fig. 19 shows. The heavy rains in March promoted the spread of Northern and Southern Leaf Blight (*Helminthosporium spp*) and ear worm and stalk borer (*Heliotis zea*) attacks on corn. Insecticide applications were ineffective because the daily rains washed out the contact insecticides. As a result the plants were weakened and readily broken by winds. The lime, phosphorus and nitrogen experiments were the most severely affected and produced unusually low yields.

Unless otherwise specified all field experiments were conducted on the Dark Red Latosol Typic Haplustox, fine, kaolinitic, isohyperthermic) the characteristics of which were described in the 1973 Annual Report.

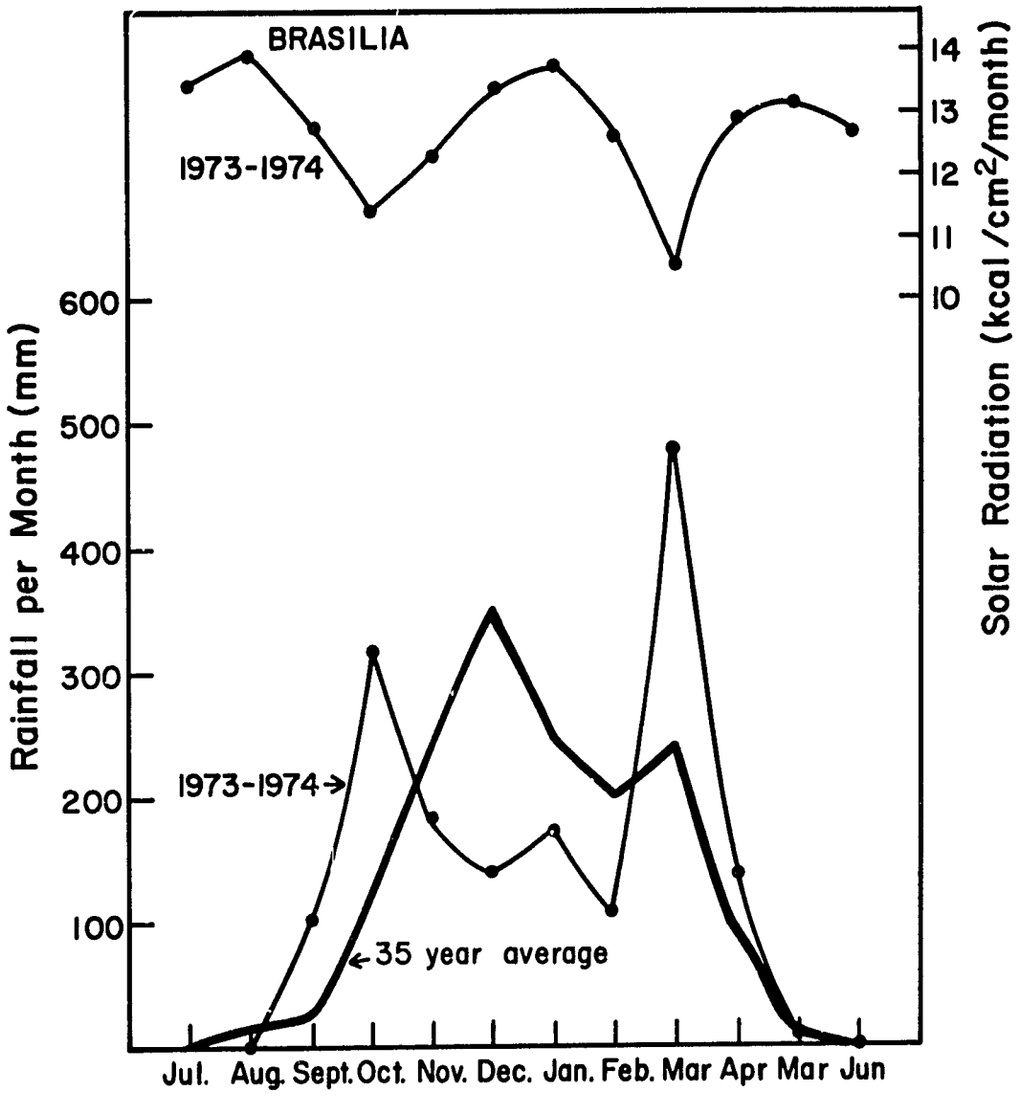


Fig. 19. Rainfall and solar radiation pattern at the Brasilia Experiment Station during the report period.

RESIDUAL EFFECT OF LIMING AND DEPTH OF INCORPORATION

Three corn crops have now been harvested in the long-term liming experiment in which four rates of lime were tested at two depths of incorporation. The three crops were planted on December 11, 1972 (rainy season), June 11, 1973 (dry season-irrigated) and December 10, 1973 (rainy season).

Yields

The results of the third crop are shown in Fig. 20. As in the first two crops, deep incorporation of lime was superior to shallow incorporation. The gap between the two depths of incorporation increased with lime rate and with each successive crop.

The cumulative yields of the three consecutive crops are also shown in Fig. 20. The superior performance of deep incorporation is evident. Although the 4 ton-deep treatment produced 93% of the yield of the 8 ton-deep treatment, the extremely favorable cost:price ratios of corn and lime make the 8 ton/ha-deep treatment the most economical so far.*

Soil Properties

The residual effect of liming so far is excellent. Table 23 shows the change in pH and exchangeable aluminum in samples taken immediately after each corn harvest. This table shows fairly stable values for each treatment. Aluminum saturation as a function of time is shown in Fig. 21. In the shallow incorporation depths aluminum saturation values remained below the critical level of 60% in the 0-15cm soil layer. There is an indication of possible lime movement and aluminum neutralization in the 15-30cm soil layer with the 8 ton/ha shallow treatment. In the other shallow incorporation treatments aluminum saturation levels hovered around the critical level.

With deep lime incorporation the top 30cms of soils were below the critical level. At the 1 ton/ha level aluminum saturation is increasing with time, reaching 60% in the second and third crops. The outcome of such trends will be better defined in the fourth and subsequent crops.

---

*104 kg of corn is needed to pay for 1 ton of lime at October 1974 prices in Brasilia. Corn price: Cr. $960/ton; lime cost; Cr. $100/ton.

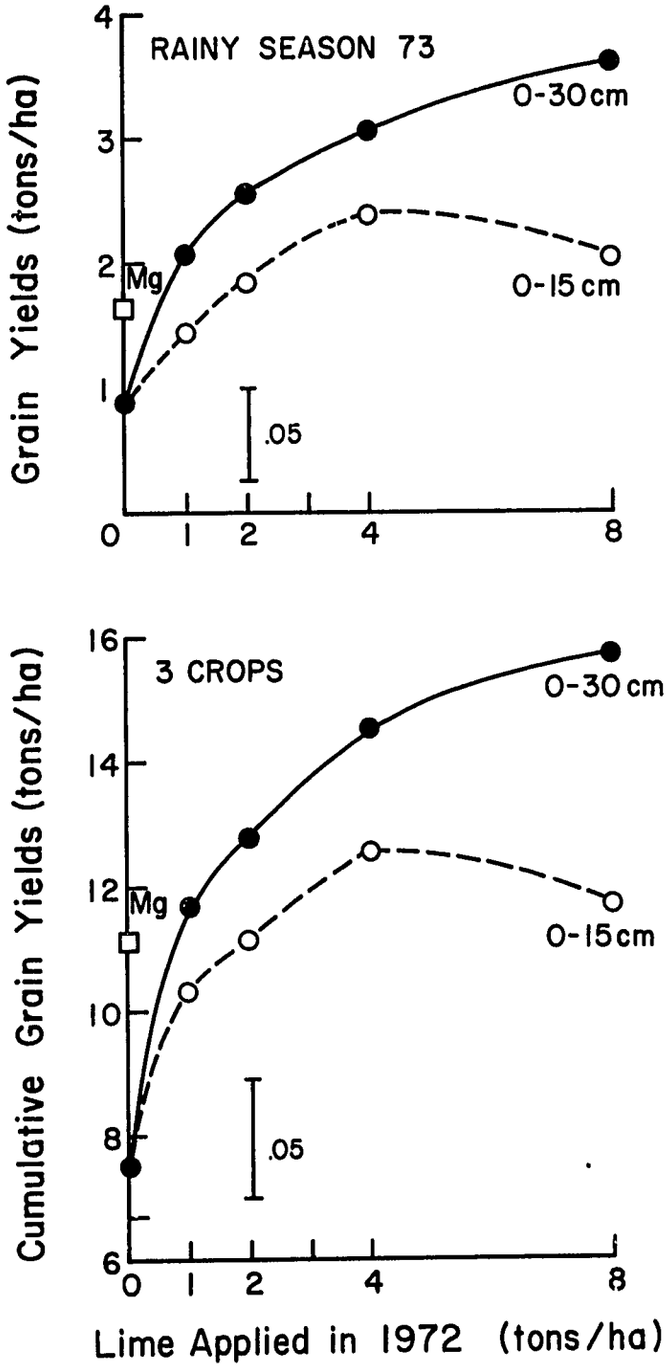


Fig. 20. Effects of depth of incorporation and liming rates in the third corn crop (top) and cumulative effect on three consecutive crops (bottom).

Table 23. Soil pH and exchangeable aluminum levels after each crop harvest as affected by depth and rate of lime applications in 1972.

Depth of lime incorp.	Lime rate	Soil depth	Soil pH after 1st crop	Soil pH after 2nd crop	Soil pH after 3rd crop	Exchangeable Al after 1st crop	Exchangeable Al after 2nd crop	Exchangeable Al after 3rd crop
(cm)	(ton/ha)	(cm)	--------- 1:1 H_2O	----------		---------- meq/100g		----------
No lime	0	0-15	4.6	4.5	4.5	1.11	0.93	1.19
		15-30	4.6	4.5	4.4	1.16	0.83	1.18
Shallow	1	0-15	5.0	4.9	5.0	0.85	0.55	0.62
(0-15)		15-30	4.8	4.7	4.6	0.98	1.00	0.99
	2	0-15	5.1	5.3	5.2	0.52	0.14	0.35
		15-30	4.8	4.8	4.7	0.97	1.00	1.08
	4	0-15	5.6	5.7	5.5	0.18	0.17	0.09
		15-30	4.8	4.7	4.8	0.92	0.79	0.92
	8	0-15	6.3	6.0	6.2	tr.	0.15	0.06
		15-30	4.8	4.9	4.8	0.74	0.57	0.68
Deep	1	0-15	5.1	4.9	4.8	0.79	0.66	0.89
(0-30)		15-30	5.0	4.9	4.7	0.88	0.86	1.03
	2	0-15	5.4	5.2	5.2	0.25	0.28	0.37
		15-30	5.2	5.1	4.9	0.66	0.40	0.73
	4	0-15	5.9	5.4	5.4	0.17	0.17	0.21
		15-30	5.4	5.1	5.0	0.34	0.43	0.51
	8	0-15	6.4	6.0	5.9	tr.	0.06	0.07
		15-30	5.9	5.5	5.4	0.16	0.15	0.13

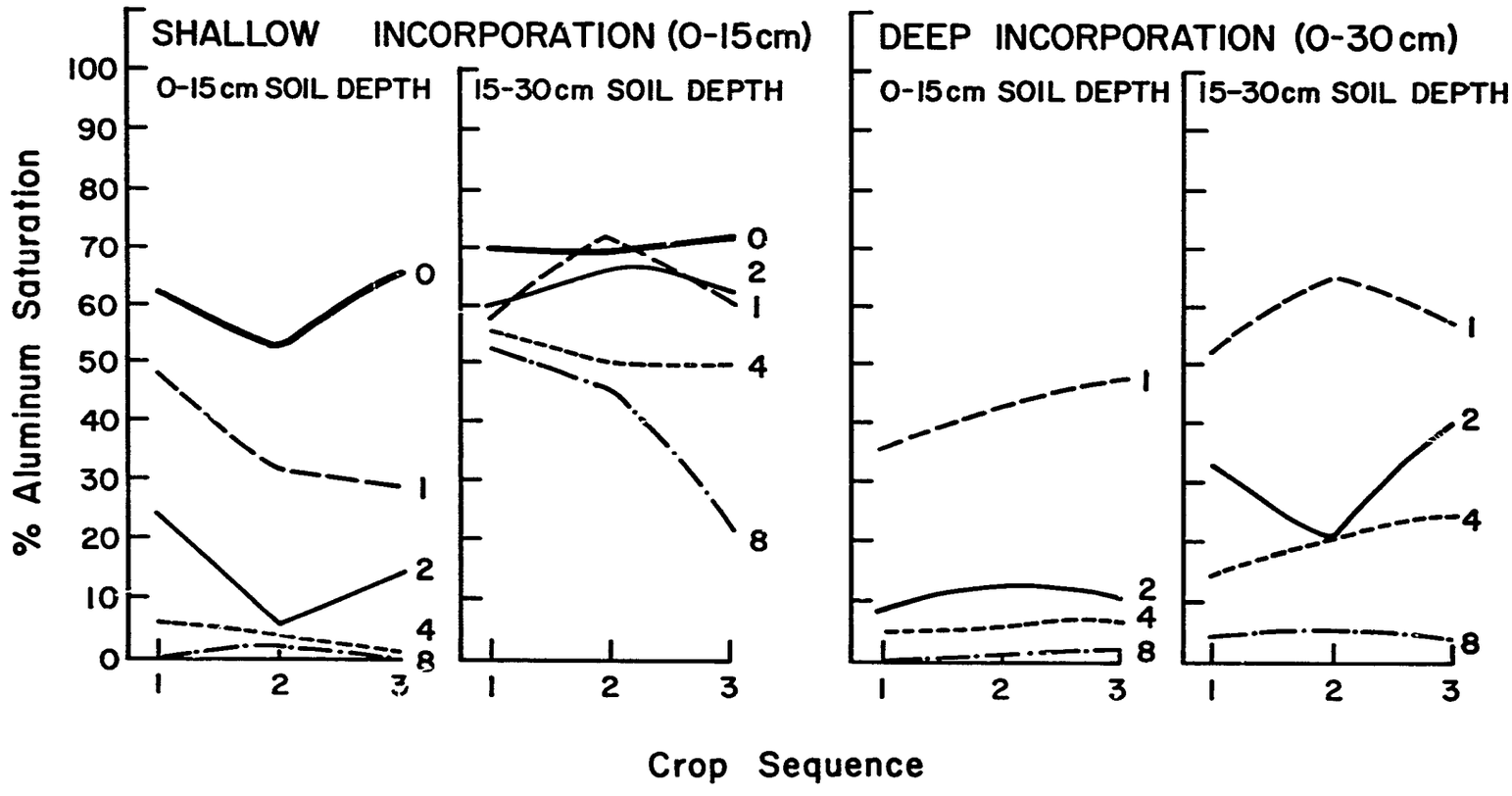


Fig. 21. Residual effects of lime rates and depth of incorporation on the aluminum saturation of the Dark Red Latosol after three consecutive corn crops. Brasília 1974. Numbers indicate tons lime/ha applied in 1972.

Water Extraction

Data presented in the 1973 Annual Report showed that the beneficial effects of deep lime incorporation are associated with greater root proliferation in the 15-30cm layer. By exploiting a larger soil volume, corn plants are able to extract more water and nutrients and to withstand dry spells better. This year soil moisture measurements with tensiometers and gypsum blocks confirmed that corn did extract more water from the 15-30cm layer. Table 24 shows the soil moisture content during a seven day period of rapid growth of the second crop. Day 50 corresponds to the day following irrigation of the experiment. Plants growing in the 4 ton-shallow treatment showed signs of wilting at Day 54, whereas plants on the 4 ton-deep treatment wilted only at Day 57. These data suggest that the root systems of plants in the deeply-limed treatment were able to deplete the available water in the 30cm zone and thus utilize it for maximum growth. On the other hand, the severely wilted plants of the shallow lime treatments were unable to take up the considerable amount of water that was still present below the 15cm zone at Day 57. This pattern of water extraction is probably due to the toxic effect of high aluminum saturation on root growth in the unlimed layers. Neither of the treatments were extracting much water at the 6cm depth where no lime was applied.

This experiment was replanted in the 1974-1975 rainy season to continue evaluating the residual effects.

Table 24. Soil water content at three depths measured during the 7th. to 8th. week for two depths of lime incorporations.

Lime	Depth of lime incorporation	Day after planting	Water content at soil depth		
			15cm	30cm	60cm
t/ha	cm		------	% H_2O by volume	------
4	0-15	50	27.0	28.2	25.4
		57	21.1	24.9	24.4
4	0-30	50	26.0	25.5	24.4
		57	20.6	19.4	23.6

Mr. Enrique Gonzalez showing the effects of depth of lime incorporation on corn wilting symptoms during a veranico. Top: 4 tons/ha incorporated at 0-15cm. Bottom: same rate incorporated at 0-30cm.

RESIDUAL EFFECT OF BROADCAST AND BANDED PHOSPHORUS APPLICATIONS

This experiment, begun in November 1972, has produced four consecutive crops of corn in two years and it is to be continued further. The broadcast phosphorus applications were made once at the start of the experiment and were incorporated by rotovation. In the banded treatments, new phosphorus applications were placed below the seed before each planting. The soil was plowed and disked after each crop, and the rows were changed in position about 15-25cm from that of the previous crop. All phosphorus has been applied as simple superphosphate, and blanket applications of 200 kg N/ha (urea) and 150 kg K_2O/ha (KCl) were made for each crop. Lime (4 tons/ha) and micronutrients (11 kg Zn/ha and 1 kg B/ha) were applied initially. Additional information regarding soil characteristics, experimental design and cultural practices were given in the 1973 Annual Report.

Yields

Yields of the four consecutive crops are shown in Fig. 22. The yields have varied considerably with season. In the 1973-1974 rainy season lower yields were due to serious insect and disease attacks. During the first rainy season, broadcast applications outyielded banded applications. From the second to fourth crops the banded treatments outyielded the broadcast treatments.

The broadcast treatment of 1280 kg P_2O_5/ha has consistently given near maximum yields. Yields for each crop are expressed as a percentage of this treatment in Fig. 23. The results show contrasting trends of a declining residual effect from broadcast applications and an increasing residual effect from the banded applications. The lower broadcast rates (160 and 320 kg P_2O_5/ha) have lost a substantial part of their residual effect during the second year in the third and fourth crops, while yields from the 640 kg P_2O_5/ha broadcast treatment declined slightly with time. The reference treatment 1280 kg P_2O_5/ha produced the maximum yield for the experiment in the fourth crop. This indicates that the residual effect of high broadcast rates is considerable. Additional crops will be needed to better estimate their value and duration.

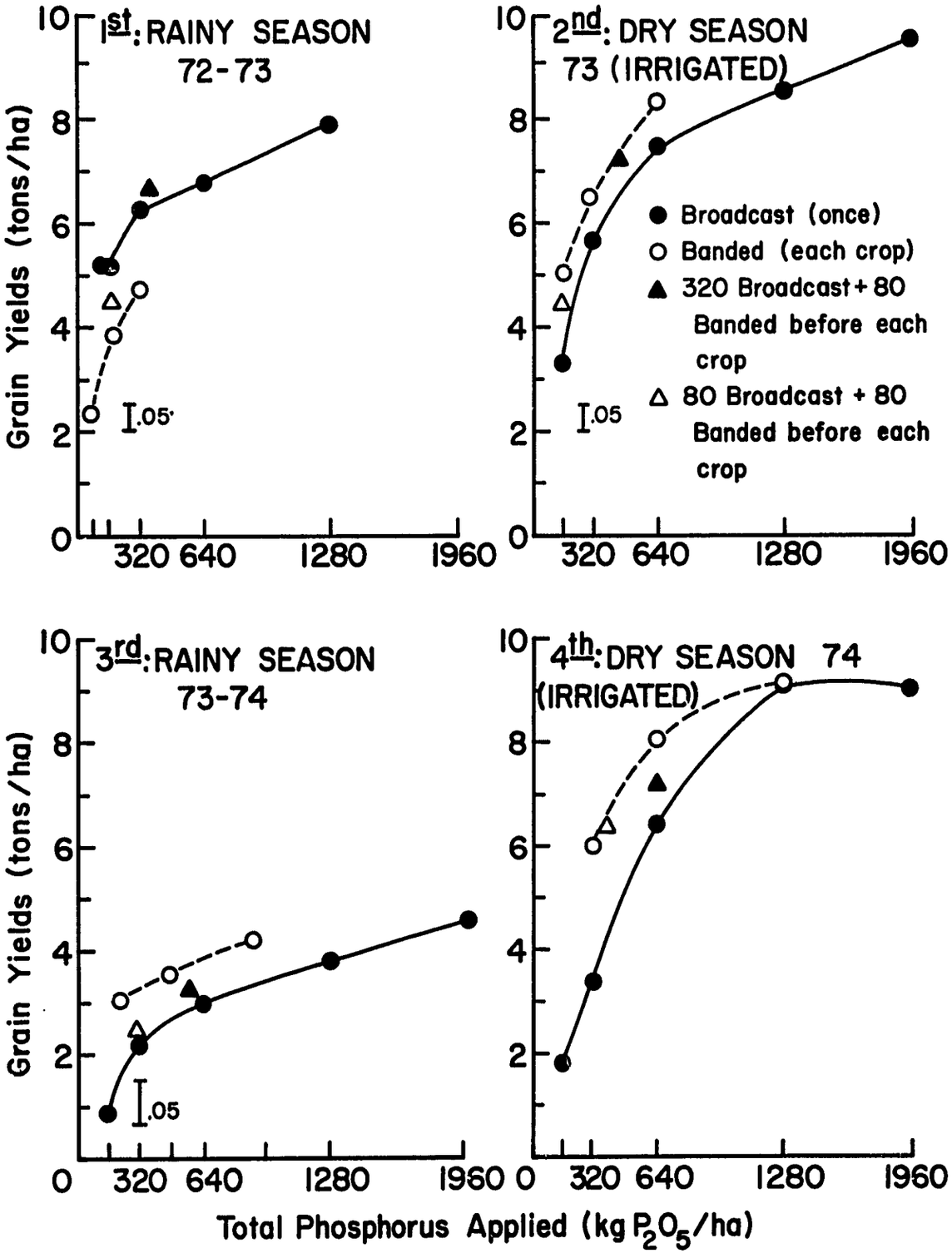


Fig 22. Corn response to phosphorus applications in four consecutive crops in Brasília.

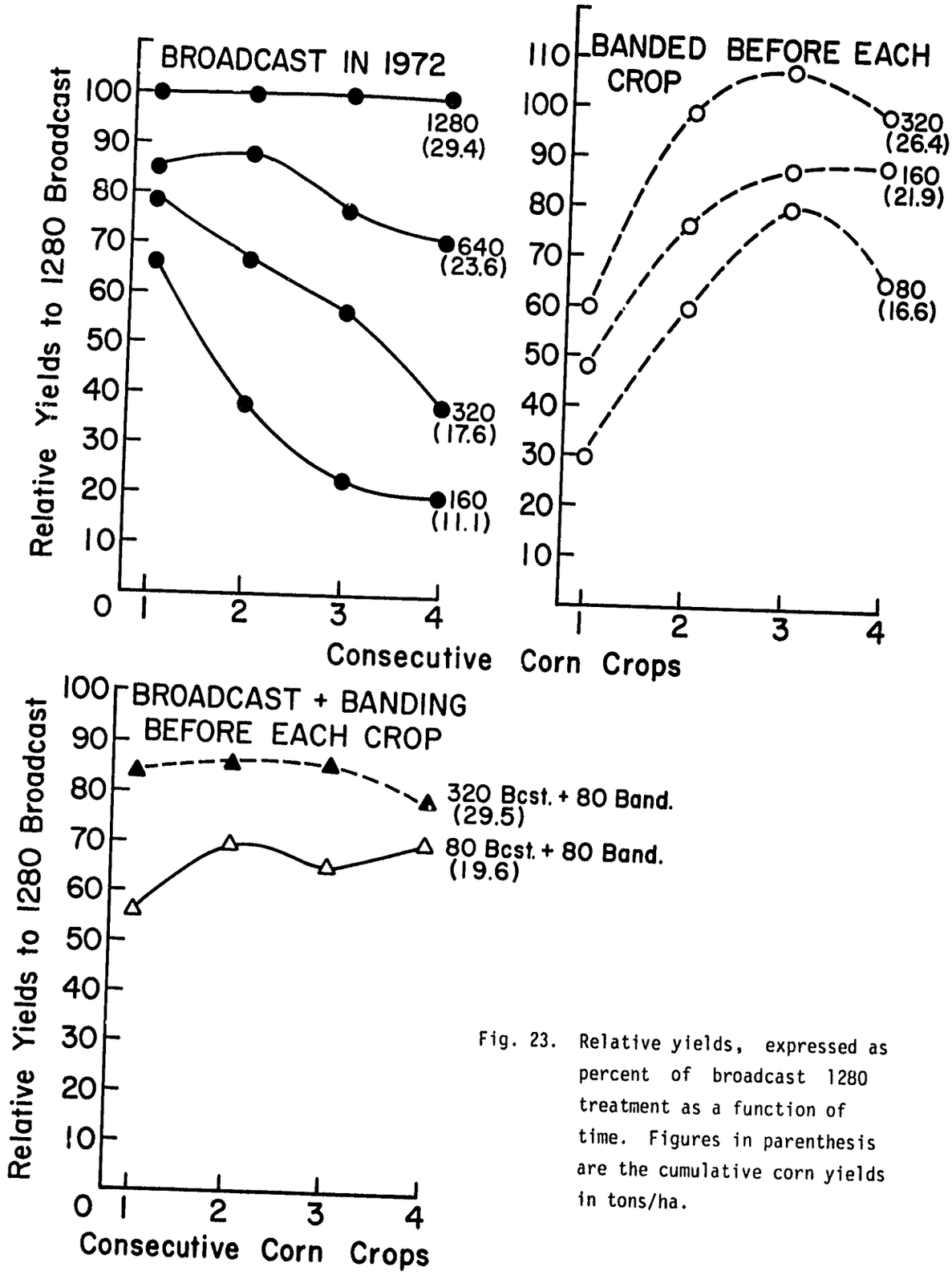
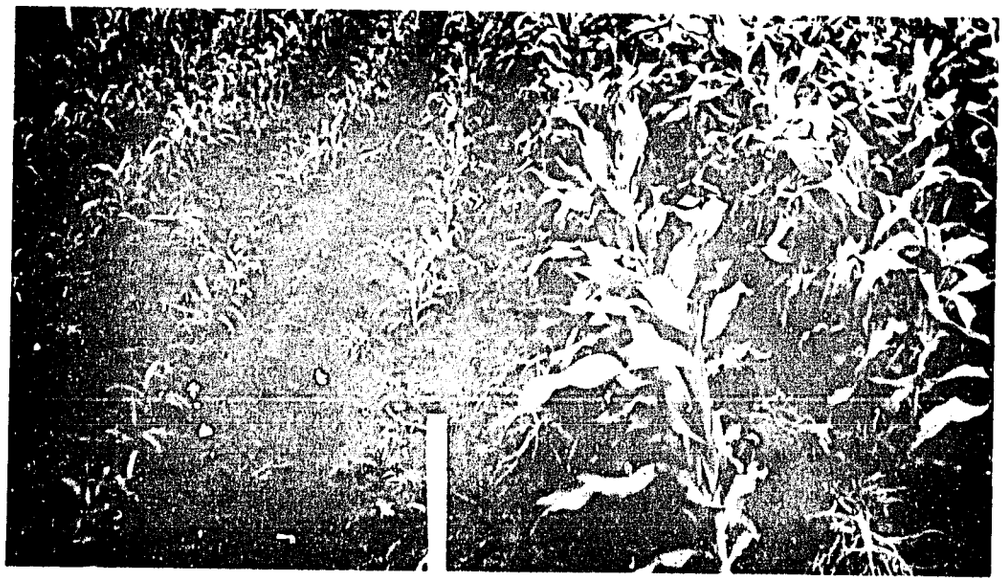


Fig. 23. Relative yields, expressed as percent of broadcast 1280 treatment as a function of time. Figures in parenthesis are the cumulative corn yields in tons/ha.

The cumulative nature of the residual effect of banded applications, also shown in Fig. 23 is equally important. Even the relatively low rate of 80 kg/ha per crop has developed fertility sufficient to produce about two-thirds of the maximum yield in the third and fourth crops. Yield increases were larger and faster with banded rates of 160 and 320 kg P_2O_5/ha and good to excellent yields were achieved by these treatments in the second and subsequent crops. Only the high banded rate of 320 kg/ha has given yields equal or superior to the high broadcast treatments. The cumulative amount of phosphorus applied in this treatment over four crops is 1280 P_2O_5/ha, or equal to the reference treatment.

The above statements suggest that high sustained corn yields can be achieved by an initial broadcast application of phosphorus followed by smaller banded applications with each crop. Results of the two treatments where this practice was used show that this is the case. An initial broadcast application of 320 kg P_2O_5/ha followed by 80 kg P_2O_5/ha banded for each crop has sustained yields of about 80% of maximum for all four crops. The importance of a fairly high initial broadcast level is shown by comparing this treatment with the treatment in which the initial broadcast application was 80 kg/ha, followed by the same banding rate. The latter treatment never caught up with the former.



Differences in the residual effect of broadcast phosphorus applied in 1972 on early corn growth during the fifth consecutive corn crop, 1974-1975 rainy season. Left: 160 kg P_2O_5/ha broadcast. Right: 1280 kg P_2O_5/ha.

Soil Analysis

Soil samples have been collected periodically from the broadcast treatments as a means of comparing soil test levels with the crop responses. The levels of phosphorus extracted from these samples by one procedure are shown in Table 25. This table shows that available phosphorus, as measured by the dilute double-acid or North Carolina extractant used in Brazil, decreased progressively with time in the higher broadcast rates. When compared with relative yields in a Cate-Nelson diagram (Fig. 24), a critical soil test level of approximately 13 ppm P separates the plots which yielded less than 80% of the 1280 broadcast treatment from those which yielded more. These relationships will be further studied in the fifth and following crops.

Economic Implications

The long-term results of this experiment are beginning to show the general nature of some economic implications of phosphorus fertilization. This is shown by a simple accounting of the variable costs of phosphorus applications, the constant costs of other fertilizers, the value of grain produced, and the resulting returns or losses for each treatment after the harvest of each crop. These estimates are shown in Table 26 using the approximate fertilizer and corn prices in Brasília as of March 1975, which are likely to vary in the future. Other production costs such as land clearing and preparation, pesticides, labor, dry season irrigation and interest charges are very indefinite and were not included at this stage. Therefore, Table 26 provides only a rough guideline.

The 160 broadcast was the most promising treatment for the first crop, followed by the 80-80 and the 320 broadcast. With additional crops the 160 broadcast treatment progressively deteriorated because the declining yields without periodic phosphorus additions could not meet the increasing costs of nitrogen and potassium additions. The higher broadcast treatments (640 and 1280 kg/ha) were uneconomical for the first crop but their residual effect allowed them to produce 1.7 and 1.5 cruzeiros worth of corn for every cruzeiro spent in all fertilizers and lime for the four crops. Similar rates of return were obtained with treatments of 320 broadcast, 80 banded per crop and 160 banded per crop. The highest return ratio as well as the highest absolute returns to fertilization were obtained with 320 kg P_2O_5/ha broadcast initially plus 80 kg P_2O_5/ha banded prior to each crop.

Table 25. Soil test phosphorus levels (North Carolina extractant) as a function of time in the broadcast treatments. Soil samples taken shortly after the first planting and after each harvest.

Broadcast P rate	Time of sampling				
	Feb. 73	May 73	Nov. 73	May 74	Oct. 74
kg P_2O_5/ha	ppm P				
160	5.2	4.6	3.9	3.6	1.7
320	7.0	8.8	7.4	5.0	2.4
640	34.4	17.7	19.5	10.0	5.8
1280	53.5	68.8	55.8	30.6	17.3
1920*	--	120.3	103.5	65.6	42.2

* applied May 1973

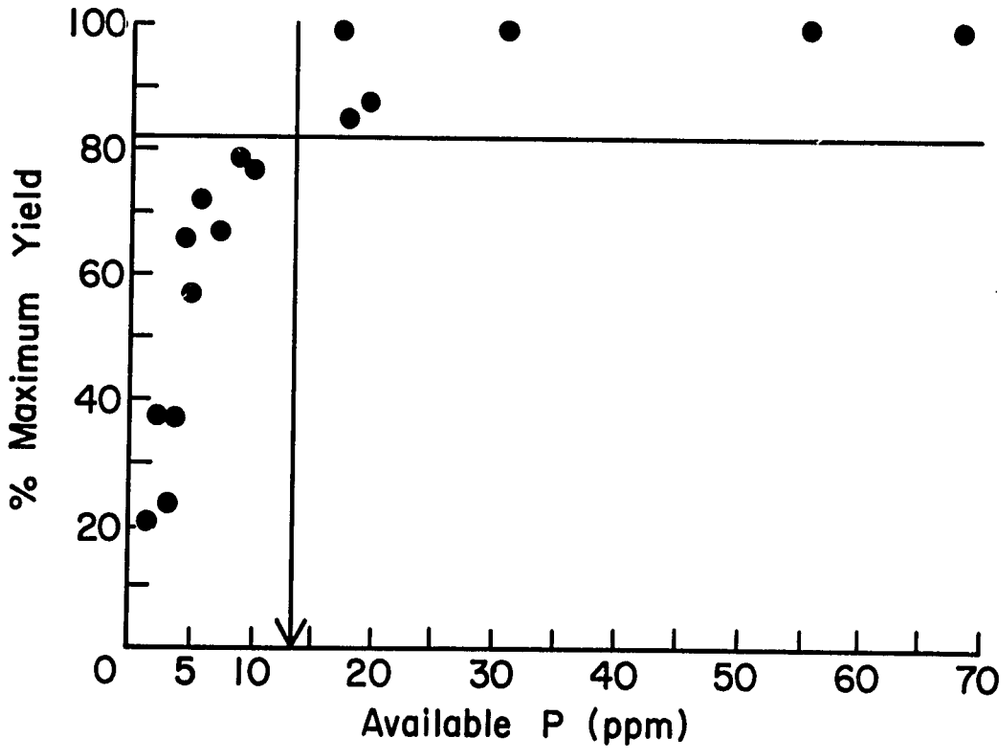


Fig. 24. Relationship between percent yield (relative to the 1280 kg P_2O_5/ha broadcast) and soil test values.

Table 26. Gross and net returns to phosphorus fertilization at March 1975 prices in Brasilia.

Treat. No.	Initial broadcast application	Banded applic. per crop	Total P added	P cost[1/]	Cost of Other fert. and lime[2/]	Total fert. and lime cost	Gross crop return[3/]	Net return or (loss)	$Cr. of added crop value per $Cr. spent in fert.
	-------- kg/ P_2O_5/ha --------			---------- Cr.$/ha ----------					
					FIRST CROP:				
1	160	0	160	1280	1944	3224	5024	1800	1.5
2	320	0	320	2560	1944	4504	6026	1522	1.3
3	640	0	640	5120	1944	7064	6524	(540)	0.9
4	1280	0	1280	10240	1944	12184	7642	(4542)	0.6
6	0	80	80	640	1944	2584	2328	(256)	0.9
7	0	160	160	1280	1944	3224	3696	472	1.1
8	0	320	320	2560	1944	4504	4604	100	1.0
9	320	80	400	3200	1944	5144	6393	1249	1.2
10	80	80	160	1280	1944	3224	4385	1161	1.3
					TOTAL OF FOUR CROPS:				
1	160	0	160	1280	7989	9269	10720	1451	1.1
2	320	0	320	2560	7989	10549	16897	6348	1.6
3	640	0	640	5120	7989	13109	22746	9637	1.7
4	1280	0	1280	10240	7989	18229	28255	9996	1.5
6	0	80	320	2560	7989	10549	15941	5392	1.5
7	0	160	640	5120	7989	13109	21040	7931	1.6
8	0	320	1280	10240	7989	18229	25398	7169	1.3
9	320	80	640	5120	7989	13109	23557	10448	1.8
10	80	80	400	3200	7989	11189	18835	7646	1.6

1/ 1 kg P_2O_5 = Cr. $8.00 = US$1.12.

2/ 1 kg N = Cr.$8.22 = US$1.15; 1 kg K_2O = Cr.$2.47 = US$0.34; 1 ton of lime = Cr.$100 = US$14; micronutrients added Cr.$475/ha = US$66.50/ha.

3/ 1 ton of corn grain = Cr.$960 = US$134.

These results suggest a strategy for phosphorus fertilization. For a cropping system with relatively high phosphorus requirements such as continuous corn, it seems logical to apply a heavy initial broadcast application as a costly but necessary investment similar to clearing and liming. Relatively small initial applications alone, such as the 160 kg P_2O_5/ha broadcast although profitable in the first crop, were uneconomical in following crops. Heavy initial applications alone, such as the 640 kg P_2O_5/ha broadcast will not return a profit until at least the second year, but a profitable residual effect thereafter appears likely. The combination of a relatively heavy initial application with smaller maintenance applications, such as treatment 9, shows promise of returning a profit somewhat earlier and sustaining profitable yields. In all cases, however, a relatively large initial application of about 300 kg P_2O_5/ha was necessary to achieve and sustain adequate yield levels and cover other fertilizer costs. In order for a farmer to make such an investment in a given parcel of land, adequate plans for intensive use of this area for several years are essential. Substantially lower fertilization costs for periodic maintenance applications will sustain good yields.

A complete strategy for phosphorus fertilization cannot be developed from this experiment alone. Crops other than corn and certain sequences of crops are known to have lower requirements for phosphorus fertilization. It is likely, however, that a fairly heavy initial capital investment in fertility improvement with plans for continual intensive cropping will be needed for profitable production systems in soils of this type.

These calculations have two interesting aspects. First, all crop yields can be considered as fertilizer response since corn dies without phosphorus applications in th s soil. Second, the broadcast treatments were applied two years prior to this analysis, before the energy crisis sharply increased fertilizer costs. In 1972 it took 6.2 kg of corn to pay for a kg of P_2O_5 (corn at Cr.\$400/ton; P_2O_5 at Cr.\$2.50/kg); in 1974 it took 8.3 kg of corn to purchase the same amount of phosphorus. Broadcast applications can serve as a hedge against inflation if the cost of phosphorus relative to the price of corn continues to increase, or just the opposite if relative prices decrease.

PHOSPHORUS SOURCES AND RATES FOR FORAGE CROPS

Objectives and Design

Early results of the previous phosphorus experiment suggested the need to explore other sources and methods of phosphate application in conjunction with species having some tolerance to high exchangeable aluminum and low phosphorus requirements. Rock phosphate sources may be more available in unlimed acid soils if the species grown can tolerate the aluminum levels. In addition, the cost of rock phosphate is lower than superphosphate.

In February 1974, two experiments of similar design were established to test responses of the Perennial grass Brachiaria decumbens and the legume Stylosanthes humilis (which is an annual but is capable of self-reseeding) to ordinary superphosphate, rock phosphates and a magnesium silicate-phosphate combination at three lime rates. The experiment was installed in neighboring plots in the clayey Dark Red Latosol area.

The phosphorus sources were:

1. Ordinary superphosphate (20% soluble P_2O_5).
2. Termofosfato: Araxá rock phosphate heated with $MgSiO_3$ containing 19% total P_2O_5 of which 18% P_2O_5 is soluble in citric acid, and available in Brasília.
3. Hiperfosfato: Moroccan rock phosphate containing 30% total P_2O_5 of which 24 to 26% P_2O_5 is soluble in citric acid. This product is finely ground with 80% finer than 300 mesh and is available in Brasília.
4. Araxá rock phosphate: a natural rock phosphate found in the Cerrado containing 28 to 30% total P_2O_5 of which 5.5% is soluble in citric acid; finely ground with 85% finer than 200 mesh
5. North Carolina rock phosphate: rock phosphate containing 30% P_2O_5; finely ground with 80% finer than 325 mesh, supplied by the Tennessee Valley Authority.

Rates of lime were equivalent to 0, 1.5 and 4.5 tons $CaCO_3$/ha on the S. humilis experiment and 0, 3, 4.5 tons $CaCO_3$/ha on B. decumbens experiment. Phosphorus was applied after the dolomitic, finely ground lime was incorporated and equilibrated, except in the unlimed treatments. Basal fertilizer applications included KCl, $ZnSO_4$, boron and molybdenum. Urea is being applied periodically on the grass experiment.

Table 27. Effect of different phosphorus sources on soil pH and available P after 24 days incubation on a Dark Red Latosol.

Source	Rate	Avail. P (Olsen)	Soil pH
	kg P_2O_5/ha	ppm	
Ordinary superphosphate	200	9	4.4
	1000	46	4.5
	2000	91	4.6
Triple superphosphate	200	7	4.3
	1000	47	4.4
	2000	91	4.4
Termofosfato	200	4	5.0
	1000	29	6.4
	2000	55	7.3
Hiperfosfato	200	5	4.8
	1000	14	5.4
	2000	18	5.5
Araxá rock phosphate	200	3	4.4
	1000	7	4.6
	2000	9	4.7

Reaction of Phosphorus Sources in the Soil

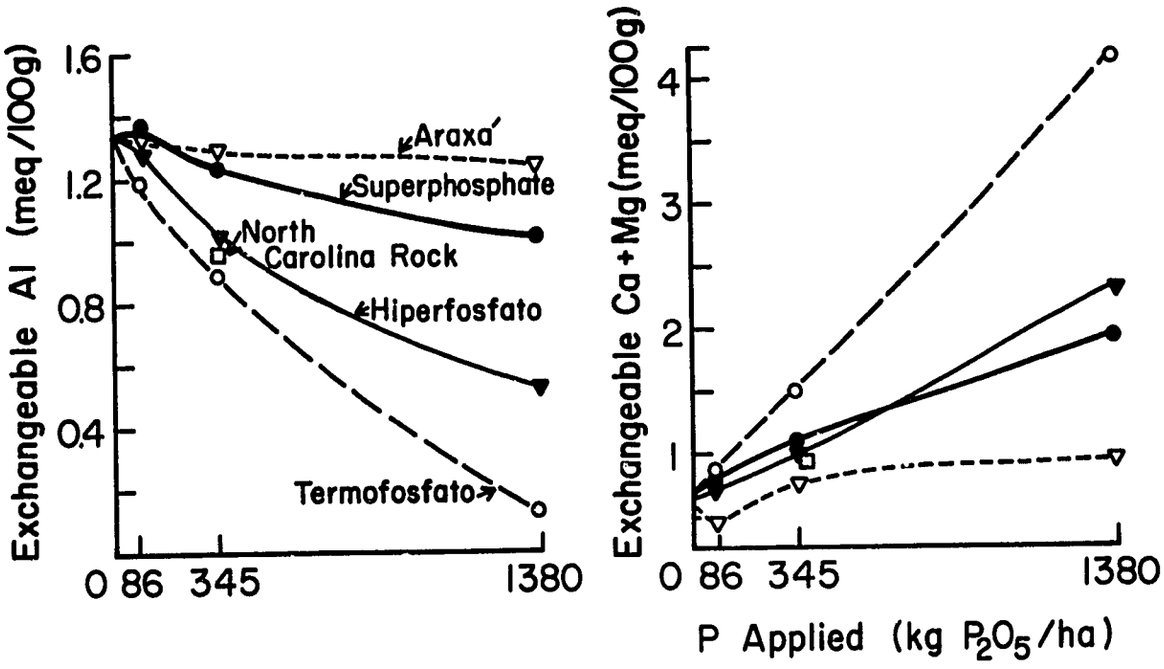
Prior to planting the field experiments the four sources were incubated for 24 days with samples of the clayey Dark Red Latosol in order to test their effect on soil pH and available phosphorus level in the soil. The results are presented in Table 27. The high reactivity of the superphosphates and to a certain extent of the Termofosfato is evident from the available phosphorus figures. The liming effect of the Termofosfato is also quite striking. To a lesser extent, the Hiperfosfato also had a liming effect. The rates of application used in the field experiment were based on this preliminary test. They were 86, 345 and 1380 kg total P_2O_5/ha for all sources, except for the North Carolina rock which was only tested at the 345 rate due to the limited amount of material available.

The effects of the different phosphorus sources on soil properties were measured in the Brachiaria plots three months after planting. The results of the unlimed plots are shown in Fig. 25. The Termofosfato source reduced the exchangeable aluminum level to practically zero and increased the exchangeable calcium and magnesium content seven times with the high phosphorus rate. Percent aluminum saturation was reduced from 68 to 48% with 345 kg P_2O_5/ha as Termofosfato. This thermally altered Araxá rock phosphate material is not only a good source of available P, but also has an excellent liming effect. The unaltered Araxá rock had little effect on exchangeable aluminum, calcium and magnesium levels. The Hiperfosfato rock also had a liming effect. The North Carolina rock performed similarly to Hiperfosfato at the only rate tested.

The liming treatments increased pH values from 5.1 to 5.5, except with the high Termofosfato rate which increased the pH to 5.9 and 6.2 with 3 and 4.5 tons lime/ha, respectively. The effect of all treatments on extractable phosphorus is shown in Table 28. The rate of 86 kg P_2O_5/ha was insufficient to reach the previously suggested critical level of 13 ppm. This generally was reached at the 345 kg P_2O_5/ha level.

Response of Brachiaria decumbens

This grass was established vegetatively on February, 1974. The dry season followed with the rains ending in mid-April. Urea (50 kg N/ha) was applied one month after planting, with no further applications until after the second harvest in December, 1974. The first cutting, which is primarily indicative of the establishment rate, was made in May, 1974. The second harvest represents regrowth during the first part of the following rainy season



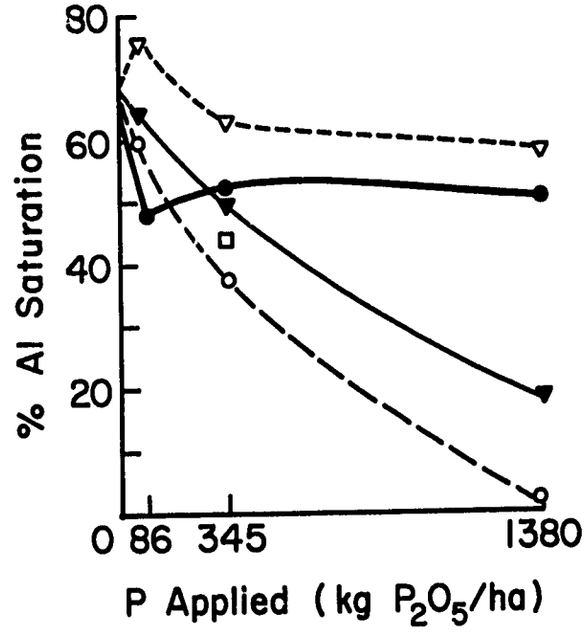


Fig. 25. Effects of phosphorus sources and rates on the exchangeable cations and percent aluminum saturation of unlimed soils three months after planting Brachiaria decumbens.

between October and December of 1974.

The first harvest indicated responses to phosphorus up to the highest rate of soluble sources applied (Fig. 26). In this early harvest, Termofosfato performed better than ordinary superphosphate. Hiperfosfato performed about as well as ordinary superphosphate except at the highest lime rate. Growth from Araxá rock treatments was much lower than other sources, which suggests that it provides less available phosphorus. Hiperfosfato and Araxá rock performed somewhat less desirably on the limed plots. Reduction of rock phosphate availability with liming has been shown previously. A possible explanation of this effect is that the higher pH tends to retard the dissolution of the apatite.

All phosphate sources increased the levels of exchangeable calcium plus magnesium and tended to reduce exchangeable aluminum and increase pH. This was indicated previously by soil analyses from the unlimed plots (Fig. 25). In the ordinary superphosphate treatments where phosphorus supplied by the fertilizer was not affected by soil pH, Brachiaria decumbens did not appear to be particularly responsive to lime applications, suggesting that it is tolerant to the levels of aluminum encountered.

December harvest yields of the lower phosphorus rates were much greater than those observed in the May harvest (Fig. 27). Establishment rates were much slower on the lower phosphate levels and growth in these stands was incomplete in the May harvest. In general, ordinary superphosphate and Termofosfato performed quite similarly. Somewhat better growth occurred with lower rates of Termofosfato (86 and 345 kg P_2O_5/ha) than with ordinary superphosphate. Hiperfosfato, with the exception of the zero lime rate, performed almost as well as ordinary superphosphate. The indication of a depressive effect of increasing lime rate in plant response to Hiperfosfato in the May harvest was not apparent in the December harvest. Although there was some indication of a depressive effect in response to Araxá in the second harvest, this factor may be diminishing with time after establishment of the grass.

Response of Stylosanthes humilis

The early stand was relatively thin and plants were allowed to attain maximum growth for seed production. Counts of plants/m^2 were made in April 1974 and again in October 1974 to obtain a measure of re-establishment after the dry season. Re-establishment was good on plots receiving no phosphate and it improved with applied phosphorus. Essentially no differences were observed in plant re-establishment in relation to lime level.

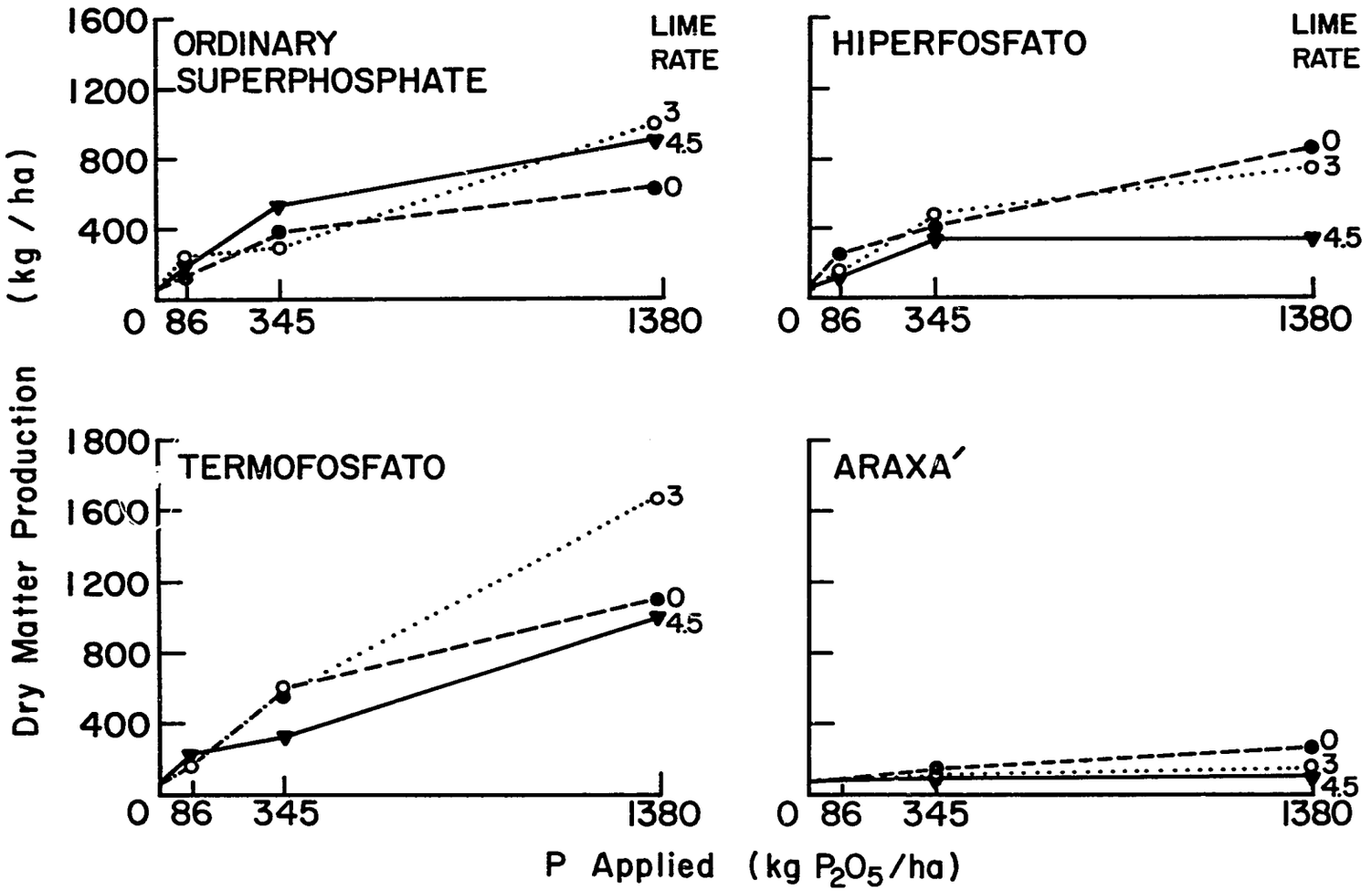


Fig. 26. Growth of Brachiaria decumbens as affected by phosphorus sources, rates and liming. First cut, May 1974. Brachiaria on North Carolina rock plots yielded 376, 433 and 1297 kg/ha for 0, 3 and 4.5 tons lime/ha.

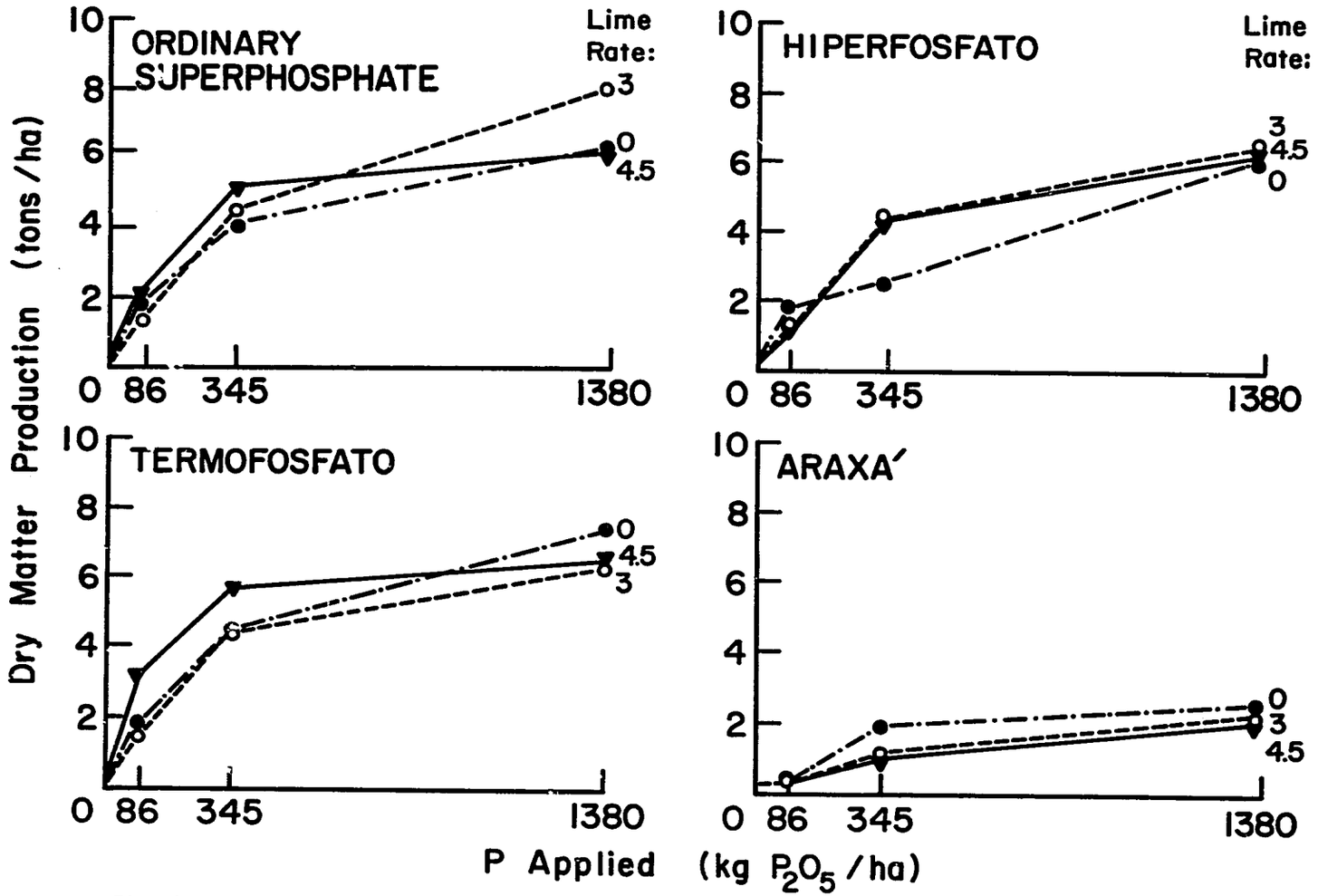


Fig. 27. Growth of Brachiaria decumbens as affected by phosphorus sources, rates and liming. Second cut, December 1974. Brachiaria on North Carolina rock plots at 345 kg P_2O_5/ha yielded 2.97, 4.28 and 4.79 tons/ha at 0, 3.5 and 4.5 tons lime/ha.

In general, the more soluble sources (ordinary superphosphate and Termofosfato) produced better re-establishment, while Araxá, the most insoluble source, produced the lowest re-establishment at a given rate of total P_2O_5. Subsequent yield data show, however, that the ability of Stylosanthes humilis to grow under sub-optimum nutritional conditions is not necessarily reflected in its capacity to produce dry matter.

Dry matter production during the early part of the 1974 wet season is shown by data from the first harvest, in December 1974 (Fig. 28). Very low yields were produced at the lower P_2O_5 levels, and all yields were considerably less than those of B. decumbens. There were yield responses to all levels of applied phosphorus from each of the sources.

The highest yields were obtained with ordinary superphosphate and Termofosfato, and the responses to these sources were similar. Yields with Hiperfosfato were somewhat lower, with the exception of the highest lime rate; the higher rates of this source only produced 2/3 of the yields with superphosphate at the same rates. The response to levels of Araxá was generally linear, but the highest rate only yielded about 1/3 of that produced by the same quantity of total P_2O_5 from ordinary superphosphate.

These data suggest a notable response of this crop to lime. This is of interest since other workers have shown that this and other Stylosanthes species favor only moderate calcium levels. The response was particularly apparent at the rate of 345 kg P_2O_5/ha with ordinary superphosphate and Termofosfato, where yields more than tripled with increasing rates of 0, 1.5 and 4.5 tons lime/ha. However, this response to lime rate was greatly diminished at the highest rate of P_2O_5 in the ordinary superphosphate treatments and was also less clear at the highest rate of Termofosfato. There was some indication of a response to lime at the upper two phosphorus rates with Hiperfosfato as well. With Araxá, though, the highest lime rate produced somewhat lower yields. Because of the limiting quantity of available phosphorus in these treatments, a reduction in phosphorus solubility at the higher lime rates was probably the cause of the observed yield decrease.

Shortly before the December harvest this species of Stylosanthes developed a fungal infection in the roots and leaves that stopped growth for the remainder of the rainy season. This species appears so susceptible to common pathogens that its usefulness in the region is very doubtful.

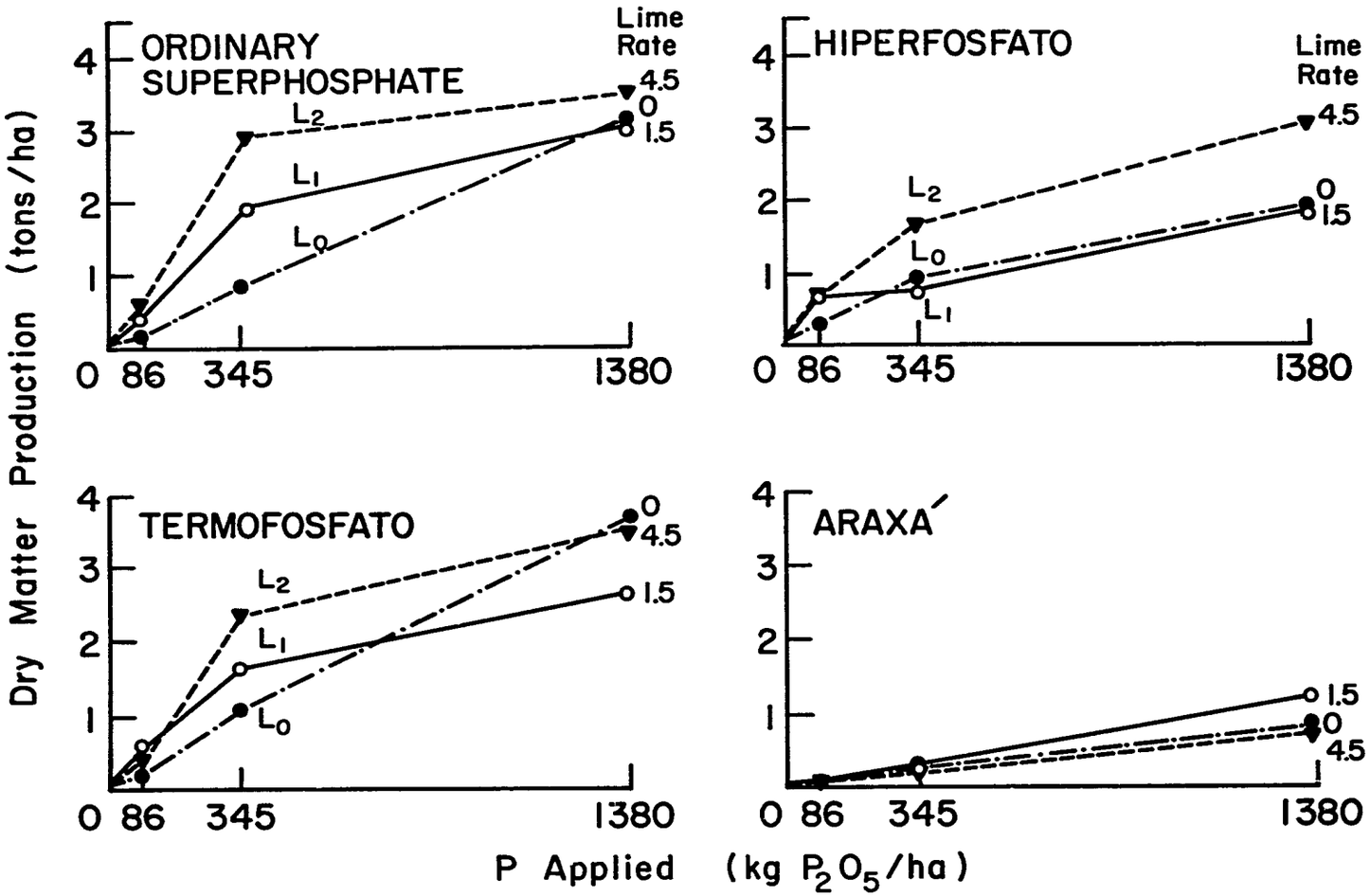
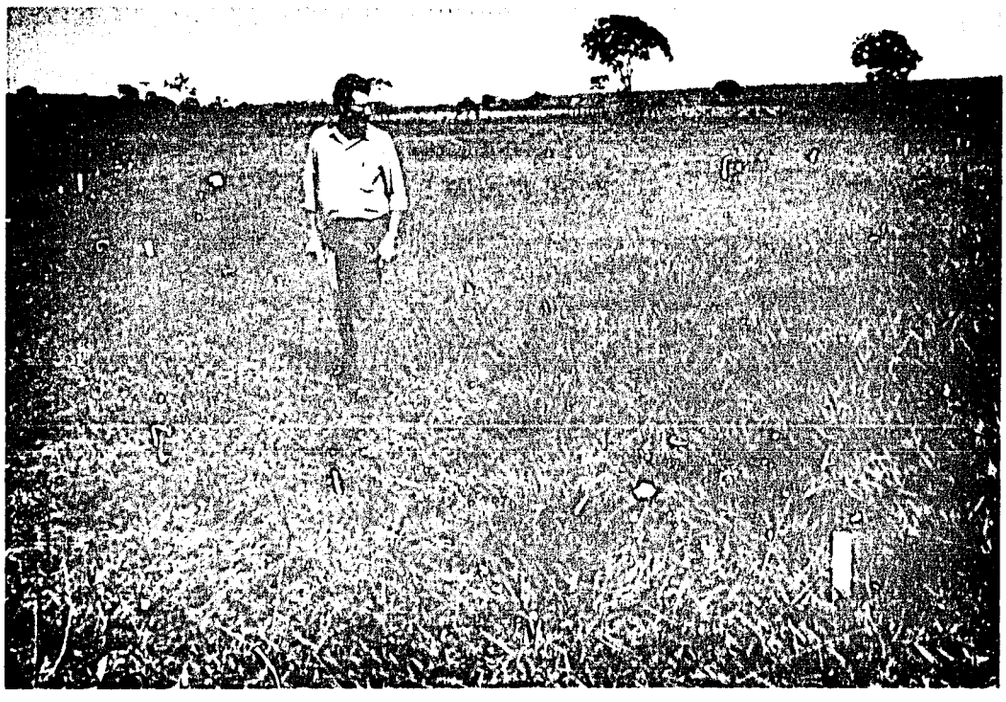


Fig. 28. Dry matter production of Stylosanthes humilis as affected by phosphorus sources, rates and liming. First cut, December 1974. Plants treated with 345 kg P_2O_5/ha of North Carolina rock yielded 1.80, 1.67 and 1.21 tons/ha at 0, 3 and 4.5 tons lime/ha respectively.

Table 28. Soil test phosphorus levels (North Carolina extraction) taken in May 1974 of the Brachiaria experiment.

Lime applied	Phosphorus applied	Ordinary Superphosphate	Termofosfato	Hiperfosfato (Morocco rock)	Araxá rock	N. Carolina rock
ton/ha	kg P_2O_5/ha	ppm P				
0	86	4.6	3.8	4.9	3.6	----
	345	17.3	36.8	19.7	15.5	14.9
	1380	69.1	38.6	172.0	47.8	----
3	86	3.8	3.7	6.1	3.2	----
	345	13.8	7.7	22.4	15.0	15.7
	1380	81.8	48.8	12.1	79.4	----
4.5	86	4.7	4.8	5.6	4.7	----
	345	12.3	9.7	27.2	13.1	21.3
	1380	76.5	64.4	23.4	61.6	----

Mean of three unfertilized treatments: 2.3 ppm.



Mr. Russell Yost examines the growth response of Brachiaria decumbens to 345 kg P_2O_5/ha as North Carolina rock phosphate without lime (right) in comparison with the 0 kg P_2O_5/ha treatment (left).

Values of double-acid (North Carolina) extractable soil phosphorus did not correlate particularly well with plant response from the rock phosphate sources. High soil test values with the Hiperfosfato, Araxá, and North Carolina rocks (Table 28) suggest that unreacted phosphorus was being dissolved by the extractant. In the case of Araxá, much of this extractable phosphorus appears to be other than plant-available phosphate. Other non-acidic extractants are being evaluated for their suitability on soils where rock phosphate has been applied.

Conclusions for the First Year

The early results of these experiments have emphasized the strong influence of quantity and quality of available phosphorus, as determined by application rate and solubility of the source, in establishment and early growth of two forage crops for these Oxisols of the Cerrado. Ordinary superphosphate, Termofosfato and Hiperfosfato have all given good early growth response in both forage species. These test species are known to tolerate some degree of exchangeable aluminum and should thus be capable of responding to rock phosphates applied to soils receiving low liming rates.

The level of citric-acid soluble phosphorus in Hiperfosfato, North Carolina rock and Araxá (all finely ground, untreated natural rock phosphates) has been reasonably indicative of early growth response to these sources. In this establishment phase of growth, the phosphorus availability of the Araxá material is severely limiting, even at the zero lime rate. Future harvests will indicate to what degree this limited early growth rate influences total production and the economics of these practices. The changing patterns of crop response to phosphorus with time and the long-term level of available soil phosphorus provided by these treatments must be evaluated by future results from these experiments.

NITROGEN FERTILIZATION

The design of the nitrogen experiment, given in last year's report, was slightly altered during the second crop in the 1973-1974 season. In Treatment 2 the initial banded application was deleted and no more fertilizer was applied. In Treatment 1, the application at 30 days was increased to 80 kg N/ha. Treatment 8 with lime-coated ammonium nitrate as the nitrogen source was repeated, but the level was raised to 20 + 80 kg N/ha. The fertilizer used in this treatment was incorrectly described as $Ca(NO_3)_2$ in the 1973 Annual Report. Treatment 9, which was a form of sulfur-coated urea (SCU) in the final planting, was changed to a new maximum nitrogen rate of 20 + 100 + 100 kg N/ha as ordinary urea. Treatment 10 was continued as SCU, but the nitrogen rate was increased to 140 kg/ha, all applied in a band below the seed prior to planting. The SCU material was also different from the first year. This material had a faster rate of nitrogen release, reported by TVA as 43% in seven days. A general application of 150 kg K_2O/ha as KCl was made and the phosphorus level was substantially raised by the broadcast application of 300 kg P_2O_5/ha and a band application of 80 kg P_2O_5/ha, all as simple superphosphate, in accordance with the results of the phosphorus experiment.

The treatment descriptions and yields for the second crop are given in Table 29. A series of treatments produced near maximum yields of over 4.5 tons/ha. The low yields of the nitrogen experiment are typical of the other experiments for the second rainy season crop. In late February, a number of the plots suffered severe lodging (as much as 70%) because of strong winds during a rainstorm. This was followed by continuous rains in March during which the insecticide applications were ineffective and very severe leaf damage occurred due to corn leaf blight. This period of unfavorable weather and disease damage occurred just after pollination and continued practically until maturity. Solar radiation levels during March were about 1/4 of that recorded for all other months of this growing period.

Comparison of the stover and grain yields from the first two crops (Table 30) shows that the ratio of stover-to-grain was about twice as high in the second crop. The stover yield was considerably greater the second year for all treatments. Furthermore, the grain yield was greater the second year for the first three treatments listed (those with lowest nitrogen level) but less for all of the higher nitrogen treatments. The higher yields at

low nitrogen levels may be due in part to the increased phosphorus application rate. However, it is apparent that the second crop did not respond in grain or stover production to a nitrogen level above 20 + 40 kg N/ha. There was somewhat more stover production with even less grain production in the lime-coated NH_4NO_3 and SCU treatments.

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

Table 29. Result of the second consecutive corn crop of the nitrogen experiment (Rainy season 1973-1974).

Treatment Number	Time of application (days after planting) 0	20	30	60	Grain yields[3/]
	------- Nitrogen applied (kg N/ha) ------				tons/ha
2	0	0	0	0	3.76 c
1	0	0	80	0	3.99 abc
3	20	0	40	0	4.63 a
4	20	0	80	0	4.64 a
5	20	0	120	0	4.50 ab
6	20	40	0	40	4.50 ab
7	20	60	0	60	4.38 abc
8	20[1/]	0	80	0	3.90 bc
9	20	100	0	100	4.54 ab
10	140[2/]	0	0	0	4.24 abc

[1/] Lime-coated NH_4NO_3.

[2/] Sulfur-coated urea.

[3/] Duncan test at 0.05 level.

Table 30. Comparison of grain and stover yields, for first and second crops in the nitrogen experiment at Brasilia.

N applied (as urea except where otherwise noted)		First Crop			Second Crop		
First year	Second year	Stover	Grain	Ratio	Stover	Grain	Ratio
---------- kg N/ha ----------		kg/ha	kg/ha		kg/ha	kg/ha	
20 + 0	0	2843	3246	0.876	5595	3757	1.489
0 + 40	0 + 80	3045	3582	0.850	5752	3994	1.440
20 + 40	20 + 40	3390	4027	0.842	6584	4630	1.425
20 + 80	20 + 80	4075	5285	0.771	6524	4638	1.407
20 + 120	20 + 120	4661	6257	0.745	6423	4504	1.426
20 + 40 + 40	20 + 40 + 40	4205	6179	0.680	6459	4499	1.436
20 + 60 + 60	20 + 60 + 60	4464	6310	0.719	6715	4377	1.534
Lime-NH_4NO_3 20 + 80	Lime-NH_4NO_3 20 + 120	4087	5423	0.754	6776	3903	1.736
SCU 20 + 80	20 + 100 + 100	3591	5096	0.705	6508	4541	1.433
SCU 20 + 80	SCU 140	4268	5677	0.752	7011	4242	1.653

ZINC FERTILIZATION

Soils in the central plateau of Brazil are quite low in zinc. Deficiencies have been reported and, as noted in last year's report, a marked response to zinc fertilization was obtained in the two experiments conducted. One of these studies was continued this year to investigate the residual effect of the applied zinc and to collect data concerning critical soil and plant levels of zinc. The original zinc treatments applied the previous year were 0, 1, 3, 9 and 27 kg Zn/ha as zinc sulfate incorporated with a rotovator to a depth of 25cm.

This year 150 kg K_2O/ha was broadcast and the field plowed. At planting 20 kg N/ha and 160 kg P_2O_5/ha were banded using urea and ordinary superphosphate. Cargill 111 corn was planted and later topdressed with 150 kg N/ha. Soil samples were taken prior to planting and are to be analyzed. The corn ear-leaves were samples at early silking. These have been analyzed by two methods, atomic absorption and emission spectroscopy.

Fig. 29 shows the yield response to zinc applied in 1972 in the first and second consecutive crops. There was a marked residual effect during the second year with maximum yields attained at the 9 kg Zn/ha rate. The yields of the second crop compare very favorably with the first crop, considering the poorer growing conditions during the 1973-1974 rainy season.

In the first year of this study boron was applied at 1 kg B/ha in addition to the five Zn rates previously mentioned. An extra 9 kg Zn/ha plot was included without B to test the need for boron. There was a tendency toward a response, but it was insignificant. As expected, there was also no effect in the second crop. It is important to note, therefore, that excellent yields have been obtained without addition of any other micronutrient except zinc. It is apparent from these data that for corn produced under these conditions zinc is the only micronutrient of immediate concern.

The results of the chemical analysis of the leaves by the two methods are shown in Fig. 30. Zinc concentration is lower when determined by atomic absorption than by emission spectroscopy. This difference is more pronounced at the lower zinc application rates. In comparing the methods, it is more likely that the emission data are in error because of matrix effects in the emission determination.

Consideration of the method of zinc determination is important when attempting to determine a critical zinc level in the ear leaf. For leaves analyzed by atomic absorption the

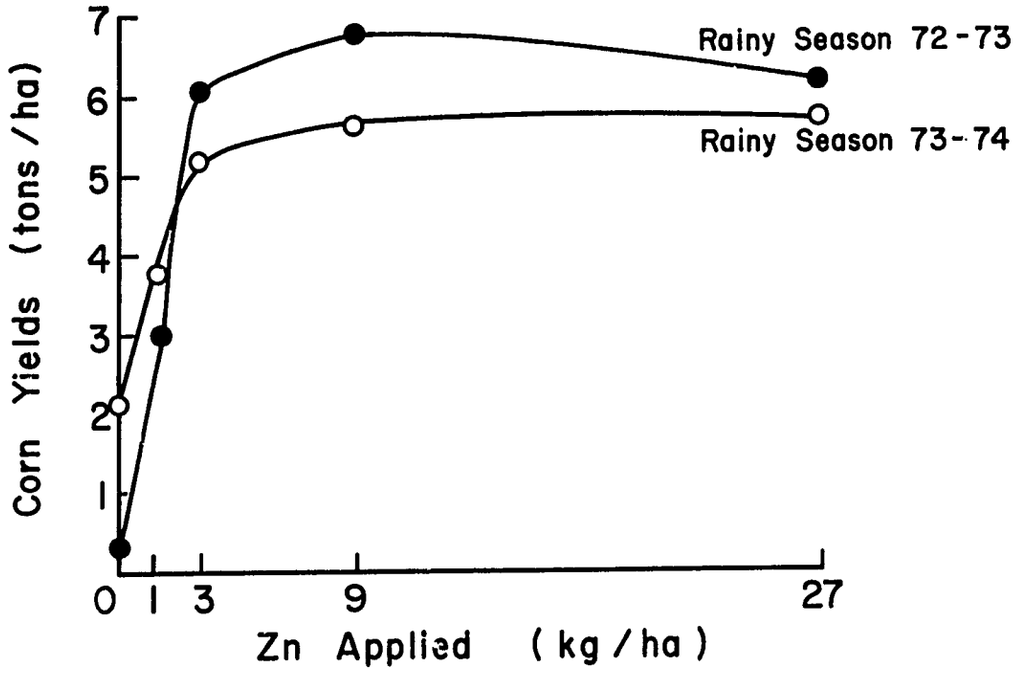


Fig. 29. Original and residual effect of zinc applied in 1972 on an Oxisol limed to pH 6.4 in Brasília.

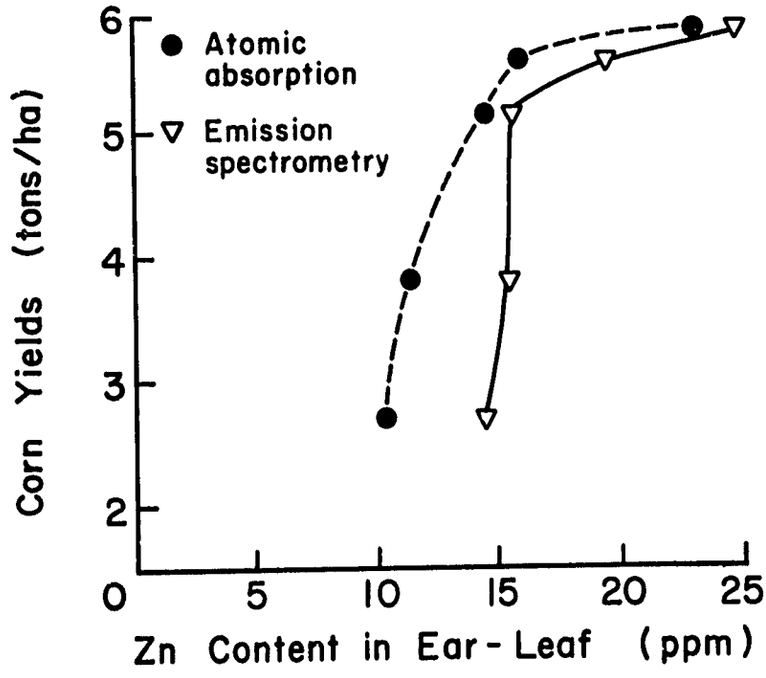


Fig. 30. Relationship between yields and zinc content of the ear leaf at early silking stage determined by two standard methods.

Table 31. Effect of residual zinc fertilization on the nutrient composition of corn ear leaves at the silking stage as determined by two methods.

Zn applied	Zn	Mg	Fe	Cu	Mn	P	K	Ca	N[1/]
kg Zn/ha	(ppm)	(%)	(ppm)	(ppm)	(ppm)	(%)	(%)	(%)	(%)
				Atomic Absorption					
0	10.2	0.18	669	15	31	0.36	2.4	0.55	2.51
1	11.7	0.17	522	11	30	0.24	2.1	0.66	2.43
3	13.8	0.16	290	8	26	0.19	2.0	0.64	2.46
9	16.6	0.13	172	7	24	0.20	2.1	0.66	2.47
27	23.1	0.13	177	7	22	0.19	1.8	0.65	2.50

Emission Spectrometry

Zn applied	Zn	Mg	Fe	Cu	Mn	P	K	Ca	B	Mo	Al
kg Zn/ha	(ppm)	(%)	(ppm)	(ppm)	(ppm)	(%)	(%)	(%)	(ppm)	(ppm)	(ppm)
0	13.8	0.20	868	16	41	0.44	2.2	0.73	10.4	1.8	117
1	15.8	0.17	648	11	38	0.30	1.9	0.83	10.0	2.0	133
3	15.8	0.15	194	9	32	0.24	1.9	0.87	9.2	1.8	164
9	18.8	0.14	112	10	34	0.23	2.0	0.88	8.5	1.8	194
27	24.4	0.13	112	9	33	0.23	1.9	0.82	10.2	2.2	226

[1/] Kjeldahl

critical zinc level would be 15 ppm, whereas that for those analyzed by emission spectroscopy would be at least 17 ppm. Although the difference between these is small, it is highly important for proper interpretation of plant analysis data.

The concentrations of other elements are also shown in Table 31. There was a buildup of several elements when little or no zinc was applied. The levels do not indicate a lack of any other micronutrient. There is a rather striking decrease in iron level in the leaves associated with an increase in leaf zinc level.

Zinc response in the Dark Red Latosol. Foreground: corn fertilized with 9 kg Zn/ha. Background: corn without added zinc.

SOIL MOISTURE STUDIES

Problems of moisture and fertility have been studied together in much of the research at Brasília. Besides the lack of moisture during the strong, five-month dry season, there are constraints to production of many agricultural crops because of:

1. Erratic rainfall distribution during the wet season with rainless periods locally known as "veranicos" which often cause severe water stress.

2. The capacity of these soils for available water storage is relatively poor, approximating that of very sandy soils, and

3. The depth and intensity of root development of many crops is restricted because of aluminum toxicity, thereby limiting water and nutrient uptake to the volume of soil in which lime can be incorporated.

A major part of this work was conducted by Mr. J. M. Wolf, who completed his field studies during the period of this report. Selected highlights from his dissertation follow.*

Rainfall Distribution

Detailed studies were made of daily rainfall data collected in the Brasília area during 42 years. Probabilities concerning certain aspects of rainfall distribution were developed from these data.

The occurrence of "veranicos" during the rainy season is not apparent from monthly precipitation means. The distribution and length of the "veranicos" is shown in Fig. 31. Daily rainfall data by 10-day periods showed marked differences in the probability of occurrence of dry spells during these periods. This is illustrated in Fig. 32. The occurrence of dry spells during the rainy season was found to be somewhat more prevalent during late December and early January.

A study of the length of the longest dry spell within each rainy season indicated a 50% probability of occurrence of at least 14 continuous days without significant rainfall in any year. There was a 15% chance that the longest dry spell would exceed three weeks. The analysis indicated only 8% probability of good rainfall distribution, i.e., that the duration of the longest dry period to be eight days or less.

---

*Wolf, James M. 1975. Water constraints to corn productivity in Central Brazil. Ph.D. Thesis, Cornell University, Ithaca, New York.

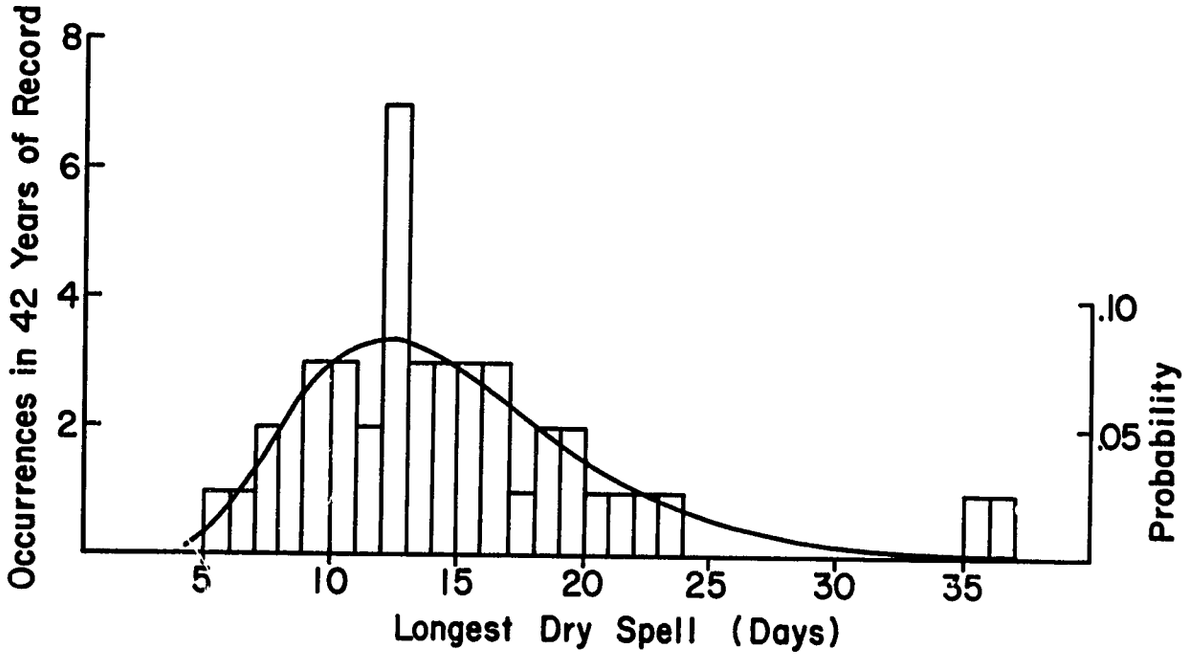


Fig. 31. Histogram of the number of occurrences of the longest wet season dry spell for Brasília, based upon precipitation for 42 years of record. Also given is the fit of the log-normal probability distribution function for the longest dry spell.

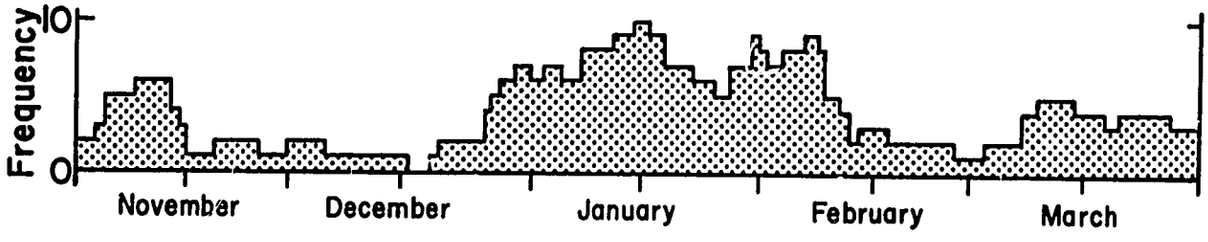


Fig. 32. Histogram showing when longest dry spells have occurred in the past for Brasília.

The frequency of occurrence of multiple dry periods during a rainy season was also studied. In a hypothetical average year, one could expect three dry periods of at least 8 days, two periods of 10 dry days or longer, and one period of at least 13 days without rain.

Water Storage and Release by the Soil

The moisture release properties of the two Oxisols is shown in Table 32. In the clayey Dark Red Latosol about 2/3 of the soil water is stored and released at tensions of less than 1 bar. There is a sharp break in the water release curve between tensions of 1/2 and 3/4 bar. As tension is increased from 1 to 15 bars, only an additional 3 to 4%, or about 1mm of water per 30cm soil depth, is released.

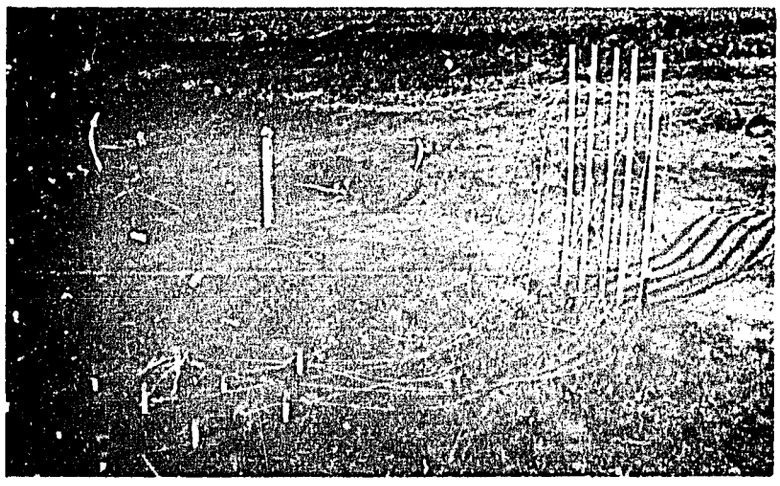
The upper limit of available water by the soils studied was considered to be the water content associated with 1/10 bar soil-water tension. This is the approximate tension achieved after 2 to 3 days of free drainage in the absence of evapotranspiration. For the clayey Dark Red Latosol, it took nearly 80 days of free drainage without evapotranspiration to achieve the 1/3-bar tension. It is possible that 3 days would have been required in the presence of evapotranspiration.

Using the tensions of 1/10 bar and 15 bars, the capacity for available water storage in the clayey Dark Red Latosol is limited to approximately 34-44mm per 30cm depth. A vigorously growing crop rooted to this depth will deplete soil water to tensions greater than 1 bar in six to seven days of high evaporative demand (typical evapotranspiration of 6mm day). Wilting of corn has been observed after six rainless days. These characteristics are comparable with those of deep sandy soils, and this is due to the dominance of strongly developed, fine structural aggregates in this clayey soil.

Soil moisture release properties were determined for the loamy Red Yellow Latosol on which the extrapolative lime-phosphorus experiment reported in a later section has been established. Soil moisture depletion with increasing tension is less abrupt and of greater range for this soil than that of the clayey Dark Red Latosol. Although the absolute amount of water released at higher tensions is small, this coarser-textured soil does release more water between tensions of 1 and 15 bars than the clayey soil (Table 32). This loamy soil has approximately 30% greater available water storage capacity than the clayey soil.

Table 32. Soil water contents and different soil moisture tensions of the two soils used at the Brasilia Experiment Station.

Soil moisture tension	Dark Red Latosol clayey (site 2)		Red-Yellow Latosol loamy
	0-45cm	45-105cm	0-75cm
bars	% H_2O (volume)		
0.1	29.3	26.9	24.7
0.2	26.0	24.0	22.0
0.3	24.3	22.5	20.6
0.4	23.1	21.4	19.6
0.5	22.2	20.7	18.7
0.7	22.1	20.5	17.2
1.0	21.7	20.3	15.5
2.0	20.9	20.0	14.0
5.0	19.5	19.0	12.4
10.0	18.5	18.2	11.2
15.0	18.0	17.8	10.6
Available water capacity (0.1-15 bar)	11.3	9.1	14.1
% Clay	46	47	33



A series of tensiometers monitoring soil moisture tensions at different profile depths in the irrigation studies.

Crop Response to Water Stress

A series of experiments were conducted during the 1973 dry season and the 1973-1974 rainy season to measure crop response to different water stress intensities. During the 1973 dry season, corn was irrigated regularly at 3, 7 and 14 days intervals. Fig. 33 shows the estimated soil moisture status of the root zone for these treatments and the yields actually achieved. Additional treatments were used to duplicate the rainfall pattern during the 1945-46 and 1953-54 rainy season which were characterized by two strong veranicos" and that of the past 1972-1973 rainy season. During the 1973-1974 rainy season the experiment had a depth of liming variable and irrigation intervals designed to break 4, 7 and 10-day "veranicos." Similar varieties, fertilization and cultural practices to the other experiments were used.

Corn yields showed good agreement with the length of the period of water stress. Yields were reduced 10% when irrigation was applied on the eighth day rather than the seventh day during a wet season "veranico." There was also an indication that the relative availability of soil moisture declined more sharply at tensions above 0.5 bar (about 60% depletion of soil moisture storage). This was shown by correlations between yield and "stress count"—the number of days when soil moisture tension exceeded specified levels. For the field experiment conducted during the dry season and the time period of 74 to 137 days after planting, nearly 70% of the yield variation among all treatments was accounted for by simply counting the number of days when soil moisture tension at 15cm exceeded 0.75 bar.

Daily soil moisture measurements were made with tensiometers and gypsum blocks installed at various depths within the growing crop. These data permitted indirect estimates of evapotranspiration rates as influenced by the treatments. Total evapotranspiration was correlated with yield. The results of the severely stressed crop irrigated at 14-day intervals during the dry season are shown in Fig. 34. For a well-watered, 150-day corn crop during the dry season, evapotranspiration was estimated at 550mm. Poorly watered treatments used an estimated 470mm for the same period. Crop evapotranspiration for the dry season was significantly correlated with climatic measurements, in particular, pan evaporation, solar radiation, and relative humidity. The following simplified model was offered for the estimation of evapotranspiration by a well-watered, dry season crop during the late

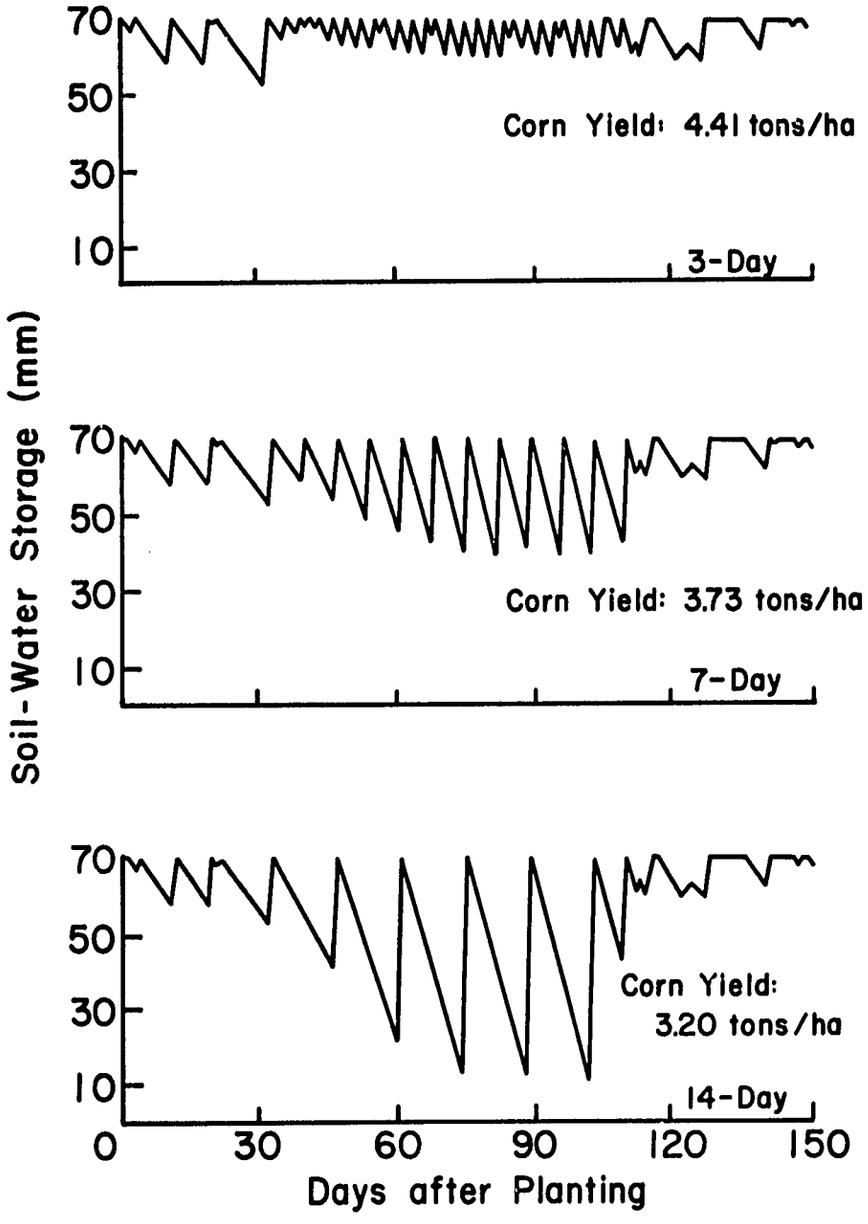


Fig. 33. Soil-water storage vs. time for regularly scheduled irrigation treatments. A 60cm root zone has been assumed. Corn yields are indicated.

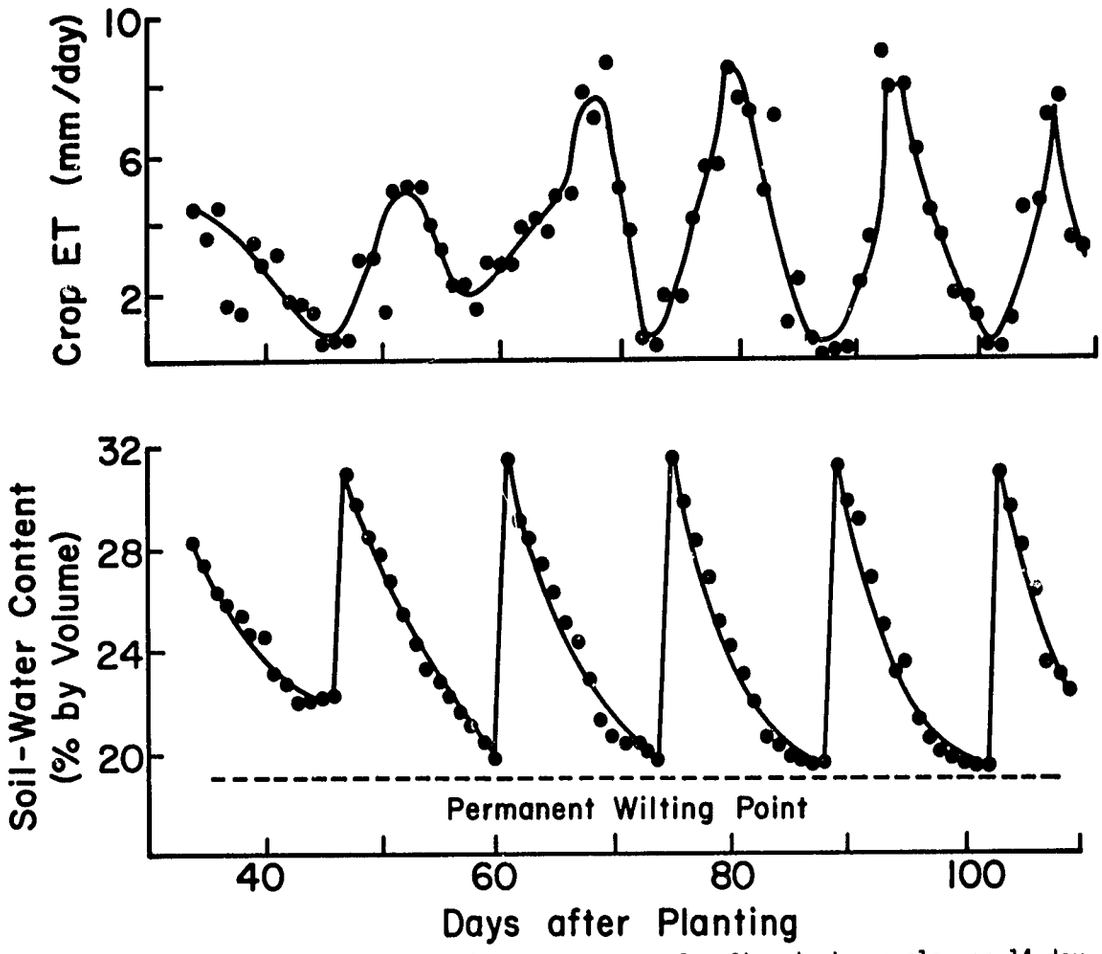


Fig. 34. Crop ET and soil-water content for five drying cycles on 14-day, severely stressed, irrigation treatments. Note that evapotranspiration lags behind restoration of soil-water content.

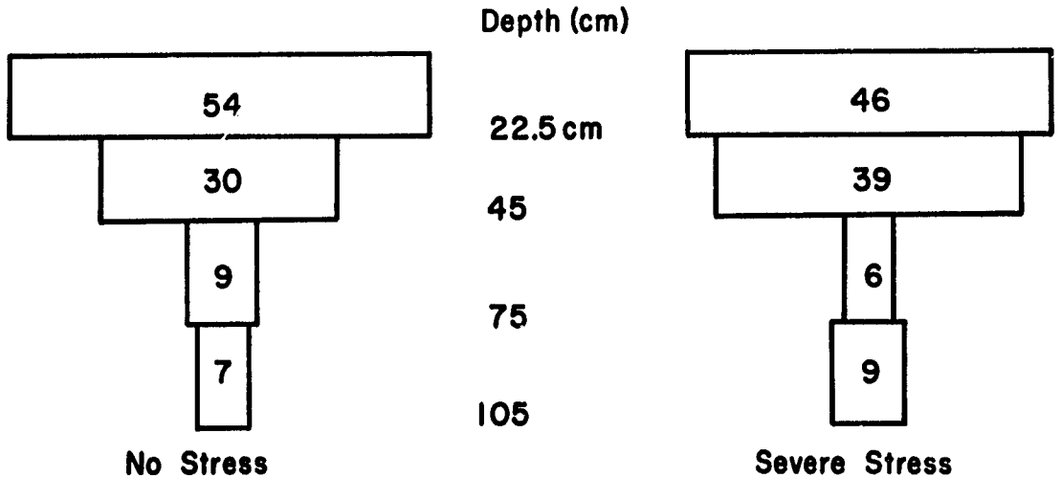


Fig. 35. Percentage water extraction by depth in the 3-4 days following an irrigation to relieve the type of water stress indicated.

vegetative-to-reproductive stage (70 to 108 days after planting):

$$\text{Crop ET} = 1.45 + 0.77\ (\text{Class A Pan Evaporation})$$

This equation have a highly significant correlation as R^2 value of .52, and coefficient of variation of 18.8%.

Daily evapotranspiration for the dry season crop was greatest during the period of three weeks prior to tasseling to two weeks thereafter (65 to 100 days after planting), and this value approximated peak evaporation from the Class A pan of 7.5mm/day. Evapotranspiration prior to 60 days after planting was less than 75% of pan evaporation.

Plants in treatments subjected to regular periods of water stress (14-day irrigations) reponded in a manner analogous to hardening in certain transplanted crops. Although recovery from visual wilting after each irrigation was practically immediate, at least 3 days were needed before daily evapotranspiration increased to levels prior to the stress. Measurements of soil moisture tension and evapotranspiration showed this effect (Fig. 34). This may be associated with root inactivation in the upper part of the profile and with other metabolic changes. This assumption, however, was not tested. In comparable plants subjected to a similar stress only once, recovery of daily evapotranspiration occurred within one to two days.

The water extraction pattern with depth was also evaluated. For the dry season corn crop, nearly 85% of the water was absorbed from the upper 45cm of the soil profile, as Fig. 35 shows. Comparable reports for corn grown in Nebraska and Illinois indicate soil water utilization to depths of 150cm or more.

Effect of Depth of Lime Incorporation

In both dry season and wet season field experiments, the treatments included lime incorporation to depths of 0-15cm and 0-30cm. Although the application was carefully done, the two depths of liming were not achieved in the dry season experiment, when checked with soil analysis. Consequently, only the rainy season results for which lime was adequately incorporated are presented in Fig. 36. Results for three dates of planting show that yields progressively decreased as the planting season was delayed. This is due to the extremely heavy rains during March and the associated disease and insect attacks previously discussed. No prolonged "veranicos" were recorded in this unusually well-distributed rainfall pattern.

Fig. 36 shows that deep incorporation was superior to shallow incorporation in the first two plantings regardless of irrigation interval. No differences were observed in the third planting, probably because of other more limiting factors such as pest attacks.

Measurements of soil moisture tension at 30cm showed that more water was extracted at this depth in the treatments with the deeper lime incorporation. Although deeper water extraction occurred, it was concluded that this was not the principal cause of the large yield response to deeper lime incorporation. In the well-watered treatments with both depths of lime incorporation, the longest period without water was four days and soil-water tension was kept at about 0.2 bar. In these treatments, corn with deeper lime incorporation yielded about 30% more than with shallow lime incorporation.

These results confirm the superiority of deeper lime incorporation in an environment not previously tested, acid subsoil and well-distributed rainfall pattern. Under these circumstances, the primary advantage would be to extract nutrients from a larger soil volume, since there was no serious water stress limitations. Results from the 1973 Annual Report strongly suggest advantages in both water and nutrient extraction with deeper liming in acid subsoils during severe water stress periods.

Growth Potential - Irrigated Dry Season vs. Rainfed Rainy Season

With the exception of precipication and low night temperatures, the dry season (May-September) and the wet season (October - April) are only moderately different in climatic aspects important for crop production. Although averages of daily maximum and minimum temperatures differ little, the minimum night temperatures in June and July may be considerably lower, thereby slowing initial crop development and maturity of the dry season crop. It takes corn approximately one month longer to mature during the dry season. Slow growth at early stages caused by low temperatures is considered the reason for the longer growth duration during the dry season.

Average monthly solar radiation is similar for these periods (about 410 k cal/cm^2/day in 1973-1974) although the number of hours of direct sunlight is considerably greater during the dry season. Pan evaporation is somewhat greater during the dry season (average 5.74mm/day vs. 5.19mm/day in 1973-1974).

Some consideration was given to comparative yield potential during these periods. Greater production commonly reported during the dry season with irrigation is not due to su-

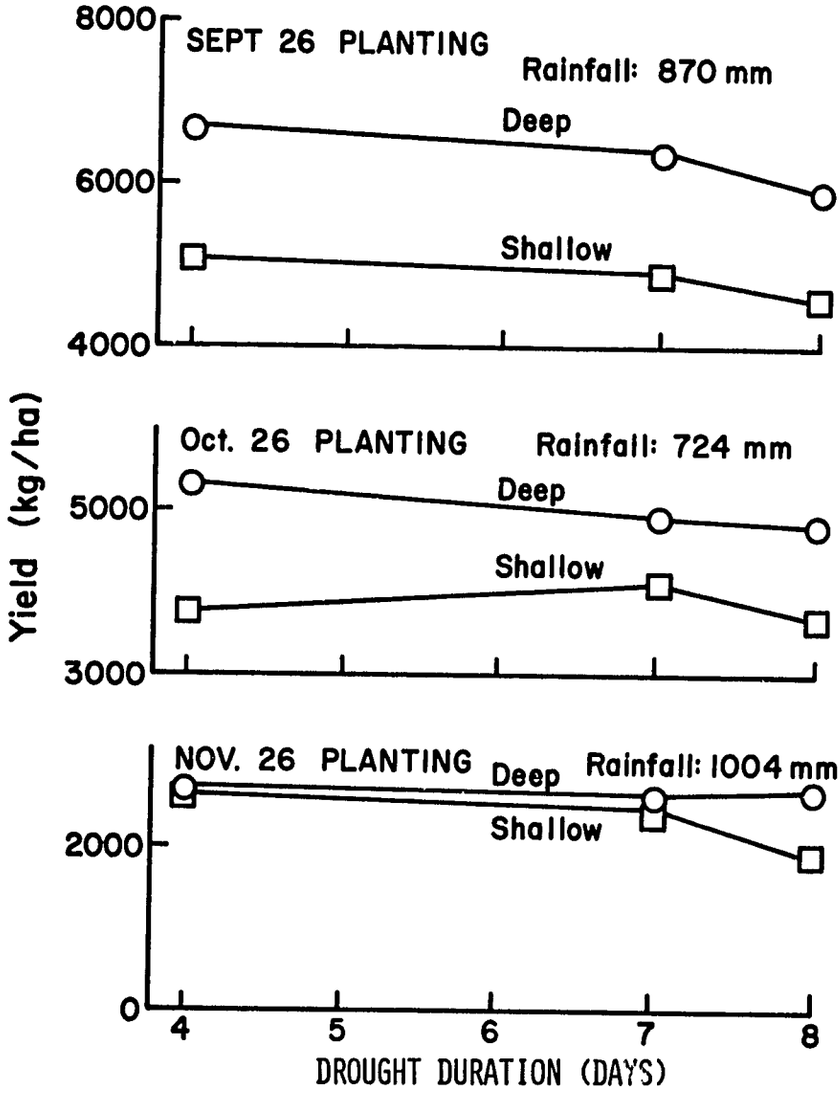


Fig. 36. Corn yields as a function of planting dates, duration of longest dry spell and depth of lime incorporation during the 1973-74 rainy season. Shallow: 0-15cm, Deep: 0-30cm.

perior light energy, but on the contrary, to frequent yield losses during the rainy season caused by variables less effectively controlled, including plant diseases, insects, and "veranicos."

The total water requirement under field conditions would depend upon the type and efficiency of an irrigation system. Under the rather efficient gravity system used in this experiment, the amount of deep percolation (water which passed through the profile before plant uptake occurred) averaged about 60% of evapotranspiration for irrigation runs of 8 meters. For a moderately well irrigated crop during the dry season, evapotranspiration was estimated at 510mm, deep percolation losses at 30mm, and rainfall at the end of the period (September-October) was expected to provide 180mm. Thus, the estimated water requirement is 630mm per dry season crop. In reality, an additional amount would be needed to compensate for percolation losses in longer irrigation runs and for conveyance losses. The use of a sprinkler system with frequent wetting of a shallow root zone would help to reduce the water requirement but would sharply increase costs.

Potential Yield Benefits from an Irrigation System

An estimate was made of the long term yield reduction due to uneven rainfall distribution during the rainy season. This was done by combining the probabilities of dry spells of various durations shown in Table 33 with the expected yield levels associated with the respective dry periods, based on the data from these experiments. This resulted in the estimate that the long term wet season yields in the Brasília area will average 54% of the maximum yields which could be achieved with a well-managed irrigation system and the high degree of soil fertility, pest control and management used on the experimental station. In addition to the possibility of approximately doubling wet-season yields, as shown by this estimate, an irrigation system once established would most likely be used for intensive dry season production, as well.

The validity of this estimate of yield losses in the absence of an irrigation facility would depend on the individual farm situation. Even though only a small portion of the farm would likely be irrigated and intensively cultivated, this would represent a high investment project because of large capital inputs required for fertilizers and other basic improvements. It is the inability to repay these inputs in the face of widely fluctuating yields which threatens the development of a more productive, prosperous and stable agriculture in

Central Brazil.

Fortunately, the Cerrado area around Brasília is blessed with numerous, year-around springs located below the first erosion surfaces. Many of them have the potential to irrigate relatively small areas of intensively managed crops or pastures, at low costs associated with gravity systems.

Table 33. Frequency of wet-season dry spells of various lengths, or longer, for Brasilia based upon 42 years of record.

Duration of dry-spell (Veranico) days	Frequency
8	3 per year
10	2 per year
13	1 per year
18	2 years in 7
22	1 year in 7

CROP PHYSIOLOGY AS AFFECTED BY SOIL MOISTURE AND FERTILITY

Further studies of relationships between moisture and fertility were begun during the 1974 dry season by Mr. Bandy. A field experiment was established with corn utilizing key fertility treatments from previous experiments including zero lime, deep vs. shallow lime incorporation, and phosphorus applied broadcast vs. banded. Three water treatments were applied over the above fertility treatments by withholding irrigation at certain times. These included no water stress, a period of water stress during early tasseling, and water stress during the early ear-filling period.

Periodic measurements are being made of a large number of variables, including air temperature, solar radiation, wind, relative humidity, pan evaporation, soil temperature and moisture at several depths on a daily basis. Plant growth was evaluated periodically by measurements of leaf number, leaf area, plant height and plant dry weight. During the stress periods, the relative water content of leaves and leaf water potential (by pressure bomb) were measured several times per day. With the use of a diffusion porometer, measures were also made of stomatal resistance, transpiration, leaf temperature, and the photosynthetic rate during the stress periods. From soil-moisture measurements the patterns of water extraction were studied. Efforts are being made with the use of an isotope technique to determine the location of the active root system as influenced by the treatment. The first results are discussed below on a preliminary basis.

Corn growth, as shown by leaf area, was somewhat greater during the first three weeks with 59 kg P_2O_5/ha applied banded than with 237 kg P_2O_5/ha applied broadcast, but this comparison was later reversed with much greater growth and yield from the broadcast treatment. There was good growth response to deeper lime incorporation, but the difference was mainly apparent after seven weeks of age. Water stress during the ear-filling stage caused much greater yield reductions than stress during early tasseling as compared with no water stress. However, the degree of yield reduction caused by water stress in the ear-filling stage was influenced by the fertility treatments. This is shown in Table 34. Once again the benefit of deeper lime incorporation in mitigating water stress periods was observed.

Measurements of relative water content (RWC) of leaves on the twelfth day without irrigation during the first stress period (early tasseling stage) gave strong indication of a beneficial moisture effect from deep lime incorporation. The relative water content for the

deep lime treatment declined less than 5% throughout the day. For the same quantity of shallow incorporated lime, however, relative water content fell nearly 12% between 8:30 and 10:30 a.m. and then rose gradually during the afternoon. In the zero lime treatment relative water content dropped some 14% and remained somewhat lower than either of the lime treatments through mid-afternoon, indicating that the plants were very slow in regaining normal leaf turgidity during the period of water stress.

Soil moisture measurements from gravimetric sampling during the periods of moisture stress also showed differences at 30cm depth in relation to lime treatments. The average soil moisture content at this depth for the seventh through fourteenth days of the earlier stress period was nearly 24% for both the zero lime and shallow lime treatments. In the treatment with deeper lime incorporation, however, deeper soil moisture extraction by the plants left only about 21.6% moisture at 30cm depth. This moisture would be held at greater than 1 bar tension.

Problems of lime reaction and fertilizer quality were encountered causing considerable difficulties in this experiment. A detailed sampling of the soil was done at approximately three and six months after incorporation and standard analyses were made of the lime and fertilizer materials used. The results indicated that dolomitic lime incorporated into moist soil and irrigated regularly had only partly dissolved after three months. This resulted in incomplete aluminum neutralization and marginal levels of exchangeable calcium and magnesium. After six months and the return of the rainy season neutralization was approaching the complete reaction expected. This observation has raised questions concerning the reactivity of lime during dry season under irrigation as opposed to incorporation during the rainy season. This problem is being investigated.

Analyses of the locally-acquired triple superphosphate materials revealed considerable variation in water-soluble P_2O_5 contents. These ranged from 46% to as little as 1% water-soluble P_2O_5. In addition to the serious problems caused by the use of this poor quality fertilizer in some experiments, this finding suggests the need for quality control over the fertilizers being marketed.

It is intended to continue the above experiments through the rainy season by utilizing the naturally occurring dry periods for stress treatments. In subsequent experiments, similar measurements will be made with other corn varieties and with upland rice with treat-

ments involving depth of lime incorporation, mulching, and row spacing. The aim of this work is to develop practical production improvements based on sound concepts of soil and crop management.

Table 34. Effect of fertility treatments on corn yield reduction caused by water stress during the ear filling stage, as compared with no water stress.

Fertility Treatment[1/]	Corn yield reduction
	-------- % --------
No lime	41.7
8 tons/ha lime, shallow incorp.	37.8
640 kg P_2O_5/ha, broadcast	20.3
160 kg P_2O_5/ha, banded	14.9
8 tons/ha lime, deep incorp.	7.8

[1/] Fertility was adequate for other nutrients except as indicated.

RESOURCES FOR IRRIGATION

Mr. Jan Pruntel completed field studies during the year. This work concentrated heavily on soil characteristics of engineering importance which will not be reported here. The following are selected highlights from this thesis.*

Under natural conditions the upland soils of the Federal District are highly permeable with constant infiltration rates ranging from 10 to 70cm/hr. Constant infiltration rate for the lowland humic gley soils averaged 10cm/hr.

Standard tests indicated comparatively strong water stability of the aggregates in the topsoil materials. However, these soils can be sufficiently compacted to greatly reduce permeability as required in pond and canal construction. Water losses due to infiltration in two ponds constructed three years previously were 12 and 16mm/hr. With maximum compaction even the upland soils had infiltration rates of 2mm or less per hour, which is quite satisfactory for water impoundment.

The moisture content for maximum compactibility of the soils was determined by the Standard Proctor Test and varied considerably among soils and for different depths at a given site. This value ranged from about 14 to 35% moisture for the soils studied. There was a negative correlation between the maximum bulk density achieved in the test and clay percentage of the soils. The optimum moisture percentage increased with clay content in the soils.

In contrast to the desirability of maximum compaction for water impoundment the degree of compaction associated with tillage of these soils could be important. These studies revealed that the soils were generally most compactible at moisture levels near field capacity. During the rainy season many tillage operations are necessarily done within two days after soil saturation by rain when the moisture content is probably near optimum for compaction. Even a small degree of soil compaction could greatly alter soil-moisture characteristics.

Impoundment of surface runoff for an irrigation water source would not generally be useful in this area. Rivers and streams are considered the most important water source for irrigation. Structures which divert these waters to storage reservoirs or directly to irri-

---

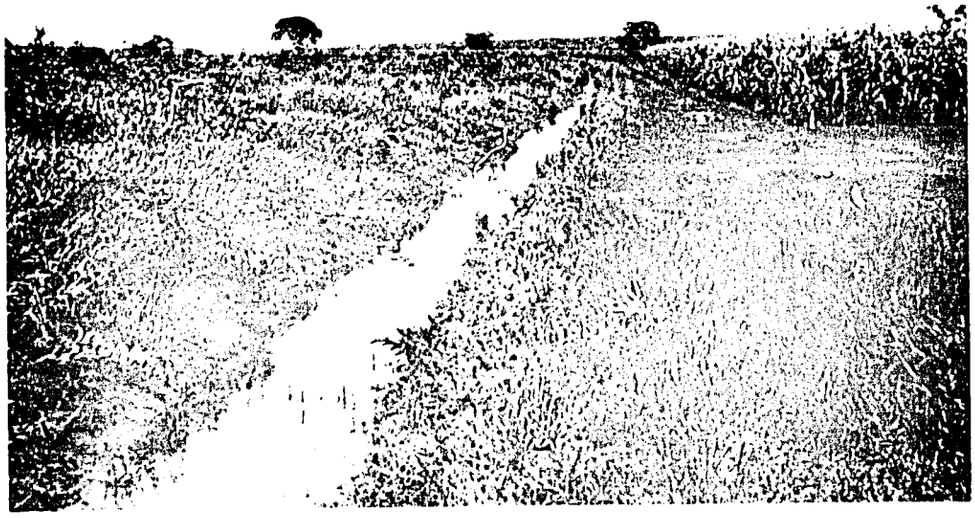
*Pruntel, Jan. 1975. Water Availability and Soil Suitability for Irrigation Water Impoundments in the Federal District of Brazil. Unpublished M.S. Thesis, Cornell University, Ithaca, New York.

gated areas are feasible. Abundant irrigation water could be provided during the rainy season for "veranico" periods or for industrial or municipal uses.

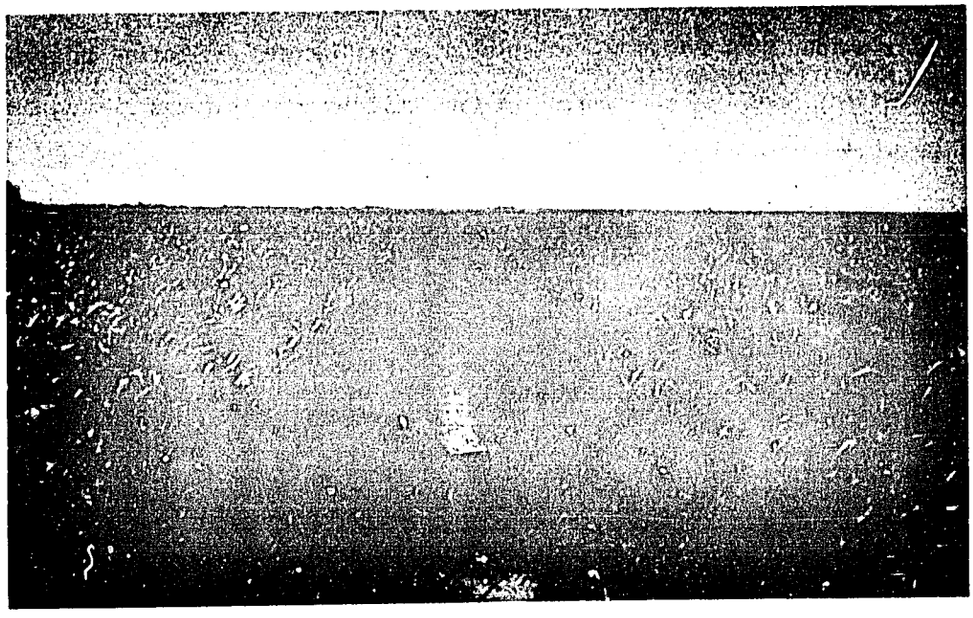
During the dry season an average of 5l/sec/km^2 is discharged by rivers. This could be utilized for irrigation of 1 to 5% of the land area. The construction of storage facilities would increase the available water and permit regulation of its use for greater effectiveness in irrigation. It is estimated that with such construction measures 10 l/sec/km^2 could be available. Depending upon the crops grown and the irrigation efficiency, this would provide sufficient water to irrigate 5 to 10% of the total area during the dry season. Year-round intensive cultivation of even 5% of the typical land holding in the Cerrado would greatly increase agricultural production from this area.

Groundwater from wells could be an important source for irrigation, especially on the high slopes or "chapadas." However, more investigation would be required to get a complete picture of the feasibility of using this source.

Many springs exist at various elevations with capacities ranging from 0.5 to 10.1 sec. and some flow throughout the dry season. This water is already partly used for irrigation, but the area irrigable from this source was considered to be relatively small.



Gravity irrigation systems, such as this developed at the Brasília Station may permit cultivation during the dry season and the elimination of water stress during the rainy season in small areas.



TOLERANCE TO ALUMINUM AND LOW AVAILABLE PHOSPHORUS

Objectives and Design.

There is clear evidence that the large majority of Cerrado Oxisols have high levels of exchangeable aluminum in the profile that adversely affect the productivity of several crops. One of the most striking effects of high aluminum saturation is a reduction of root penetration that inhibits the use of subsoil nutrients and moisture. In addition, these Oxisols require large quantities of phosphorus fertilizer to satisfy the high fixation capacity and supply this nutrient in sufficient quantity for good yields. Aluminum toxicity and phosphorus deficiency frequently occur together in these soils. It is difficult to separate these two problems because of the tendency of aluminum to react chemically with phosphorus.

Taking into consideration the present high cost of phosphorus fertilizers and the strong evidence of varietal and species differences in tolerating high levels of exchangeable aluminum and low levels of phosphorus, it appears that the selection and use of certain crops and varieties which present tolerance to both situations must be considered as an integral part of a solution to the problems which this project is tackling.

A literature review* has indicated the existence of varietal and species differences in tolerance to both aluminum toxicity and low available phosphorus and that these differences are related to the ability of the plant to absorb and utilize phosphorus in the presence of high levels of aluminum. A series of recent studies has focused attention on the external and internal critical levels of phosphorus and the relationships between parameters such as phosphorus absorption rate, phosphorus translocation rate and plant growth rate. Emphasis has been placed on the use of the nutrient solution as a rapid and reproducible technique where the variables under study (pH, Al and P) can be controlled with an acceptable degree of precision. As a result of this, nutrient culture seems to be more practical than soil as a preliminary screening medium, since one avoids the introduction of several conflicting factors associated with soil culture which affect aluminum and phosphorus solubility.

---

*Salinas, J. G. and P. A. Sanchez. 1975. Soil-plant relationships affecting varietal and species differences in tolerance to low available soil phosphorus. Ciência e Cultura (in press).

Based on the above consideration and as a starting point prior to the experimental work in Brazil, two solution culture experiments were conducted by Mr. José Salinas in Raleigh. The general objective was to identify the mechanisms responsible for aluminum-phosphorus interactions, and for differential tolerance to high aluminum and to low available phosphorus using varieties of corn, rice and beans.

The first experiment was established to evaluate the response of three corn varieties (Yellow Carimagua, White Carimagua and Dekalb XL 45-A), four bean (Phaseolus vulgaris) varieties (Carimagua 101, 157, 181, and a local bush bean) and five rice varieties (IR 5, IR8, IR20, CICA 4, and Bluebonnet 50) to different levels of aluminum in nutrient solution in the presence of an adequate phosphorus level. These varieties were selected on the basis of observed differences in reaction to the factors under study. The objectives were to determine critical external concentrations of aluminum for the evaluation of aluminum tolerance and to test the hypothesis that aluminum tolerance is associated with the ability to absorb and utilize phosphorus in the presence of aluminum. Eight day-old seedlings of various corn and bean varieties and twenty day-old seedlings of several rice varieties were grown for seven days in single 10-liter pots containing a complete Hoagland's solution without aluminum. After harvesting some of the seedlings, the rest of the plants were grown for 10 additional days under four levels of aluminum, (0.5, 1.2 and 4 ppm Al in nutrient solution). At the end of the seven-day and 10-day periods the plant tops and roots were harvested, dried and weighed for yield and analyzed for aluminum and phosphorus. During the experiment, the pH of the nutrient solution was maintained at 4.5 and the solution was stirred by continuous aeration.

The second experiment was established to study varietal differences for combined tolerance for both aluminum toxicity and low available phosphorus. A 2^2 factorial experiment was employed with two aluminum levels (0 and 3 ppm Al) and two phosphorus levels (0.5 and 5 micromoles P/liter) in nutrient culture. The corn varieties used were Yellow Carimagua and Dekalb XL 45-A. Five rice varieties (IR5, IR8, IR20, CICA 4 and Bluebonnet 50) were used. The procedure employed was the same as that of the first experiment with the exception that during the first seven days of plant growth and before initiating the treatments, the phosphorus concentration in nutrient solution was 0.5 uM P/l in all pots. the pH and concentrations of P and Al were measured every two days and the pH and P levels were corrected as

needed. An additional treatment was added in the second experiment in which calcium was considered as a critical factor in addition to phosphorus and aluminum.

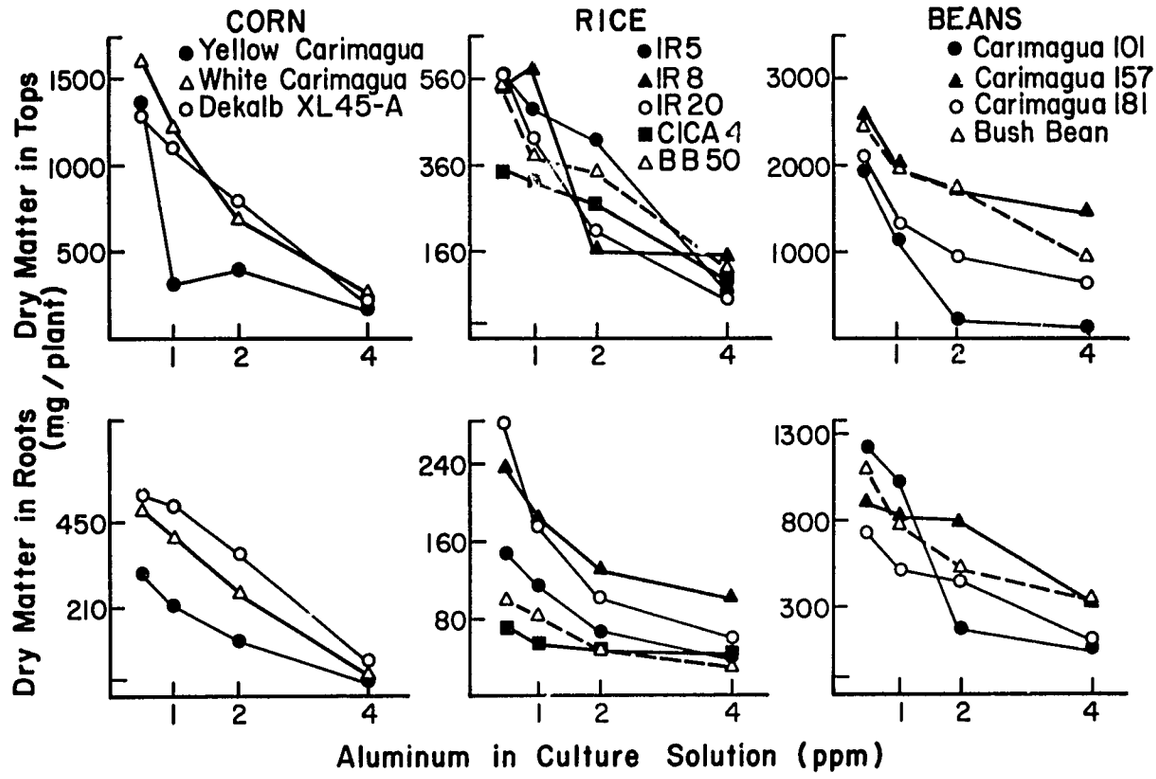
Results - First Experiment

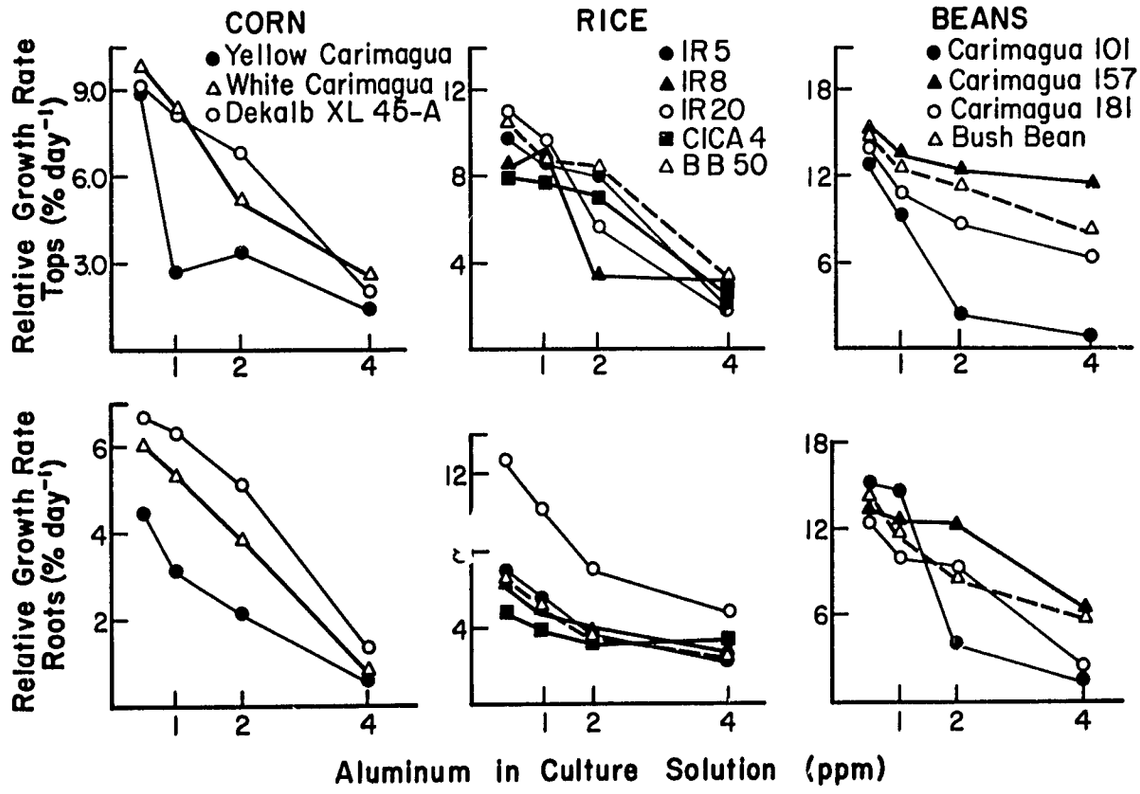
The results for the first experiment are shown in Figs. 38 and 39. The degree of aluminum damage to tops and roots in all varieties of corn, rice and beans studied increased with aluminum concentration. Both dry matter production and relative growth rate (RGR) of tops and roots were similarly reduced with increasing aluminum concentration.

Under the conditions of this experiment, varietal differences were observed. In corn, Dekalb XL 45-A and White Carimagua were less injured by the aluminum levels than Yellow Carimagua. This is shown in Figs. 37 and 38. In rice, all the varieties showed a gradual decrease in dry matter and relative growth rate with increases in aluminum level. In terms of relative growth rate of roots, all varieties were about equally affected by increasing aluminum except for IR20 in which relative growth rate was less reduced. In beans, Carimagua 157 and bush beans were more tolerant to these aluminum levels, while Carimagua 101 was quite sensitive, especially at the two highest levels of aluminum.

In all species studied, increasing aluminum resulted in decreased phosphorus absorption rates (PAR). This is shown in Fig. 39. In addition, the varieties which were shown to be relatively tolerant to aluminum by dry matter production and Relative Growth Rate also tended to have generally higher levels of phosphorus absorption rates than the sensitive varieties. In corn, for example, the average phosphorus absorption rate over all aluminum levels for Dekalb XL 45-A was 1.46 ugP/mg dry root/day, for White Carimagua 1.21 and for Yellow Carimagua 1.04. In rice, the phosphorus absorption rate levels were in the order of: IR20>IR5>BB50>IR8>CICA 4 with average values of 0.93, 0.92, 0.90, 0.79 and 0.72 ugP/mg dry root/day, respectively. In beans, the order was bush beans > Carimagua 181 > Carimagua 147 > Carimagua 101 with average values of 1.51, 1.47, 1.38 and 1.18 ugp/mg dry root/day, respectively. These results suggest that the differential ability to absorb phosphorus by varieties within the same species is an effective parameter for identifying varietal or species differences to aluminum toxicity.

Increasing aluminum in nutrient solution caused the phosphorus taken up to be accumulated in the roots and consequently restricted its translocation to the tops in all species under study (Fig. 39). Again, the corn, rice and bean varieties more tolerant to these alu-


CORN
Yellow Carimagua
White Carimagua
Dekalb XL45-A
RICE
IR5
IR 8
IR20
CICA 4
BB 50
BEANS
Carimagua 101
Carimagua 157
Carimagua 181
Bush Bean
Dry Matter in Tops
Dry Matter in Roots
(mg / plant)
Aluminum in Culture Solution (ppm)


CORN
Yellow Carimagua
White Carimagua
Dekalb XL 45-A
RICE
IR 5
IR8
IR20
CICA 4
BB 50
BEANS
Carimagua 101
Carimagua 157
Carimagua 181
Bush Bean
Relative Growth Rate
Tops (% day⁻¹)
Relative Growth Rate
Roots (% day⁻¹)
Aluminum in Culture Solution (ppm)

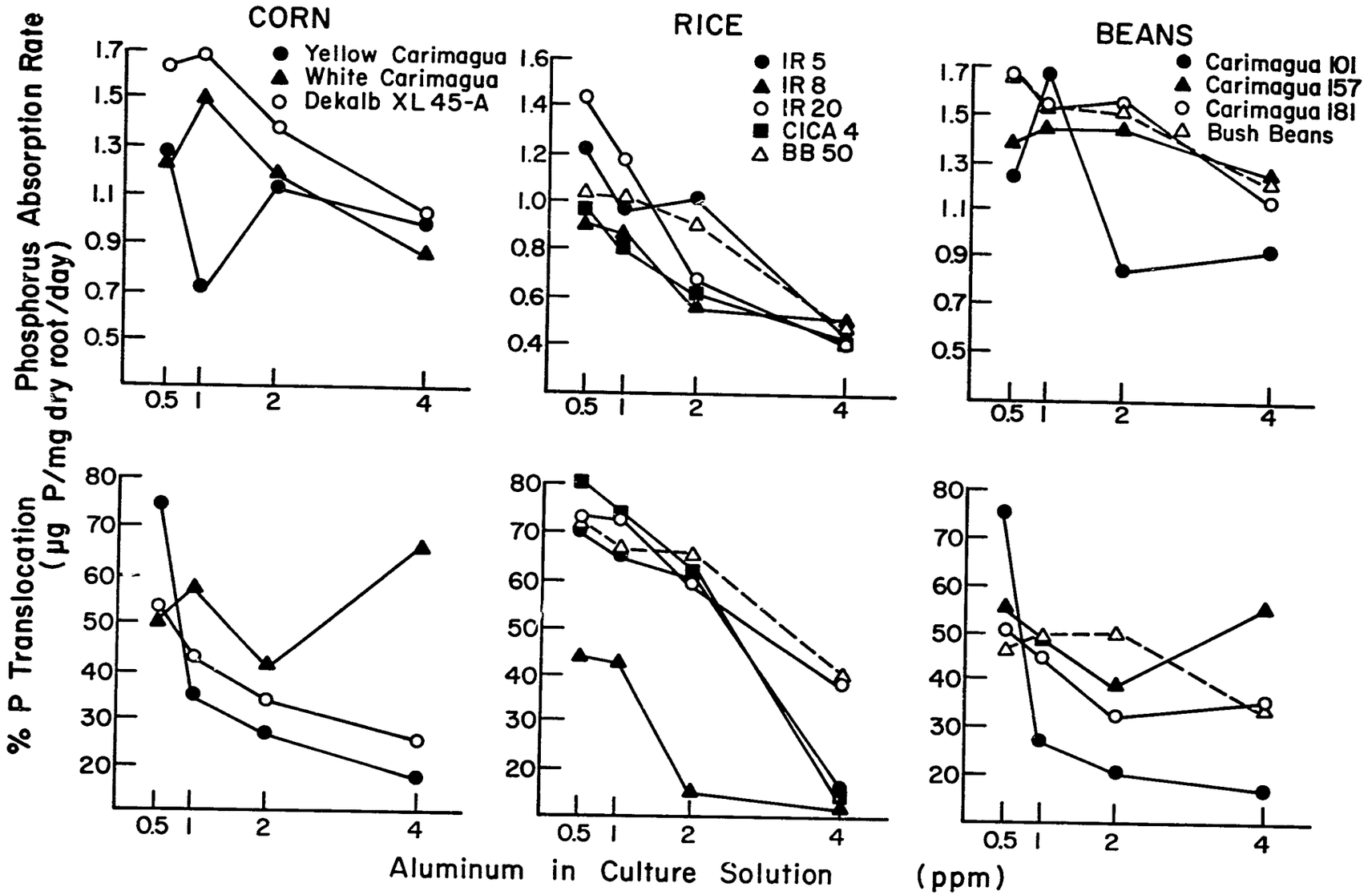


Fig. 39. Influence of aluminum on absorption and translocation of phosphorus by corn, rice and bean varieties. First greenhouse experiment.

minum levels (as shown by dry matter production and phosphorus absorption rate) also showed higher values of phosphorus translocation than sensitive varieties. As aluminum concentration in solution increased from 0.5 to 4 ppm, Dekalb XL 45-A corn decreased its phosphorus translocation rate (PTR) from 53 to 25%, and White Carimagua maintained about 50% while Yellow Carimagua decreased from 76 to 18%. In rice, CICA 4 and IR8 showed greater reduction of their phosphorus translocation rates; CICA 4 from 83 to 8% and IR8 from 45 to 3%, while BB50, IR20 and IR5 decreased from 72 to 39, 73 to 38 and 70 to 14%, respectively. In beans, Carimagua 101 was the variety with greatest reduction, from 75 to 14%, while in Carimagua 181 the phosphorus translocation rate fell from 51 to 36%, bush bean from 48 to 36%, and Carimagua 157 remained approximately constant at 50%.

These results indicate that the accumulation and distribution of phosphorus is affected by external aluminum supply and that the phosphorus translocation rate is also an important parameter for evaluating varietal and species differences where phosphorus-aluminum interactions exist.

Although an increased aluminum level in nutrient solution increased the aluminum absorption rate, it decreased the portion of absorbed aluminum which was translocated to the top (Fig. 40). This indicates that most of the absorbed aluminum was accumulated in the roots and relatively little was transported to the tops. Average values of aluminum accumulated in the roots for all varieties and levels of aluminum in solution were 93% in corn varieties, 84% in the rice varieties and 89% in bean varieties. In general, the sensitive varieties such as Yellow Carimagua in corn, CICA 4 in rice, and Carimagua 101 in beans, showed lower levels of translocated aluminum than tolerant varieties. This seems to indicate that varieties sensitive to aluminum toxicity accumulate considerable amounts of aluminum in the roots but they accumulate little in the tops.

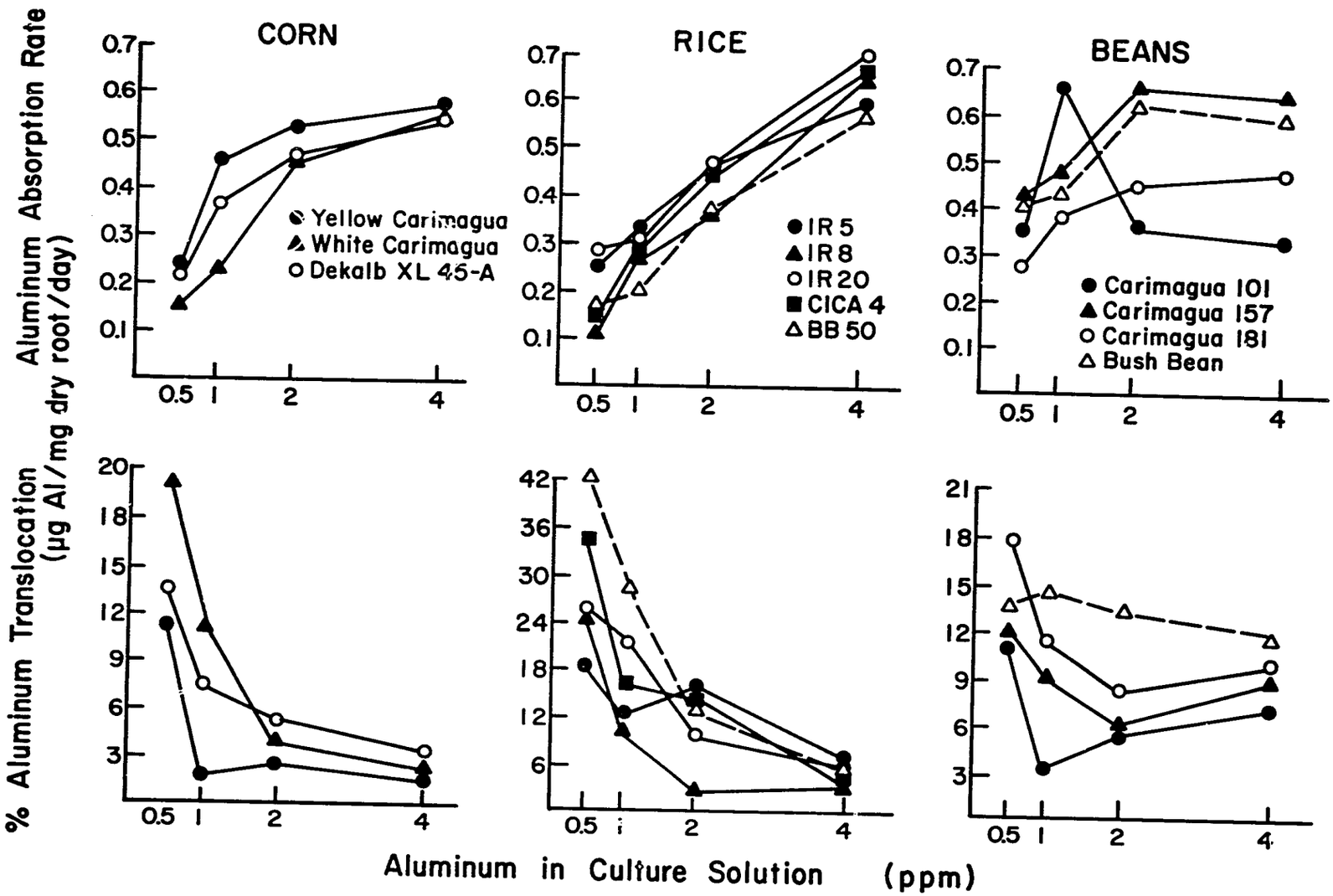


Fig. 40. Aluminum absorption and translocation by corn, rice and bean varieties under influence of aluminum in nutrient solution. First greenhouse experiment.

Results - Second Experiment

The results of the second experiment are shown in Figs. 41 to 43. These results were interpreted in terms of the critical factors developed by certain treatments as indicated below:

Treatment Number	P (uM/l)	Al (ppm)	Ca (ppm)	Criti l Factors
1	5.0	0	120	None
2	0.5	0	120	P
3	5.0	3	120	Al
4	0.5	3	120	P and Al
5	0.5	3	4	Al and Ca

Phosphorus as Critical Factor (Treatments 1 vs. 2)

When phosphorus concentration in the nutrient solution was decreased by a factor of 10, some differences were noted among varieties of both rice and corn. Root yields were reduced by about 55% and relative growth rate values for roots by about 42% in IR5, IR8, and BB50; the corresponding reductions for IR20 and CICA 4 were about 35 and 23%, respectively. Fig. 41 shows the relative total dry matter production of both rice and corn varieties. In corn, the reduction for both parameters was about 60% for Yellow Carimagua and nearly 40 for Dekalb XL 45-A. The reduction in root length due to decreased phosphorus level was more severe for BB50 and CICA 4 rice varieties and for the Yellow Carimagua corn.

Different decreases in the yields and relative growth rate values for plant tops were also noted. In rice, BB50 was more severely affected than the other four varieties, with nearly a 60% reduction in top growth versus 25-35% reductions in the other varieties. The top growth reduction in Dekalb XL 45-A corn was about 50% while that for Yellow Carimagua was about 60%.

Phosphorus absorption rates (PAR) were reduced in all rice and corn varieties when the external phosphorus supply was diminished (Fig. 42). In rice, the decrease in phosphorus absorption rates followed the order of IR8, BB50, IR20, CICA 4 and IR5. The phosphorus absorption rates of both corn varieties fell to half. In most cases when phosphorus supply was diminished, its translocation rate increased slightly in rice varieties and remained about constant in corn varieties (Fig. 43).

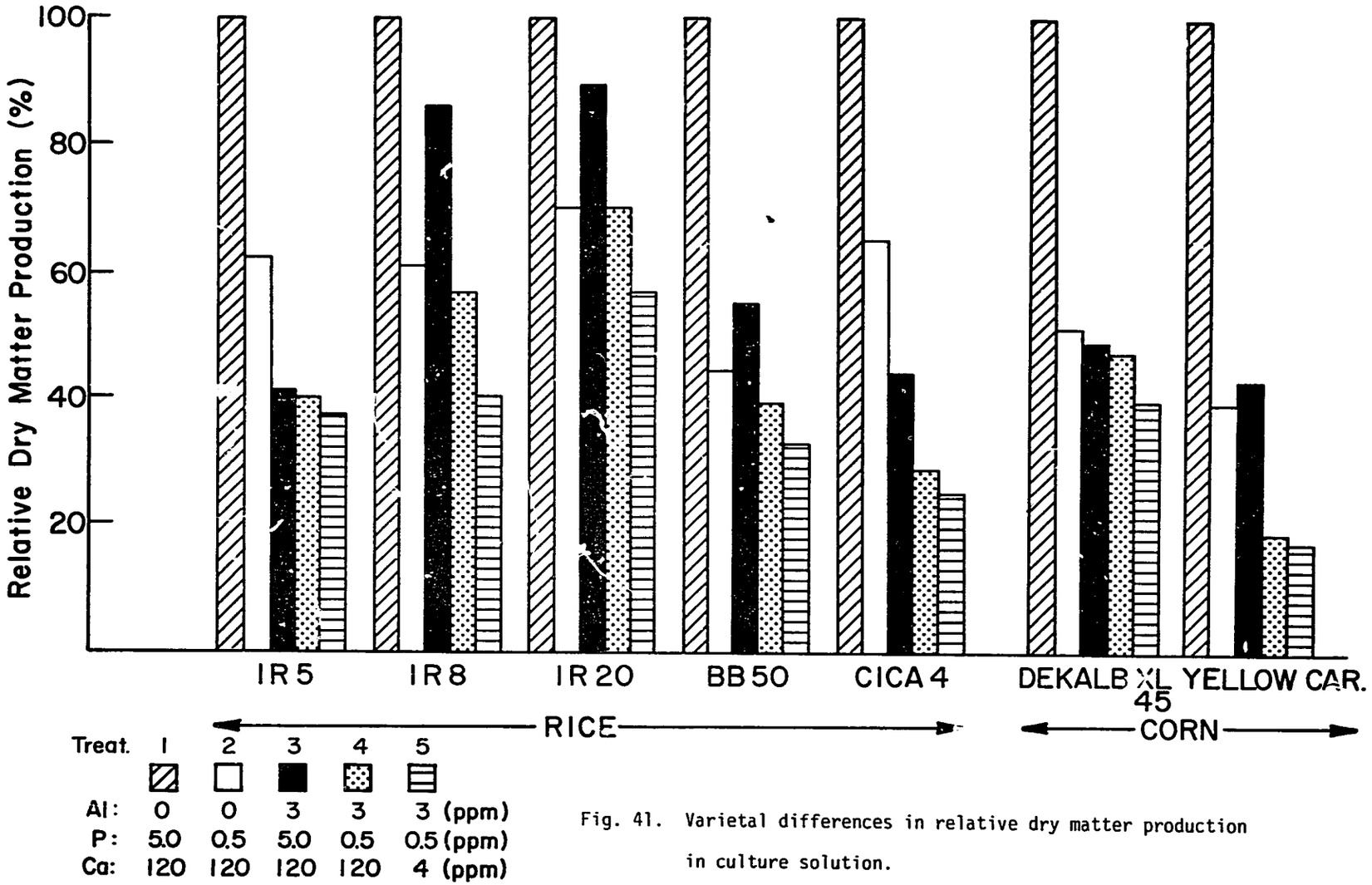


Fig. 41. Varietal differences in relative dry matter production in culture solution.

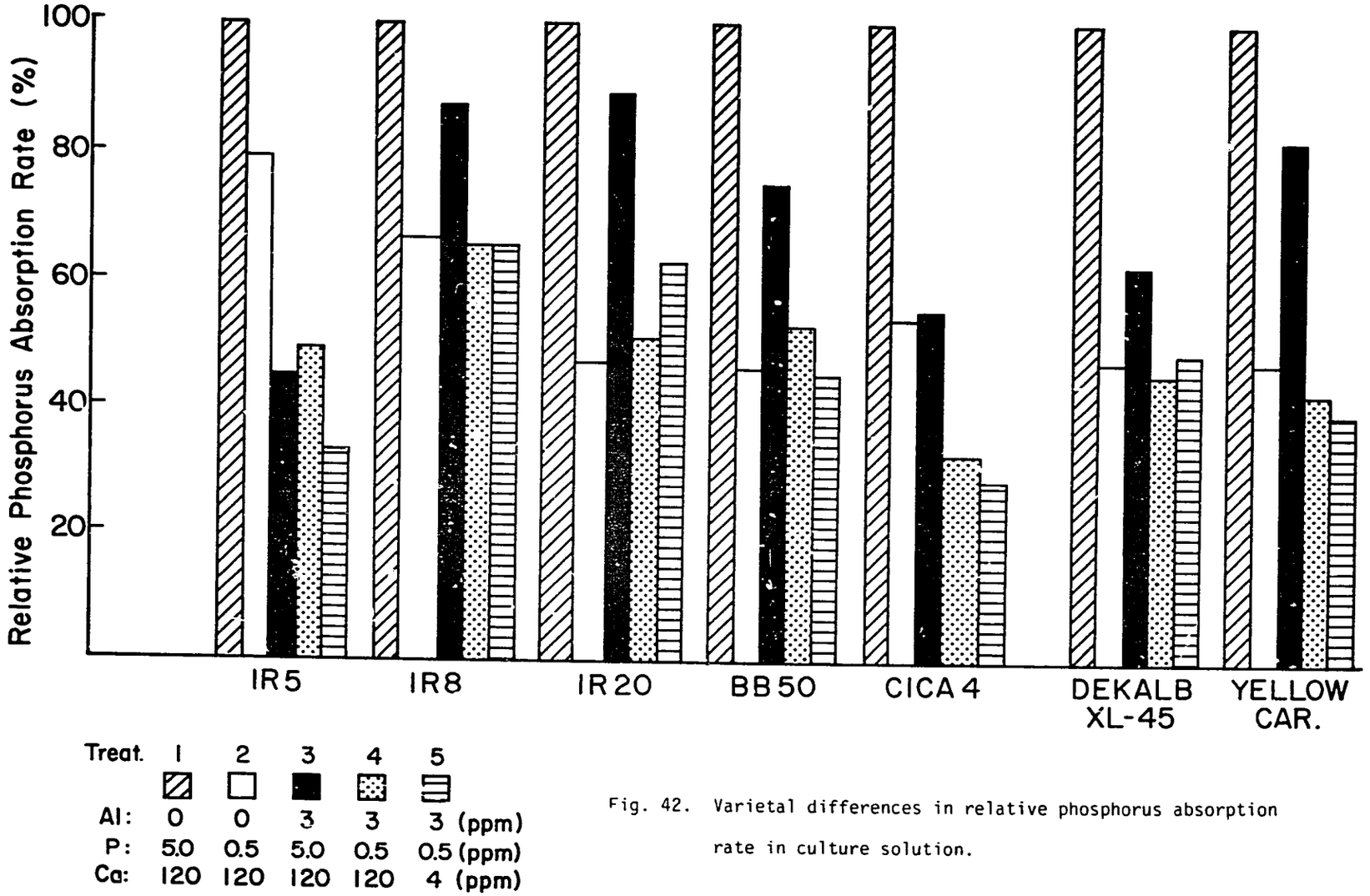


Fig. 42. Varietal differences in relative phosphorus absorption rate in culture solution.

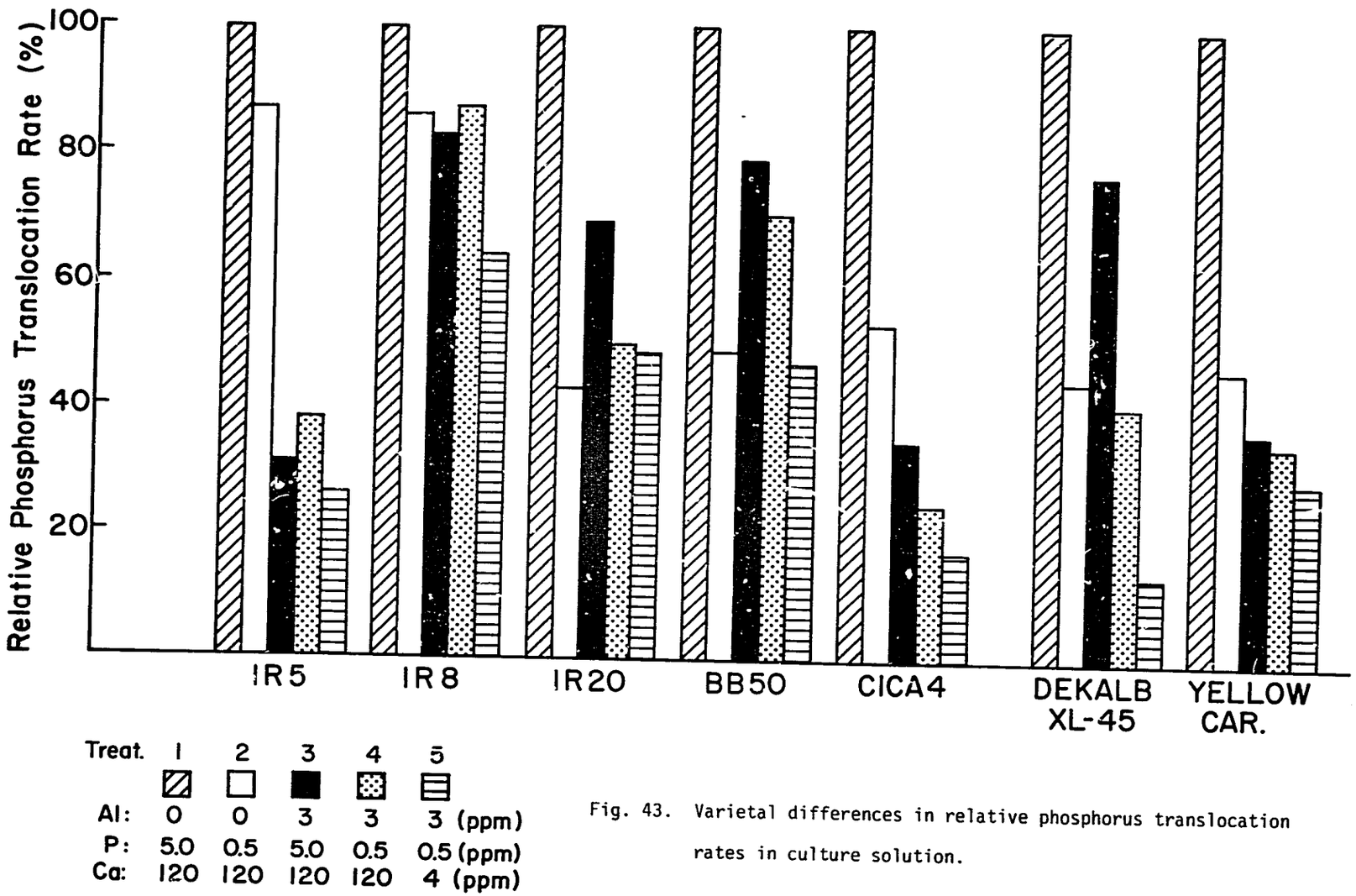


Fig. 43. Varietal differences in relative phosphorus translocation rates in culture solution.

Aluminum as Critical Factor (1 vs. 3)

Adding 3 ppm of aluminum to the nutrient solutions caused the yield and relative growth rate (RGR) of both roots and tops to decrease in all varieties of both species.

The rice varieties most seriously affected were BB50 in terms of root yield and IR5 and CICA 4 in terms of top yields, with reduction of more than 50% in these cases. In general, the variety in which growth was least affected by the presence of aluminum alone was IR20. Top and root growth in IR20 decreased by less than 20% in this treatment. The variety IR8 also showed relatively little growth reduction.

In response to aluminum in the nutrient solution, the Yellow Carimagua corn variety showed much greater decreases in root growth and in root length (about 75%), but a lesser decrease in top growth than the variety Dekalb XL 45-A.

Just as in the first experiment, the addition of aluminum to the nutrient solution decreased the rates of absorption and translocation of phosphorus in both species. In rice, it is possible to distinguish three different groups on the basis of phosphorus absorption rates: IR20 with the highest rate, BB50 and CICA 4 with intermediate rates, and IR8 and IR5 with the lowest rates. In corn, both varieties had almost the same phosphorus absorption rate. In terms of phosphorus translocation rates (PTR), CICA 4 showed the greatest reduction due to the addition of aluminum and the phosphorus translocation rate was about the same for the two corn varieties.

In general, when aluminum was added to the nutrient solution, rice and corn varieties increased their aluminum absorption rates (AAR) and decreased their aluminum translocation rates (ATR). IR20 in rice and Dekalb XL 45-A in corn were the varieties with the highest aluminum absorption and translocation rates. CICA 4 and IR8 rice varieties and the Yellow Carimagua corn variety had the lowest aluminum translocation rates.

Aluminum and Phosphorus as Critical Factors

When the rice and corn varieties under study were subjected to the influence of aluminum (3 ppm) and low available phosphorus (0, 5 μM/l) in solution, yields and growth rates of roots and tops were sometimes reduced more than from either of these "critical factors" alone. This was the case for CICA 4 rice and was generally true for both corn varieties. For IR8 and IR20 rice, the top and root yields with low phosphorus and aluminum were more like the low phosphorus condition alone. The rice varieties which maintained the best over-

all top and root yields in the presence of aluminum and low phosphorus were IR20 and IR8. These varieties produced about 70% and 35 to 50% of the top and root yields, respectively, as compared with the control treatment of high phosphorus without aluminum. The variety CICA 4 gave the poorest top yield, (a reduction of about 80% from the control treatment), although its root growth was relatively good and similar to that of IR8.

For the corn varieties, Yellow Carimagua showed a greater reduction in top and root yields as compared with the control treatment than did Dekalb XL 45-A.

Phosphorus absorption rates were further decreased under critical aluminum-phosphorus influence as compared with either critical factors alone for IR5 and CICA 4 rice. For IR20, IR8, BB50 rice and for both corn varieties the phosphorus absorption rate was similar to that under the low phosphorus level in the absence of aluminum. The varieties IR5 and CICA 4 exhibited greater reduction in the phosphorus absorption rate than did IR8 and BB50 (about 67 vs. 40) as compared with the control treatment of no limiting conditions. For both corn varieties the phosphorus absorption rate was reduced to about 45% of the control treatment.

In this treatment the phosphorus translocation rates for IR5, CICA 4 and both corn varieties were reduced in about the same degree as that caused by the presence of aluminum where phosphorus was adequate. For IR8, IR20 and BB50 the phosphorus translocation rate was equal or greater than that of the control treatment where no limiting factors were present.

Aluminum absorption rates decreased markedly while the aluminum translocation rates increased slightly in the presence of aluminum with low phosphorus as contrasted with the presence of aluminum and high phosphorus for all rice varieties. The Dekalb XL 45-A corn behaved similarly but aluminum translocation in the Yellow Carimagua corn was very low in the presence of aluminum with low phosphorus. These results suggest that the absorption and accumulation of aluminum in the roots in enhanced by a fairly high phosphorus level. IR20 had the highest aluminum translocation rate and a fairly high aluminum absorption rate.

In general, the results of this experiment show that IR20 was the rice variety with more ample resistance to low available phosphorus, to the presence of aluminum and also to the combined conditions of aluminum with low phosphorus. When phosphorus was a critical factor, BB50 presented greater reductions in top growth than the other four varieties. CICA 4, IR5, and BB50 were generally quite sensitive to the presence ot aluminum alone, and when phosphorus and aluminum were the critical factors, CICA 4 was the most sensitive rice

variety. In corn, Dekalb XL 45-A was generally less adversely affected by either low phosphorus or aluminum alone. The greater tolerance of this variety as compared with the Yellow Carimagua corn was even more striking where both aluminum and low phosphorus conditions were present.

Aluminum, Phosphorus and Calcium as Critical Factors (1 vs. 5)

In Treatment 5 calcium and phosphorus were low and aluminum concentration was high. Total dry matter production of rice and corn was reduced in the presence of these "critical factors" when compared to Treatment 1. CICA 4 had the highest reduction of the rice varieties (75%) and IR20 had the least (43%). Yellow Carimagua corn showed 83% reduction and Dekalb XL 45-A, 61%.

In terms of relative growth rates of tops and roots, IR20 was the exception within rice varieties showing a minimum reduction in these rates. The rest of the rice varieties showed a reduction of over 40%. In corn, both varieties had similar reductions in relative growth rate of tops (about 28%), but in terms of relative growth rates of roots, Yellow Carimagua was affected considerably more than Dekalb XL 45-A, showing a reduction of 78%.

Phosphorus absorption rates (PAR) were reduced in all rice and corn varieties. In rice the order was: CICA 4 > IR5 > BB50 > IR20 > IR8 and in the corn varieties, Yellow Carimagua fell into 61% while Dekalb XL 45-A fell to 23%. In terms of phosphorus translocation rates (PTR), it was observed that BB50 increased slightly its phosphorus translocation rates (4%) IR8 decreased 3%, IR5 and IR20 decreased about 20% and CICA 4, 40%. In corn, the phosphorus translocation rates of both varieties decreased equally (64%).

When calcium was a critical factor, in addition to aluminum and phosphorus, aluminum absorption rates (AAR) increased and aluminum translocation rates (ATR) decreased in rice and corn varieties. All rice varieties showed almost a similar increment in aluminum absorption rates, about 39 μg Al/mg dry root/day. In corn, Dekalb XL 45-A showed an aluminum absorption rate about five times higher than Yellow Carimagua. High reductions in aluminum translocation rates were in rice and corn varieties (in rice about 75% and in corn about 90%). These results indicate that when calcium is included as a critical factor, the parameters related to aluminum absorption rates and aluminum translocation rates do not identify clearly varietal differences.

With respect to calcium absorption rates (CAR), all rice and corn varieties showed a considerable reduction (more than 50%) in their absorption rates when aluminum was present and phosphorus and calcium concentrations were low. Within rice varieties, IR20 had the least reduction (50%) while the remaining varieties had 72%. In corn, Yellow Carimagua had 94% and Dekalb XL 45-A showed 78%.

In contrast to the strong reduction of the calcium absorption rate, the translocation of this nutrient to the tops was not affected when levels of aluminum, phosphorus and calcium were critical. In general, the rice varieties translocated almost 80% of the calcium absorbed and corn varieties about 70%. The same situation was observed when none of these three elements were critical factors. These results indicate that calcium translocation rates in the absence or presence of aluminum low phosphorus and low calcium do not constitute a parameter as effective as calcium absorption rates for the identification of aluminum-tolerant varieties.

The measurements of top and root yields, root length, growth rates, phosphorus absorption and translocation rates and aluminum absorption and translocation rates as done in both experiments for the evaluation of differences between varieties of rice and corn seem to be critical parameters in the study of varietal tolerance to aluminum and low available phosphorus. There is need for continuing these studies with other crops using nutrient cultures as a preliminary screening medium after which follow-up experiments under field conditions must be carried out to evaluate promising varieties and species in agronomic and economic terms.

EXTRAPOLATION STUDIES

In addition to the clayey Dark Red Latosols, another major type of Oxisol is very abundant in the Cerrado. Due to differences in color, they are referred to in the Brazilian soil classification systems as Red-Yellow Latosols (Latosol Vermelho Amarelo). A large proportion of these soils have loamy rather than clayey textures. Red-Yellow Latosols are commonly found in the flat first erosion surfaces or "chapadas." The Cline-Buol study recommended that the usefulness of this research project could be considerably increased by testing the more important results on a Red-Yellow Latosol. During this year two experiments were installed to appraise whether the results obtained in the clayey Dark Red Latosol would differ when applied to a loamy and a clayey Red-Yellow Latosol in the Brasília area, under similar climatic conditions.

Lime-Phosphorus Experiments on a Loamy Red-Yellow Latosol

This experiment was established on the flat first erosion surface at the Brasília Experiment Station. The soil properties are shown in Table 35. Laboratory analyses suggest that the soil fixes only slightly less phosphorus than the Dark Red Latosol. Both soils are similarly low in calcium, magnesium and phosphorus. The most important chemical difference is the smaller quantity of exchangeable aluminum and consequently the small degree of aluminum saturation in the subsoil as compared with the Dark Red Latosol. The most outstanding physical difference is the greater amount of available water (14.5 H_2O) held by the soil in spite of its loamy texture. This is approximately 30 higher than the available storage in the Dark Red Latosol, as previously discussed.

The experiment established on this soil has several features common to the earlier experiments although with some modifications. Deep and shallow depths of lime incorporation were compared with an unlimed check. Two levels of phosphorus as simple superphosphate, a moderate level and a very high level were included. The yield response to residual effects of these applications and chemical soil tests will be followed for several crops, as this is one of the most important comparisons among such soils. Most of the phosphorus treatments were applied as triple superphosphate at the moderate rate of 400 kg P_2O_5 broadcast and 100 kg P_2O_5 banded. All plots are double the standard width of the earlier experiments. These plots will be divided into two plots in future crops. The basic magnesium application

Table 35. Properties of the loamy Red Yellow Latosol on the first erosion surface of the Brasilia Experiment Station. Classification: Acric Haplustox, loamy, kaolinitic, isohyperthermic.

Horizon	pH	Al	Ca + Mg	Al satn.	P Double acid
cm	H_2O	------ meq/100g -----		%	ppm
0 - 15	4.8	0.48	1.10	30	<1
15 - 30	4.8	0.43	0.88	33	<1
30 - 45	5.1	0.22	0.97	19	<1
45 - 60	5.0	0.13	0.61	18	<1

Table 36. Results of the first wet season corn crop from the extrapolation experiment conducted on the loamy Red-Yellow Latosol at Brasilia.

Treatment No.	Method & amount of materials applied					
	Lime	P Broadcast	P Banded	Source	Mg application	Grain yields
	ton/ha	--- kg P_2C_5/ha ---			kg Mg/ha	(kg/ha)*
6	4 deep	2000		Simple superphosphate	50 bdcst	6040 a
4	4 deep	400	100	Simple superphosphate	50 bdcst	5498 ab
8	4 deep	400	100	Triple superphosphate	20 bdcst	5372 ab
5	4 deep	400		Simple superphosphate	50 bdcst	5105 bcd
2	4 deep	400	100	Triple superphosphate	50 bdcst	4816 bcde
7	4 shallow	400	100	Triple superphosphate	20 band	4714 bcde
1	0	400	100	Simple superphosphate	50 bdcst	4508 de
3	4 shallow	400	100	Triple superphosphate	50 bdcst	4181 e

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

was 50 kg Mg/ha as magnesium sulfate except for Treatments 7 and 8 in which 20 kg/ha was banded. This was done in order to have a specific comparison with another experiment on the clayey Dark Red Latosol but does not suggest special practical importance of this technique.

The description of the treatments and yields are given in Table 36. This first corn crop was less damaged by leaf blight and insects than were experiments on the Dark Red Latosol, thus invalidating direct comparisons between these soils. Nevertheless, these factors limited yield potential and suggest some effects may not have been expressed in this first crop. These results suggest that incorporating lime to 30cm is not beneficial in Oxisols with low aluminum saturation and higher water holding capacity. Less phosphorus was needed to approach maximum yields than on the clayey Dark Red Latosol. The additional banded application did not increase yields. In spite of the extremely low exchangeable magnesium levels, yields with 20 kg Mg/ha were similar to those obtained with 50 kg Mg/ha.

Phosphorus-Nitrogen Experiment with Beans at Agua Limpa

An experiment was established in January-February 1974 at the Agua Limpa farm owned by the University of Brasília in order to test the extrapolability of the results to a different soil and crop. The project was done in conjunction with the Department of Agronomic Engineering of the University, the Fundação Zoobotânica do Distrito Federal, the National Bean Program of EMBRAPA, and five agronomy students at the University. Each student was assigned principal responsibility for a portion of the data collected, and this work will serve as his undergraduate thesis for the Engenheiro degree. One of the students was awarded a scholarship from the Brazilian National Research Council (CNPq) for her participation in the project.

The soil on which the experiment is located is classified as a Red-Yellow Latosol of clayey texture. Chemical properties of this soil are shown in Table 37. This soil is also common in the Cerrado and is quite similar in chemical properties to the loamy Red-Yellow Latosol at the Brasília Station. The main difference is its higher clay content. Exchangeable aluminum is only about 0.6 me/100g at the surface and decreases to 0.3 me/100g at 50cm depth.

The design of the experiment is similar to the corn phosphorus experiment at the experiment station. Three levels of phosphorus (simple superphosphate) were broadcast initially and there is also one level of banded phosphorus alone. Three levels of nitrogen were

Table 37. Chemical characteristics of the clayey Red Yellow Latosol site at the Agua Limpa farm used for the phosphorus-nitrogen experiment with beans.

Depth	pH	Exch. Al	Exch. Ca + Mg	Al satn.	Avail. P (NC method)
(cm)	H_2O	------ meq/100g ------		%	ppm
0 - 7	4.79	0.58	0.30	66	tr.
7 - 22	4.76	0.51	0.28	65	tr.
22 - 42	4.83	0.28	0.20	58	tr.
47 - 58	5.04	0.11	0.12	48	tr.
58 - 90	5.42	0.04	0.13	23	tr.

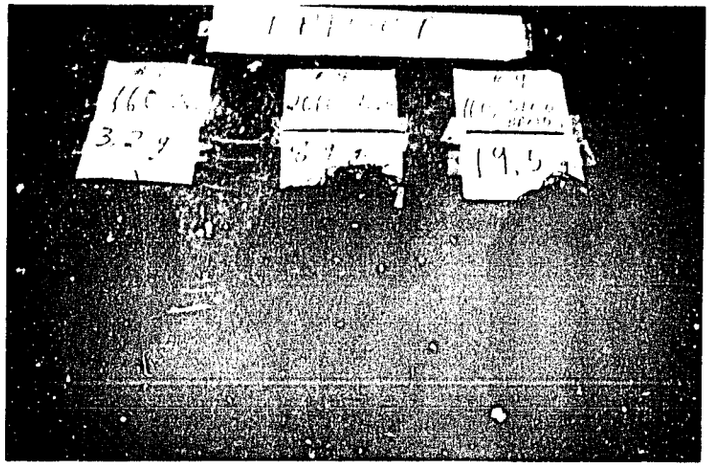
Table 38. Treatments and yields of dry beans (Phaseolus vulgaris) in an experiment conducted on the Agua Limpa farm.

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

$LSD._{05}$ = 251 kg/ha

applied as urea, since previous results suggested a strong response by *Phaseolus vulgaris* to nitrogen fertilization. The experiment is a randomized complete block with split plots. There are nine fertilizer treatments with four varieties as subplots, and four replications.

The treatments and yields of the first crop are shown in Table 38. In addition to yield, data were collected on root weight, foliage weight, pod weight, and bean weight. In general, there were significant responses to all levels of phosphorus and to the level of 60 kg N/ha. Perhaps the most important result is the relatively good yield attained by the banded application of 160 kg P_2O_5. Root studies indicate that the weight of roots extracted from the banded treatments was at least double that of the highest broadcast treatment. Considerable root proliferation was apparent around the phosphorus band. A comparison between the results of this experiment with beans and those of the first corn crop from the phosphorus experiment on the Dark Red Latosol suggests greater ability of beans to utilize banded phosphorus. Although the maximum yield was obtained with 2060 kg/ha of P_2O_5 broadcast, over 70% of this maximum yield was obtained with only 160 kg P_2O_5/ha banded. This suggests the importance of using crops with tap root systems in the rotation as a means of utilizing banded phosphorus more effectively.



The effect phosphorus placement and rate on root growth of Carioca beans in the extrapolation experiment at Agua Limpa. From left to right: 160 kg P_2O_5/ha broadcast, 2060 kg P_2O_5 broadcast and 160 kg P_2O_5/ha banded.

OUTREACH STUDY OF PROPERTIES OF "CERRADO" SOILS

A survey was conducted by Mr. Alfredo S. Lopes* by first collecting 518 composite top-soil samples from under natural vegetation over an area of approximately 600,000 square kilometers in Central Brazil. The specific sampling sites were indicated in the 1973 Annual Report. In each of these 171 sites an average of three samples was taken according to slope position. Natural vegetation classified at each site was distributed as follows: 65 under campo limpo, 148 under campo cerrado, 255 under typical cerrado, 45 under cerradao and 16 samples under semi-deciduous forest vegetation (mata). These represent the natural gradient from grassland to forest vegetation.

Soil Properties

A summary of the chemical, physical and other soil characteristics of these samples as evaluated in the laboratory is presented in Table 39. Some of the conclusions that can be drawn from those data are described below:

The variation in texture of the soils is large. Extreme variation in the textural components exists, ranging from coarse sands to heavy clays. Ths distribution of the color components (hue, value, and chroma) shows that hue ranges widely from 2.5YR to 10YR. The large majority (86%) have chromas of 4 to 6, an indication of good drainage.

These soils are very acid; about half (48%) have pH values lower than 5.0 and the rest (50%) have pH values between 5.0 and 5.9. Only nine samples have a pH of 6.0 or more. The delta pH was negative in all cases except one, indicating the predominance of cation exchange over anion exchange in spite of the high contents of iron and aluminum oxides.

These soils are moderately well to well-supplied with organic matter (60% of the samples contain between 1.5 and 3.0% organic matter) but the net negative charge of these soils, as reflected by the effective CEC, is low. Therefore, the ability for cation adsorption is also low.

The base status of these soils is extremely low. The vast majority (96%) have less than 1.5 meq Ca^{++}/100 cc. Likewise, 90% of the samples have less than 0.5 meq/Mg^{++}/100 cc,

---

*Lopes, A. S. 1975. A survey of the fertility status of soils under cerrado vegetation in Brazil. M.S. Thesis, North Carolina State University, 138 pp.

Table 39. Summary of the range in soil properties observed in 518 topsoil samples under cerrado vegetation in Brazil (included 16 samples under forest vegetation).

Soil Property	Accepted Critical level*	samples below Critical level	Range	Median	Highest frequency range Level	Total
		%				%
pH (H_2O)	<5.0	48	4.3 to 6.2	5.0	4.8 to 5.2	58
pH (KCl)	--	--	3.7 to 5.4	4.2	4.0 to 4.6	88
ΔpH	--	--	0.0 to -1.4	-0.7	-0.4 to -1.0	62
Organic Matter (%)	<1.5	17	0.7 to 6.0	2.2	1.0 to 3.5	88
Exch. Ca(meq/100 cc)	<1.5	96	0.04 to 6.81	0.25	<0.4	76
Exch. Mg(meq/100 cc)	<0.5	90	0.00 to 2.02	0.09	<0.2	74
Extr. K*(meq/100 cc)	<0.15	85	0.02 to 0.61	0.08	0.05 to 0.10	60
Exch. Al (meq/100 cc)	>0.25	91**	0.08 to 2.40	0.56	0.25 to 0.75	64
Eff. CEC (meq/100 cc)	<4.0	97	0.35 to 8.10	1.1	0.5 to 1.5	
Al saturation (%)	> 20	92**	1.0 to 89.4	59.0	50 to 80	60
Extr. P*** (ppm)	< 10	99	0.1 to 16.5	0.4	0.2 to 1.0	79
Extr. Zn*** (ppm)	<1.0	95	0.2 to 2.2	0.6	0.5 to 0.8	69
Extr. Cu*** (ppm)	<1.0	70	0.0 to 9.7	0.6	0.2 to 1.0	59
Extr. Mn*** (ppm)	<5.0	37	0.6 to 92.2	7.6	0 to 10	57
Extr. Fe*** (ppm)	?	--	3.7 to 74.0	32.5	25 to 40	58
Clay (%)	--	--	4.5 to 72.4	33.5	10 to 60	89
Silt (%)	--	--	1.6 to 57.4	15.3	10 to 20	43
Sand (%)	--	--	4.3 to 93.9	48.6	20 to 60	58
Hue	--	--	10R to 10YR	----	2.5YR to 5YR	65
Value	--	--	3 to 6	----	3 to 4	78
Chroma	--	--	1 to 6	----	4 to 6	86

*According to Brazilian soil testing service standards for Minas Gerais.

**%above the critical value

***Extracted by 0.05 N HCl + 0.025 N H_2SO_4

which is considered the critical level in these areas. About 85% of the soils have less than 0.15 meq K^+/100 cc, which is less than the suggested critical level for this nutrient. The vast majority of these soils are, therefore, extremely deficient in calcium, magnesium and potassium.

Although most of the soils (75%) have moderate levels of exchangeable aluminum (0.25 to 1.0 meq/100 cc), the proportion of the exchange capacity saturated by aluminum is high due to the low base status. Over 78% of the samples have more than 40% aluminum saturation which suggests aluminum toxicity for most crops and pastures. These relatively modest exchangeable aluminum contents, however, require less lime for neutralization than is needed by acid soils of Southern Brazil.

The low base status and moderate exchangeable aluminum are indicative of very low levels of effective CEC. The vast majority (80%) of the samples have less than 2 meq effective CEC/100 cc, which suggests a great leaching potential and underscores the advanced weathering stage of these soils.

The extremely low levels of extractable phosphorus are among the lowest recorded. Special analytical modifications were needed in order to detect phosphorus in many of these soils. The phosphorus critical level used in these areas is 10 ppm. Over 91% of the samples had less than 2 ppm of available phosphorus.

Most of these soils are also extremely deficient in two micronutrients; zinc (95% of the samples below the critical level of 1 ppm zinc), and copper (70% of the samples below 1 ppm copper). The availability of manganese and iron seems adequate in most of the area surveyed.

Relationships Between Soil Properties and Native Vegetation

This survey also gave some insight concerning possible relationships between topsoil chemical and physical properties and the vegetation gradient (types of cerrado and forest vegetation). The results summarized in Table 40 clearly show that the transition from campo limpo to forest vegetation through the physiognomic intermediate steps (campo cerrado, cerrado and cerradão) is directly correlated with soil pH, exchangeable calcium and magnesium, extractable potassium, effective CEC, extractable phosphorus, zinc, and manganese. The gradient is inversely related to percent aluminum saturation and pH. No relationships were found with soil texture, amount of exchangeable aluminum, extractable iron, or organic

Table 40. Relationship between type of native vegetation and average topsoil properties in the Cerrado. Numbers of samples for each vegetation class in parenthesis.

Soil Property	Campo Limpo (64)	Campo Cerrado (148)	Cerrado (255)	Cerradão (45)	Forest (16)
pH (H_2O)	4.87a*	4.94ab	5.00b	5.14b	5.28c
ΔpH	-0.71ab	-0.69a	-0.76bc	-0.82dc	-0.93d
Organic matter (%)	2.21a	2.33a	2.35	2.32a	3.14b
Exch. Ca** (meq/100 cc)	0.20a	0.33ab	0.45b	0.69c	1.50d
Exch. Mg** (meq/100 cc)	0.06a	0.13a	0.21b	0.38c	0.55d
Extr. K*** (meq/100 cc)	0.08a	0.10ab	0.11b	0.13b	0.17c
Exch. Al (meq/100 cc)	0.74	0.63a	0.66a	0.61a	0.78a
Eff. CEC (meq/100 cc)	1.08a	1.19a	1.43b	1.81c	3.00d
Al saturation (%)	66a	58b	54b	44c	40c
Extr. P** (ppm)	0.5a	0.5a	0.9b	2.1b	1.4c
Extr. Zn** (ppm)	0.58a	0.61a	0.66b	0.67b	1.11c
Extr. Cu** (ppm)	0.60a	0.79ab	0.94b	1.32c	0.95bc
Extr. Mn** (ppm)	5.4a	10.3b	15.9c	22.9d	24.1d
Extr. Fe** (ppm)	35.7a	33.9a	33.0a	27.1b	37.2c
Clay (%)	33a	36a	34a	32a	37a
Silt (%)	20a	16b	15b	16b	16b
Sand (%)	46a	48a	51a	53a	47a
Hue	7.3YRa	6.7YRa	5.4YRb	4.4YRc	4.4YRc
Value	4.3a	4.2a	3.8b	3.5c	3.6bc
Chroma	4.5a	4.7a	4.9a	4.7a	5.7b

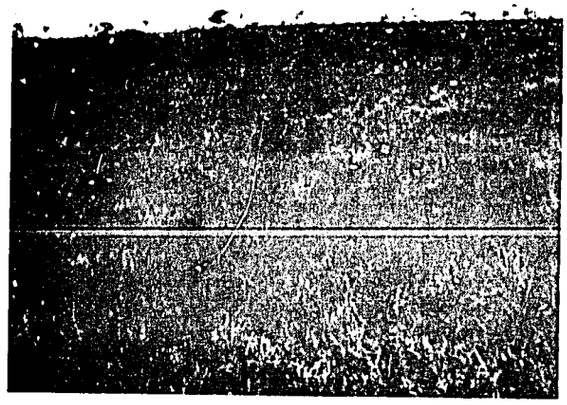
*Means for each line not followed by the same letter are significantly different at the 0.05 probability level.

**Extracted by 0.05N HCl + 0.025NH_2SO_4

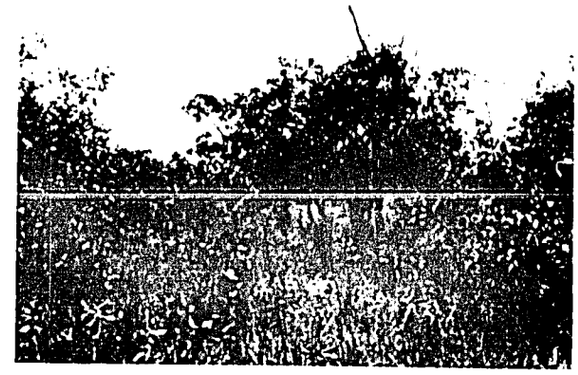
*** Extracted with neutral N KCl.

matter. The latter parameter is much higher in the forest due to the greater biomass cycling. There is also a gradual change in topsoil color from campo limpo to forest. Campo limpo and campo cerrado tend to occur more in the red-yellow soils while taller vegetation, cerradão and forest are almost exclusively found in the dark red soils. Cerrado vegetation can occur in both colors.

These results clearly indicate that the changes in native vegetation in Central Brazil (from campo limpo through campo cerrado, cerrado, cerradão and forest) are probably due to a gradual increase in the supply of various soil nutrients and a decrease in aluminum saturation.



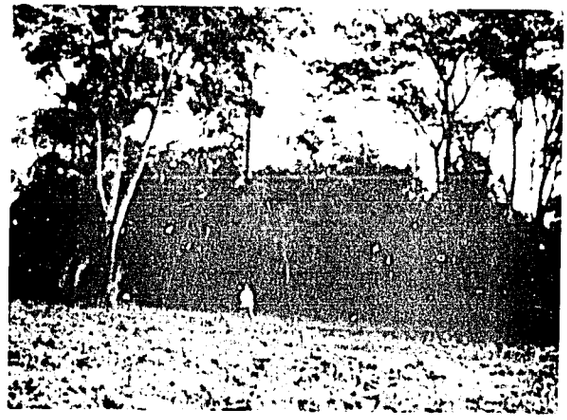
1 - Campo Limpo



2 - Campo Cerrado

3 - Cerrado

4 - Cerradão



5 - Semideciduous Forest

The five main vegetation gradients in the Cerrado are related to soil properties.

CENTRAL AMERICA

Improving multiple cropping systems in small farms in Central America such as this one near Cartago, Costa Rica is one of the main objectives of the Program.

Research in Central America focuses on soil management problems in densely populated areas where most of the food crops are produced in small farming units. Unlike the Amazon and the Cerrado, this region is densely populated and extremely heterogeneous in terms of climate and soils. During this year work continued on the fertility-management aspects of multiple cropping systems, upland rice and forage sorghum fertilization. At the annual project review in Turrialba, a decision was made to concentrate all future work on intercropped systems. The experiments on rice and forage sorghum were terminated this year, although not all the data and interpretation is available at the time of writing.

A total of 15 field experiments were conducted by Dr. Donald Oelsligle in cooperation with the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Ministries of Agriculture of Costa Rica and El Salvador and the International Soil Fertility Evaluation and Imrpovement Program staff. Drs. R. E. McCollum, F. R. Cox, and P. A. Sanchez assisted through short-term assignments. The laboratory and greenhouse work was conducted at CATIE, the Costa Rica and El Salvador soil testing laboratories and at Raleigh.

Plans were made to completely integrate the program's activities in Central America with the proposed Cropping Systems Research Program to be conducted by CATIE under a contract with AID/ROCAP in 1975. Our specialists will participate in the soil fertility-management and soil characterization aspects of this larger project.

The following personnel changes took place during the year. Dr. D. D. Oelsligle resigned in December 17, 1974 to return to his family farm business in Nebraska. A replacement is being recruited. In. Alvaro Cordero, Head of the soils section of the Costa Rican Minstry of Agriculture arrived in Raleigh in August 1974 to conduct studies leading to the Ph.D. degree. His research will be on the fundamental aspects of intercropping. Ing. Alfredo Alvarado returned to the University of Costa Rica after obtaining an M.S. degree in soil genesis and classification. He will continue to cooperate with our activities in his area of specialization in Central America.

INTENSIVE MULTIPLE CROPPING SYSTEMS

The current thinking of scientists in Central America in increasing food production by associating crops stems from a long history of practices by farmers all over the world. Agronomists are trying to "catch up" with farmers before they can hope to improve their systems. Many of their practices usually have a reason although not always obvious. Various crop combinations were studied at Turrialba with three fertility levels in an attempt to obtain general information which could be used in designing cropping systems. The soil properties, experimental design and the first year's results are described in the 1973 Annual Report. Rainfall and solar radiation during crop growth is shown in Fig. 44, the cropping sequences in Fig. 45, and the fertilization levels used in Table 41.

The five original cropping systems described in the 1973 Annual Report were modified to incorporate that year's observations. The large plots were divided in two. The basic pattern consisted of planting corn in 75cms rows in the latter part of the rainy season and interplant cassava in the corn rows at a 1.5 x 2m spacing two weeks later in Systems A-1 and A-2, or three months later in Systems B-1 and B-2. When corn was about three months old, a third crop was relay-planted between the corn rows. Rice was planted in System A-1, soybeans in A-2, a bush-type bean in B-1 and a climbing-type bean in B-4. A fourth crop was planted between the corn-cassava rows after harvesting the beans; rice in System A-2, soybeans in B-1 and sweet potato in A-2. Thus, System A-1 consisted of three harvests a year while A-2, B-1 and B-2 consisted of four.

Monoculture checks of the short-statured crops were planted at the same time in the C plots, in single stands with the optimum spacing. The D plots were used for an additional experimental system which was not completely harvested at the time of writing. The E plots continued in Elephant grass (Pennisetum purpureum) forage production as an indication of the maximum dry matter production potential of the environment and fertility levels.

Yields

The yield data is shown in Table 42. The yields of corn and cassava were substantially lower than the previous year. Upland rice yields were excellent in the January monoculture planting but poor in the May planting due to water stress. Table 43 expresses yields as a percentage of monoculture. The competitive ability of the bush-type bean appeared to be

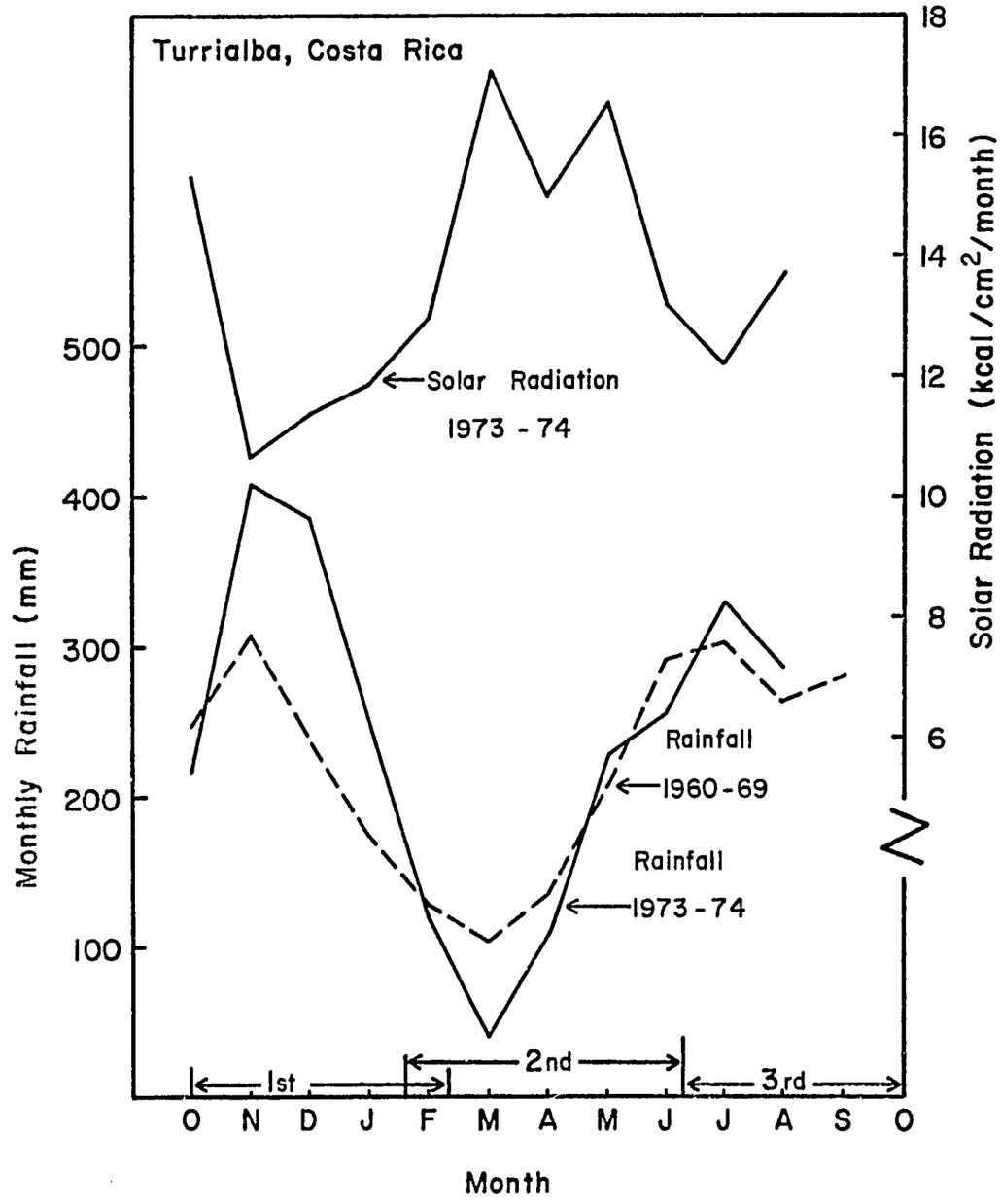


Fig. 44. Monthly rainfall and solar radiation at Turrialba, Costa Rica during the reporting period. Lines labelled 1st, 2nd, and 3rd refer to the corn-soybean intercropping experiment.

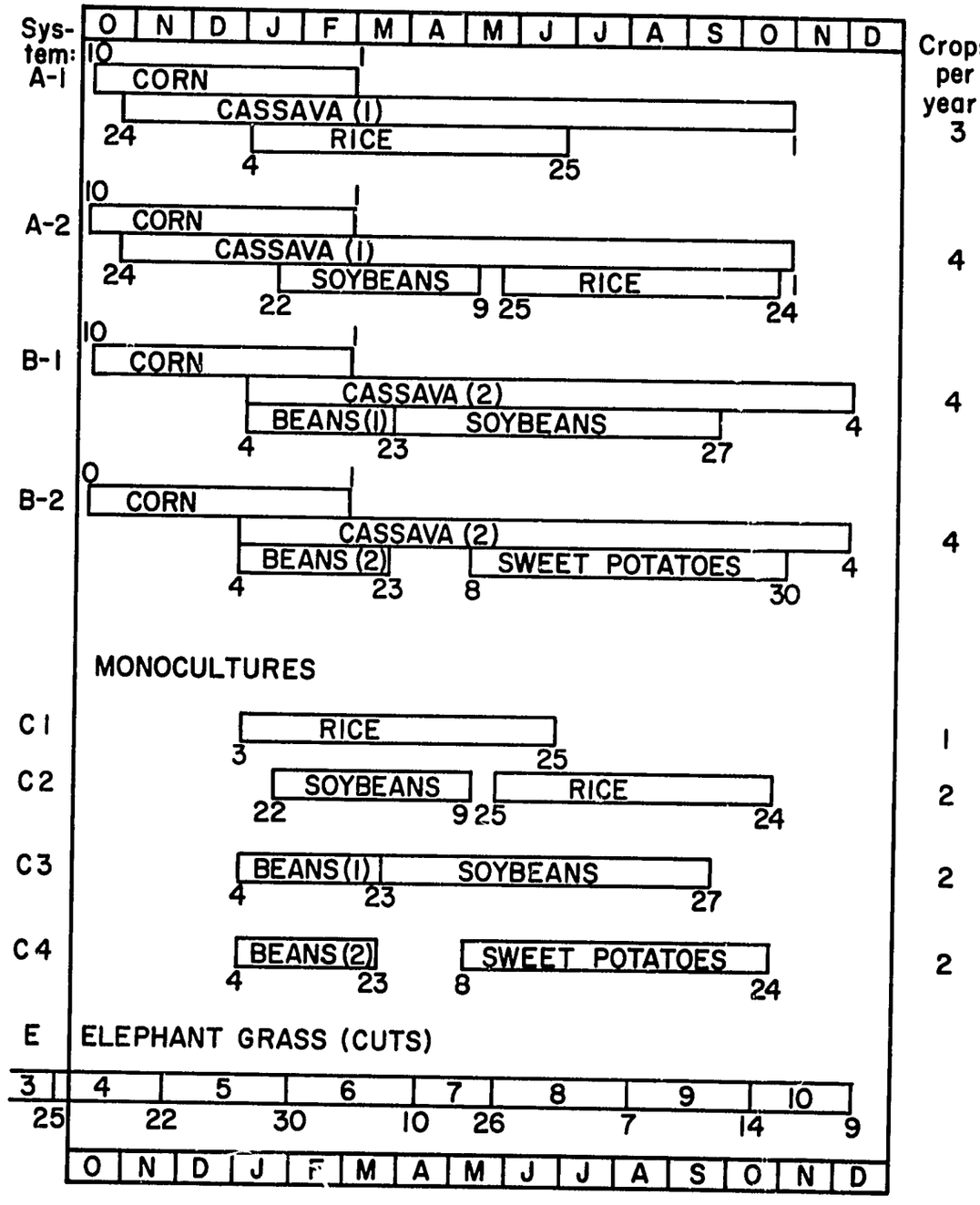


Fig. 45. Chronogram of cropping systems used in the intensive multiple cropping experiment, Oct. 1973-Dec. 1974. Varieties: Corn: E. Hernandez; Cassava: (1) Mangui, (2) Valencia; Rice: CR-1113; Soybeans: Jupiter; Beans: (1) 27-R (bush type), (2) CATIE 1 (climbing type); Sweet potatoes: local.

Table 41. Fertilizer applications for different intercropping combinations at Turrialba, 1974. Rates refer to the medium level. The low level received no fertilizer and the high level received twice the indicated amount.

Cropping system		N	P_2O_5	K_2O
		---------- kg/ha ----------		
A-1	Corn/Cassava/Rice	150	20	120
A-2	Corn/Cassava/Soybeans/Rice	162	144	132
B-1	Corn/Cassava/Beans/Soybeans	212	144	132
B-2	Corn/Cassava/Beans/Sweet potato	212	144	132
C	Monocultures (single stands)			
C-1	Rice (Analog of A-1)	50	0	50
C-2	Soybeans/Rice (Analog of A-2)	62	124	72
C-3	Beans/Soybeans (Analog of B-1)	112	124	72
C-4	Beans/Sweet potatoes (Analog of B-2)	112	124	72
E	Elephant grass	250	100	100

View of Elephant grass growth at the three fertility levels.

Front = high; middle = low; back = medium.

Table 42. Crop yields of the intensive multiple cropping experiment.

Cropping System	Crop	Fertility level		
		Low	Medium	High
		----------	ton/ha	----------
A-1	Corn	0.77	1.26	1.13
	Cassava (1)	9.33	0.33	12.43
	Rice (Jan.)	0.98	1.50	1.40
A-2	Corn	0.77	1.26	1.13
	Cassava (1)	8.77	9.13	11.53
	Soybeans (Jan.)	1.15	1.33	1.78
	Rice (May)	0.61	0.61	0.40
B-1	Corn	0.77	1.26	1.13
	Cassava (2)	12.80	12.10	15.50
	Beans (1)	1.04	2.04	2.44
	Soybeans (Jan.)	0.86	0.90	0.90
B-2	Corn	0.77	1.26	1.13
	Cassava (2)	9.30	12.80	13.80
	Beans (2)	0.61	1.49	2.25
	Sweet potato	10.20	9.70	6.40
Monocultures:				
C-1	Rice (Jan.)	3.05	3.98	3.04
C-2	Soybeans (Jan.)	1.07	1.89	2.11
	Rice (May)	1.37	2.01	1.02
C-3	Beans (1)	1.19	2.23	3.14
	Soybeans (May)	1.60	1.72	1.80
C-4	Beans (2)	1.09	2.33	2.89
	Sweet potato	10.90	10.50	7.40
E	Elephant grass			
	6 cuts (Sept. 26-73/Oct. 14-74)	17.54	35.68	49.79
	10 cuts (May 21-73/Dec. 9-74)	28.30	52.83	77.60

better than that of the climbing-type beans. Soybeans also seem to be a good competitor when planted at the same time as the beans. Of the short-statured crops planted, rice was the least competitive and sweet potatoes the most competitive. The fertility response was highest with beans and lowest in sweet potatoes, which produced negative responses.

The comparison between cropping systems cannot be done with yield data. It is best to compare systems in terms of their economic and food value.

Economic Interpretation

Of the four combinations tried, those which contained beans and did not contain rice were the most profitable (Table 44). Even with the high cost of fertilizer, the medium rate was an economical venture. Although there was probably some benefit from previous fertilization, net returns from the non-fertilized plots, especially the corn-cassava-beans-soybeans and the corn-cassava-beans-sweet potatoes combinations were surprisingly high. Compared with monocultures, it is obvious that these intensive intercropping multiple cropping systems are more profitable. Double cropping of monocultures could be more profitable but this is seldom practiced by farmers in this area.

Energy and protein production:

The amounts of energy and protein produced with the different cropping combinations are given in Table 45. They are based on standard tables developed by INCAP. As would be expected, the combinations which included both beans and soybeans were the highest in protein production; and the combinations which included both cassava and sweet potatoes were the highest in the energy production. Systems B-1 and B-2 were the most productive. FAO estimates that 2700 calories of energy and 65g protein are the daily requirements for a 55-kg man. At these levels of production one hectare in a corn-cassava-soybean-sweet potato system could produce in about 14 months, enough energy to feed 31 men for one year and enough protein for 28 men for one year. By using beans instead of soybeans (an introductory crop), the combination could produce energy for 29 men and protein for 18 men.

Table 45 also shows that the intensive intercropped systems provided more energy and protein than the monocultures. Growing two monocultures of bean and soybeans in a year exceeded the intercropped systems in terms of protein production but were inferior in energy.

Table 43. Relative yields of intercropped short-statured crops expressed as percent of monoculture.

Crop	Fertility level		
	Low	Medium	High
	------ % of monoculture yields -----		
Rice (January planting)	32	38	46
Rice (May planting)	44	30	39
Beans (bush-type)	87	91	78
Beans (climbing-type)	56	64	78
Soybeans (January planting)	107	70	84
Soybeans (May planting)	54	52	50
Sweet potatoes	93	92	86

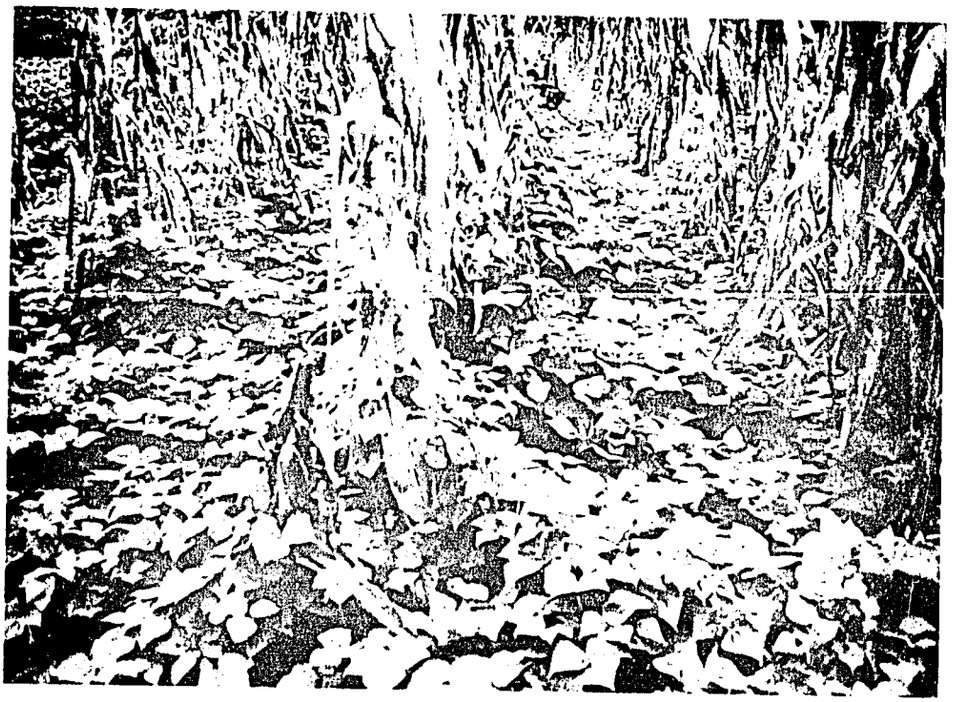
Table 44. Gross returns less fertilizer cost from different cropping combinations. (Time 1 year and 14 months).

Cropping system		Fertility level		
		Low	Medium	High
		---------- US$/ha ----------		
A-1	Corn/Cassava/Rice	668	695	634
A-2	Corn/Cassava/Soybeans/Rice	1150	1122	1100
B-1	Corn/Cassava/Bush beans/Soybeans	1581	1898	1953
B-2	Corn/Cassava/Climbing beans/Sweet potatoes	1421	1797	1735
Monocultures:				
C-1	Rice	488	590	391
C-2	Soybeans	524	842	865
	Rice	219	274	68
C-3	Beans (bush)	583	1009	1370
	Soybeans	784	759	714
C-4	Beans (climbing)	534	1057	1248
	Sweet potatoes	654	546	276

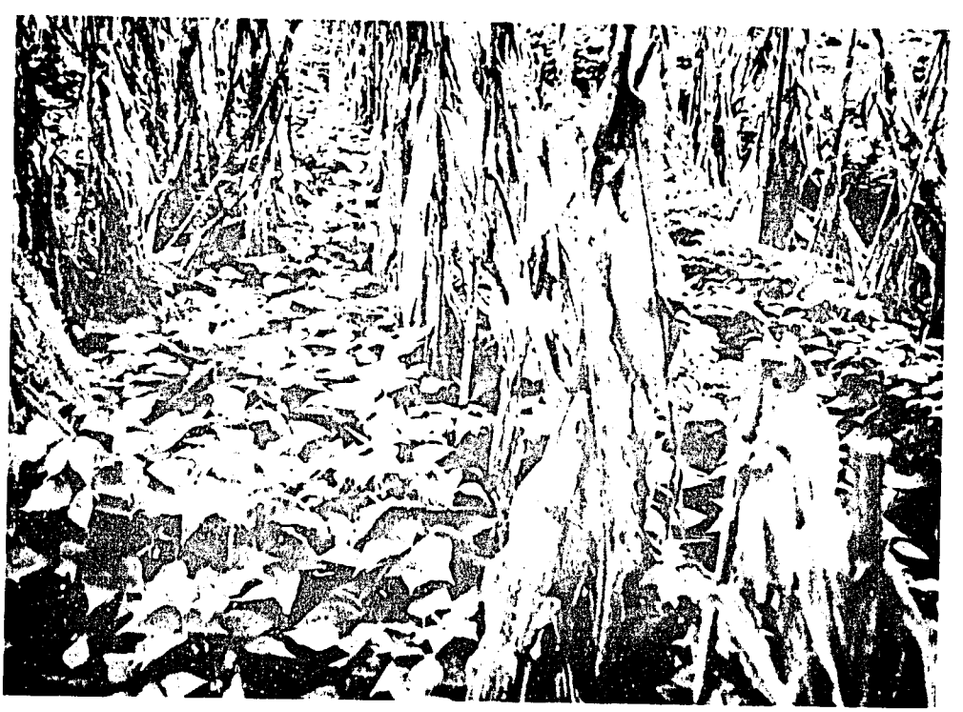
Prices in Costa Rica (1974): Nitrogen: US$0.70/kg N; Phosphorus: US$0.50/kg P_2O_5; Potassium: US$0.25/kg K_2O; corn: US$0.18/kg; rice: US$0.16; soybeans: US$0.49/kg; sweet potatoes: US$0.06/kg; and cassava: US$0.04/kg. Exchange rate: 8.21 colones per US$.

Table 45. Energy and protein production with four intercropped combinations at low and medium fertility in relation to monocultures.

Cropping systems		Energy		Protein	
		Low fertility	Medium fertility	Low fertility	Medium fertility
		---- Mcal/ha -----		------ kg/ha -------	
A-1	Corn/Cassava/Rice	19,6[illegible]	22,324	235	319
A-2	Corn/Cassava/Soybeans/Rice	21,1[illegible]	24,113	587	697
B-1	Corn/Cassava/Beans/Soybeans	26,692	30,970	716	989
B-2	Corn/Cassava/Beans/Sweet potato	28,543	37,717	432	700
Monocultures:					
	Beans (ave. bush & climbing types)	4,014	7,683	251	502
	Soybeans (ave. Jan. & May plantings)	5,313	7,183	446	603
	Rice (ave. Jan. & May plantings)	5,630	7,631	112	159
	Sweet potatoes	12,664	12,810	142	137



Adequately fertilized intensive multiple cropping systems produce more gross returns, energy and protein per hectare than monocultures. Top photo shows cropping System B-2 with climbing beans and corn. Bottom photo shows cropping System B-1 with bush beans and corn.



For both species, yields were inversely related to population pressure. That is, with increasing bean populations, the corn yields decreased, and as the corn population increases the bean yields decreased. This relationship appears in Fig. 46. In all cases, however, intercropping was superior to splitting the fields in half and growing two monocultures. The land equivalent ratios shown in Table 47 indicate this. On the average of N rates, the 100% corn-100% bean combination produced 25% higher yields than monocultures, the 100% corn-50% bean combination 24% more and the 50% corn-100% beans 13% more.

The factors which have been studied in the past for their importance in crop production as monocultures (insects, diseases, weeds, fertility, etc.) need to be considered once again in their relations to associating crops together. In soil fertility, the question arises as to how best can high production be maintained or assured and what is the best way of doing it when there is more than one crop growing on the same soil at the same time.

When the corn and bean yields from the different combinations are expressed in percent yields of the monoculture, it appears that within a specific cropping combination at the different N levels there is in general very little difference in the relative yields of the two crops (Fig. 46). The relationships change as the relative proportion of the two crops changes, but within a given cropping combination the relative yields remain fairly constant. This would seem to imply that given a certain environment and other factors of production remaining relatively constant the proportionate yields of a given cropping combination will remain the same under different soil fertility regimes. Since the dry season was approaching, fertilizer nitrogen was all broadcast at planting time, thus establishing uniform but different N regimes for the different cropping combinations. This effect needs further study, but if true may help in establishing some of the principles needed in determining fertilization practices for cropping associations.

The intercropping effects varied with nitrogen rate. Fig. 47 shows the LER values as a function of nitrogen applied. LER values increased sharply at the highest nitrogen rate in all crop combinations. The 100% corn-100% bean and the 100% corn-50% bean combinations maintained a stable LER of about 1.20 from 0 to 200 kg N/ha, while the 50% corn-100% bean combination had LER values at 100 and 200 kg N/ha which approached the yield of monocultures. With the exception of the last crop combination, the corn-bean intercrops utilized nitrogen more efficiently than if the field was split in halves and grown to the two monocultures.

NITROGEN FERTILIZATION OF VARIOUS CORN AND BEAN COMBINATIONS

Intercropping systems involving corn and beans are common management practices in Latin America. Work by scientists in Mexico and El Salvador has shown that more total energy and protein per unit of land can be produced by intercropping than under monoculture.

There has been little or no work done, however, the nutritional aspects of the corn-bean intercropping combinations. Thus, an experiment was conducted at CATIE to obtain preliminary information on nitrogen responses when corn and beans were associated in different combinations.

Field beans (*Phaseolus vulgaris* cv. CATIE-1) and corn (*Zea mays* cv. Maicena) were planted on December 24, 1973 on a Colorado soil with the following topsoil properties: pH 5.5, available P 13 µg/ml, 0.8 meq K/100 ml, 10 meq CEC/100 ml and 99% base saturation. A factorial experiment with five row spacing combinations and four nitrogen levels was arranged in a randomized complete block design with three replications. The population treatments are shown in Table 46.

Treatment 2 had one row of beans between the corn rows; Treatment 3 had two bean rows between corn rows; and Treatment 4 had one row of corn every four bean rows. Each treatment received four levels of N (0, 100, 200, and 300 kg/ha as NH_4NO_3), all broadcast and incorporated prior to planting. The experimental area also received a uniform application of 200 kg P_2O_5/ha and 100 kg K_2O/ha as simple superphosphate and potassium chloride.

Beans were harvested at 90 days and the corn was harvested at 134 days after planting. Bean and corn grain yields were adjusted to 13.0 and 15.5% moisture respectively. Grain samples from each plot were taken for moisture and N determinations.

Grain yields

Significant grain yield responses to N were obtained with both corn and beans (Table 47). In the monocultures, corn yields increased from 2.73 to 3.54 tons/ha while bean yields increased from 1.13 to 2.60 ton/ha with N applications. It is interesting to note that yields of corn increased only up to the 100 kg N/ha level while bean yields significantly increased up to the 200 kg N/ha level. Thus, it appears that under a given N regime, beans will require more N for high yields than will corn. Bazan in Costa Rica also found strong bean responses to high N applications.

Table 46. Description of intercropped combinations used in the nitrogen experiment.

	Treatment		Corn		Beans	
	Corn	Beans	Population	Row spacing	Population	Row spacing
	%	%	1000/ha	m	1000/ha	m
1	100	0	50	1.0	0	0
2	100	50	50	1.0	100	1.0
3	100	100	50	1.0	200	0.5
4	50	100	25	2.0	200	0.5
5	0	100	0	0	200	0.5

General view of the corn-bean intercropping nitrogen experiment. In the foreground: the 50% corn-100% beans combination. In the background: the 100% corn-100% bean treatment.

Table 47. Grain yield response by corn and beans to nitrogen applications in intercropped combinations and monoculture.

Treatment		0 kg N/ha			100 kg N/ha			200 kg N/ha			300 kg N/ha		
Corn	Beans	Corn	Beans	LER[1/]	Corn	Beans	LER	Corn	Beans	LER	Corn	Beans	LER
%	%	------ tons/ha -----			-----tons/ha -----			----- tons/ha -----			------ tons/ha ------		
100	0	2.73	-	1.00	3.40	-	1.00	3.54	-	1.00	3.09	-	1.00
100	50	2.13	0.47	1.20	2.84	0.72	1.22	2.73	0.95	1.14	3.09	1.05	1.40
100	100	1.60	0.66	1.17	1.88	1.21	1.18	2.17	1.59	1.24	2.40	1.67	1.42
50	100	1.04	1.01	1.27	1.07	1.43	1.05	1.13	1.76	1.01	1.25	2.08	1.20
0	100	-	1.13	1.00	-	1.92	1.00	-	2.53	1.00	-	2.60	1.00

$LSD_{.05}$: Corn: 0.62 ton/ha

Beans: 0.45 ton/ha

[1/] Land equivalent ratio: $\frac{\text{Corn yields intercropped}}{\text{Corn yields monoculture}} + \frac{\text{Bean yields intercropped}}{\text{Bean yields monoculture}}$

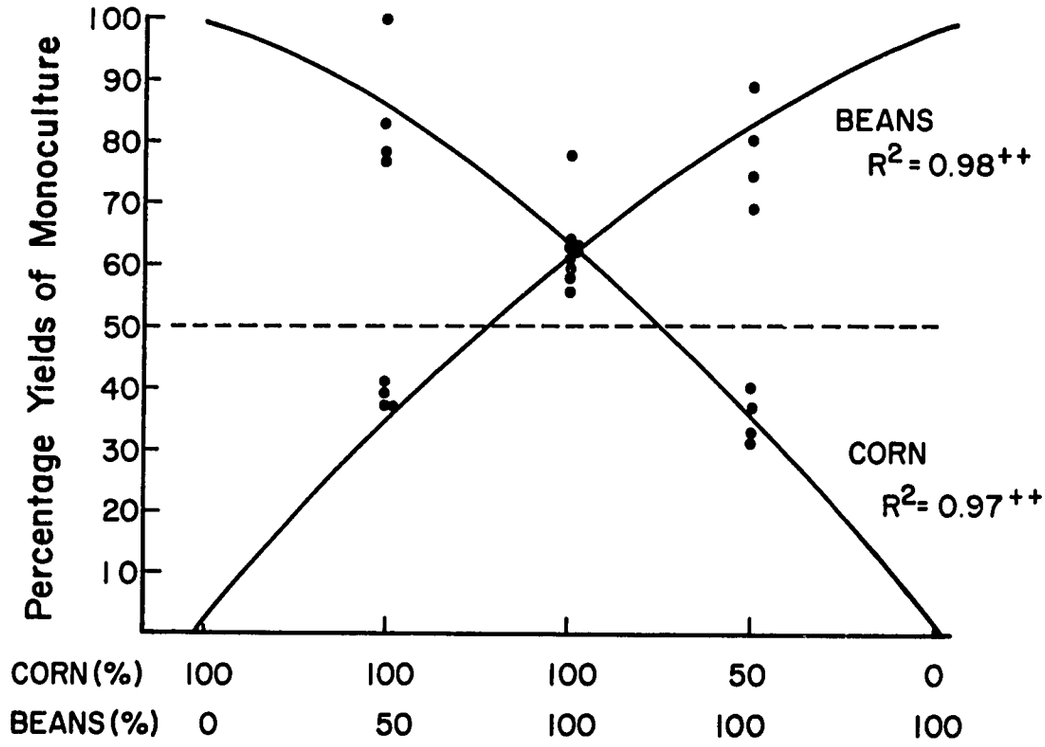


Fig. 46. Percentage yields of various intercrop combinations of corn and beans relative to monoculture. Dots represent various N levels.

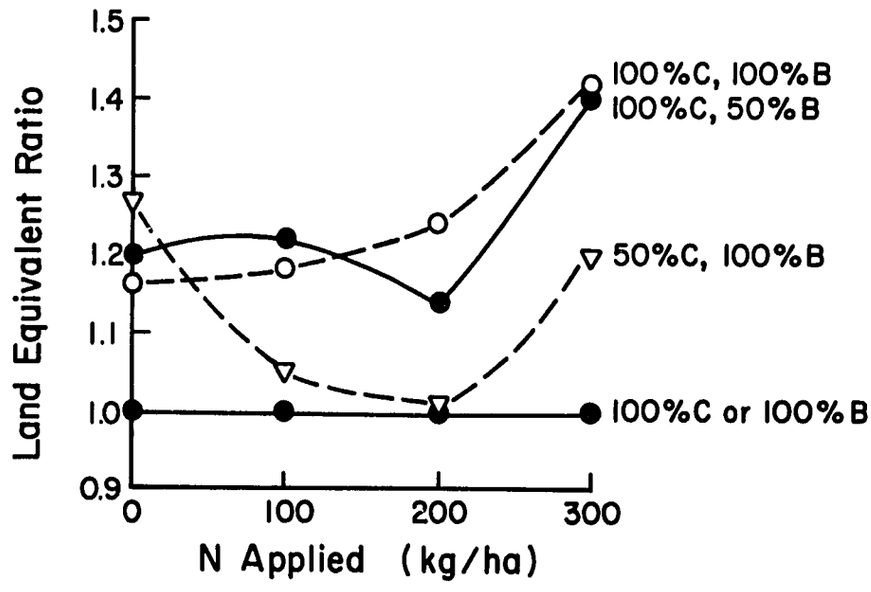


Fig. 47. Effect of nitrogen applications on the efficiency of three corn-bean intercropped systems in Turrialba.

Economic Interpretation

Considering the economics of the different combinations local prices will determine the maximum return per hectare. In Costa Rica, bean prices are exceptionally high relative to corn[1/]. Given these prices, the maximum return, less N fertilizer, was obtained at 300 kg N/ha on the bean monoculture. When no N was applied, the maximum return was at the most intense cropping combination (100% corn-100% beans), which is what subsistence farmers do. Fig. 48 shows that nitrogen applications increased the gross returns of the intercropped systems. When considering these relationships, local prices will determine which combination will be most advantageous.

Energy and Protein Production

To obtain energy production values for the different combinations, the factors of 361 cal/100g corn grain and 337 cal/100g grains were used. Energy production (Fig. 49) was closely related to the amount of corn produced with maximum energy production being either with monoculture corn or corn with a low population of beans, irrespective of the N level.

Protein content (total N x 6.25) of the corn grain was not affected by N levels, but the protein content of bean grains was in general significantly increased when N was applied (Table 48). Whether the increased protein in the beans can be utilized or not will require further study. The physiology of the bean plant with respect to N assimilation is interesting. Protein contents in three of the four cropping combinations increased significantly as the rate of N was increased from 200 to 300 kg/ha, however, in none of the four combinations was there a significant increase in grain yield for the last increment on N. When the amount of protein produced per combination (Fig. 50) is considered, with no N being applied, protein production is maximized at the highest population pressure (100% corn-100% bean). However, due to the increase in protein content of the beans with increasing N rates, the maximum protein production shifts towards the bean monoculture with increasing N rates. It should be noted, however, that bean yields reported here are higher than those usually obtained commercially.

[1/]At the time when this research was carried out, corn on the market was U.S.$8.20/100 lbs. and beans were U.S.$22.25/100 lbs.

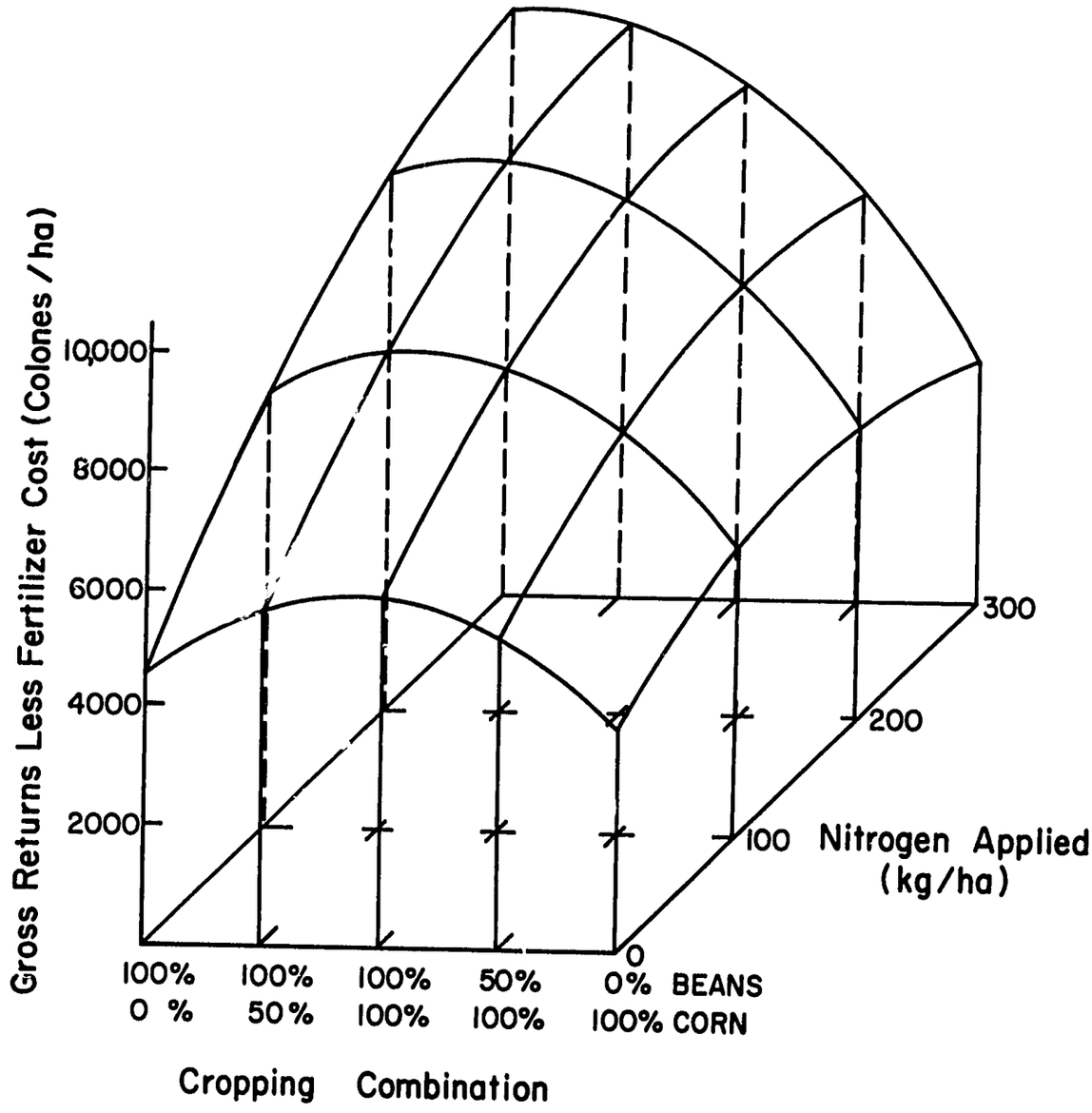


Fig. 48. Gross return less N cost at various corn-bean cropping combinations and different N levels in Turrialba. 1 U.S.$ = 8.21 colones.

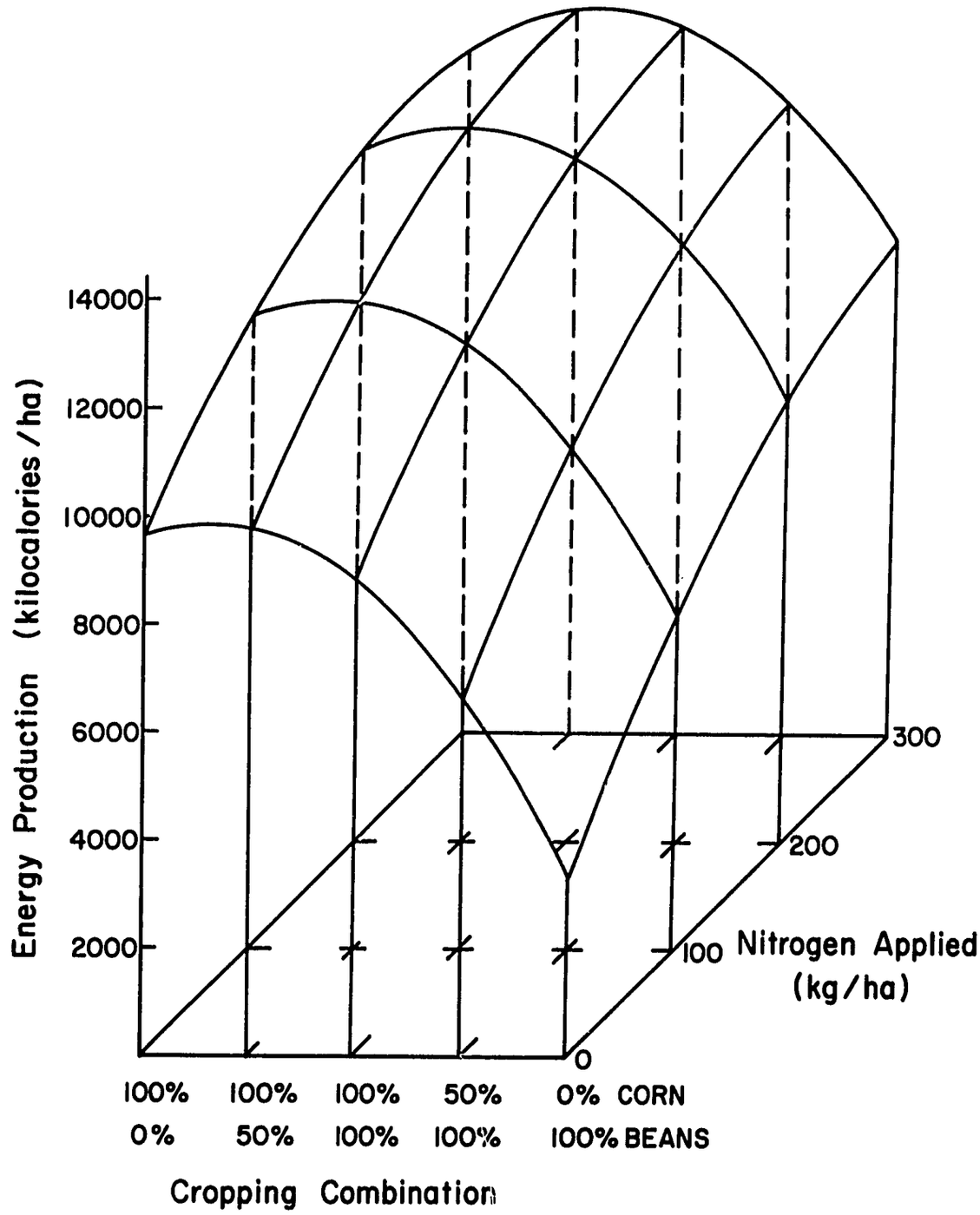


Fig. 49. Energy production at various corn-bean cropping combinations and different N levels.

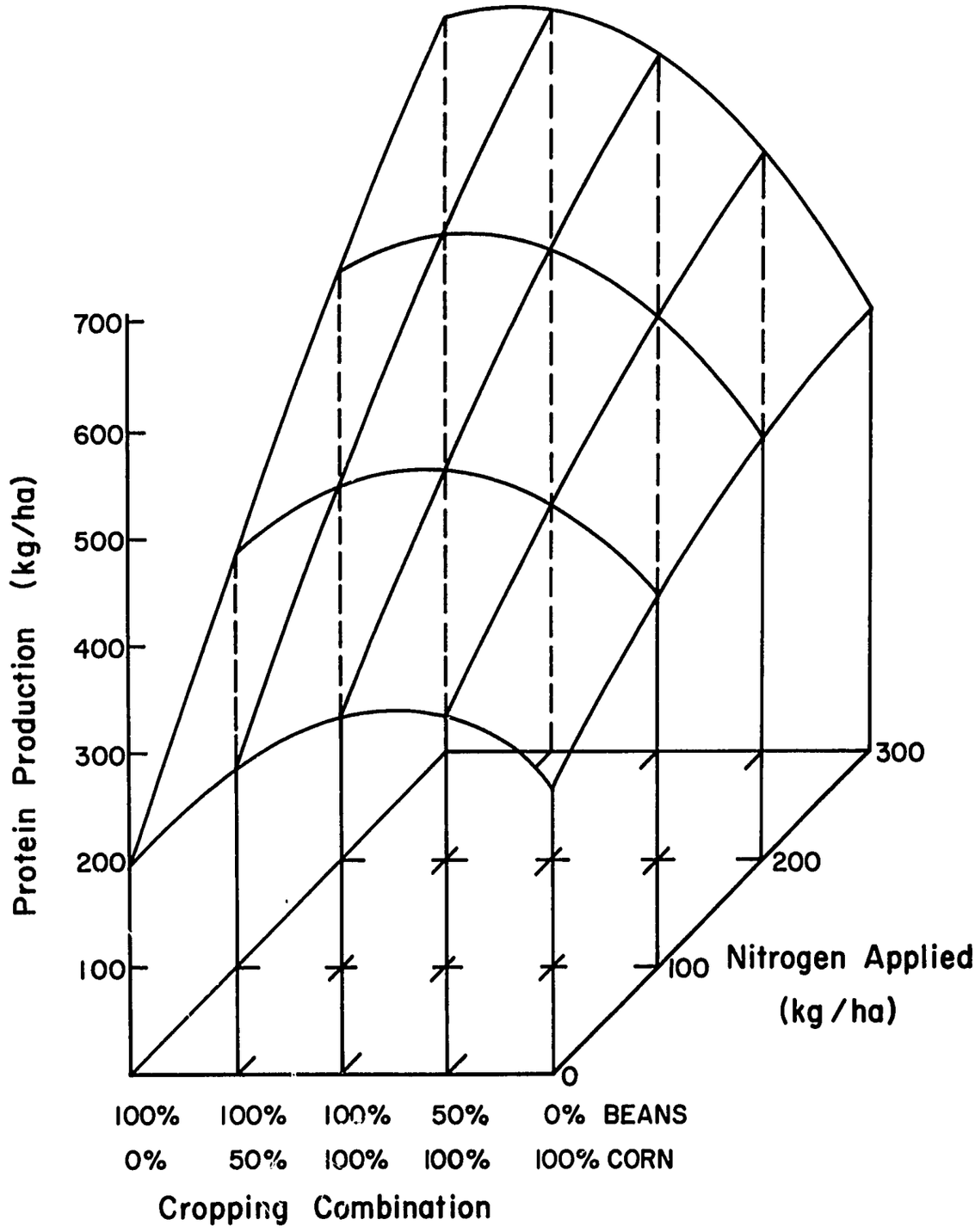
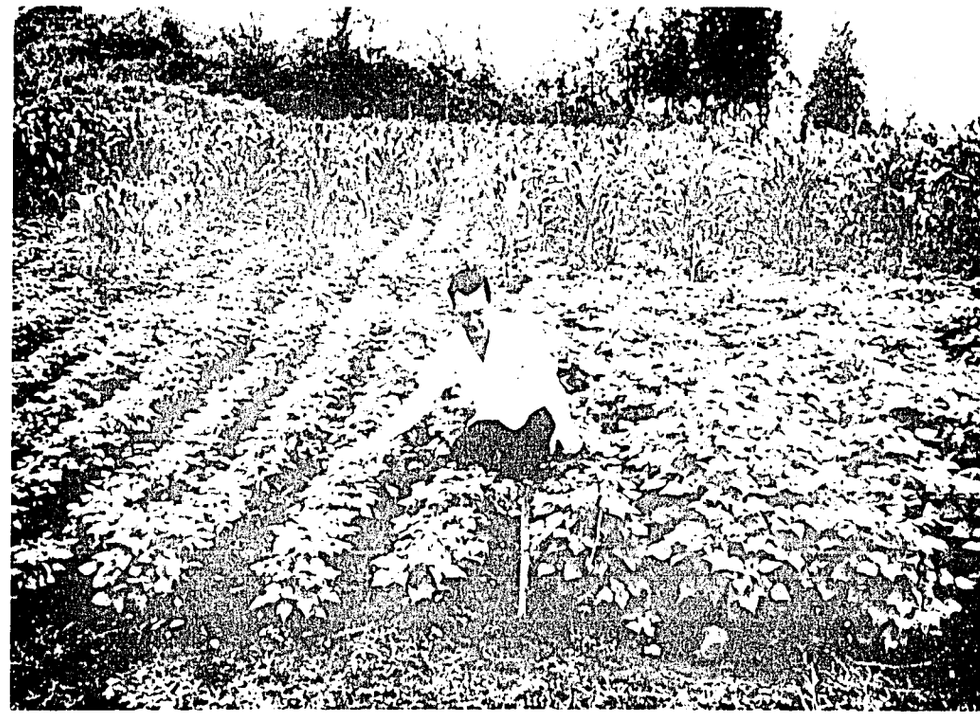


Fig. 50. Protein production at various corn-bean cropping combinations and different N levels.

Table 48. Grain protein content of corn and beans as a function of nitrogen rate and intercropping system.

Crop combination	Nitrogen applied (kg/ha)			
	0	100	200	300
	% protein			
100% corn	10.4	10.1	11.0	11.4
100% corn 50% beans	10.2 19.4	10.3 22.0	10.3 23.9	10.6 25.3
100% corn 100% beans	9.7 19.2	10.3 22.6	10.0 24.0	10.8 27.1
50% corn 100% beans	10.3 18.9	10.1 22.1	10.4 23.2	9.8 25.9
100% beans	20.1	21.5	21.6	26.4

LSD (.05) Corn = 1.2%, Beans = 1.9%.



The strong response of bush bean monocultures to nitrogen applications. Left: 0 kg N/ha. Right: 200 kg N/ha. Some intercropped treatments are shown in the back.

For maximum protein production, then beans should be emphasized in the combination. For maximum energy production, corn should be emphasized.

COMBINING CORN AND SOYBEANS

Corn and beans is the more popular cropping combination in Central America but bean production is limited by both excessive water and by diseases during the wet season. Besides having a higher protein content in the grain, soybeans appear to be less susceptible to water and disease problems than the common bean. There is also the beneficial effect of residual N which follows soybeans that appear to be doubtful with beans. In order to obtain more information on intercropping corn and soybeans under intensive management throughout the cropping year, the following work was initiated.

Corn and soybeans were planted alone and together for three consecutive plantings on a Colorado soil located in plots adjacent to the first experiment reported in this chapter. Planting times and climatic data during the duration of the experiment are given in Fig. 44. An initial application of 400 kg P_2O_5/ha was made to avoid P deficiencies with additional amounts of fertilizer added in bands at planting (Table 49). Nitrogen was topdressed on the corn at approximately 40 days after planting. The soybeans were inoculated with *Rhizobium* sp. prior to planting. Corn and soybeans were planted in 60cm rows as monocultures and in three intercropped combinations. The combinations used were: 1) corn and soybeans planted in alternate 60cm rows, 2) planted in alternate 30cm rows and 3) both crops planted in the same row at 60cm. In all combinations and in the monocultures, corn and soybeans were planted to give 50,000 and 40,000 plants per hectare, respectively. Varieties for the first planting were a local, tall-statured corn (Eladio Hernández) and Bragg soybeans. In the second and third plantings, the short-statured Tuxpeño Planta Baja variety and the taller Jupiter soybean variety were used. At harvest time, grain samples were taken and yields corrected to 13.0% moisture for the soybeans and 15.5% moisture for the corn. Plant height measurements were taken at approximately 75 days from planting. Solar radiation was measured in various corn and soybean rows for a 12-day period during the grain filling period with a Bellani Alcohol pyranometer.

Table 49. Fertilizers rates used in the three corn and soybean croppings, Turrialba, Costa Rica.

Cropping system	Fertilization per crop*		
	First	Second	Third
	---------- kg/ha of N, P_2O_5, K_2O ----------		
Corn monoculture	150-20-70	164-48-24	160-120-60
Soybeans monoculture	10-20-20	24-48-24	30-60-30
Corn & Soybeans	160-40-90	188-96-48	190-180-90

*Initial application of 400 kg/ha P_2O_5.

Table 50. Corn and soybean grain yields when grown alone and together for three successive plantings.

Treatment	First Planting			Second Planting			Third Planting		
	Corn	Soybeans	LER	Corn	Soybeans	LER	Corn	Soybeans	LER
	---------- Grain yields (ton/ha) ----------								
Corn monoculture	2.55	-		2.87	-		4.53	-	
Soybean monoculture	-	1.34			2.14			1.05	
Corn & Soybeans intercropped:									
Alternate 60 cm rows	2.67	0.55	1.46	0.64	0.96	0.66	3.78	0.37	1.18
Alternate 30 cm rows	3.63	0.43	1.74	0.57	1.23	0.77	4.64	0.34	1.35
Same rows, 60 cm	3.04	0.40	1.49	0.59	1.27	0.80	3.89	0.28	1.12
$LSD_{.05}$	0.97	0.31		0.64	0.43		1.01	0.13	

Grain yields are shown in Table 50; plant heights in Table 51 and solar radiation measurements in Table 52. For the first crop, there was no detrimental effect on corn yields when intercropped with soybeans. Soybean yields were about 34% of the monoculture with no differences among the three methods of interplanting them with corn. Although a tall corn cultivar was used, interplanted soybeans did not alter plant height. Due to strong winds during the later part of the growing season, support was required for the corn to avoid lodging. With the intense shading from the tall corn (28% light penetration), soybean heights significantly increased when intercropped. The LER values ranged from 1.46 to 1.74, indicating a very strong benefit of intercropping, particularly in 30cm alternate rows.

During the second crop there was an intense dry period (Fig. 44). Corn yields were significantly decreased when grown with soybeans. Soybean yields were also decreased but not as much as in the previous planting. Corn heights were also significantly decreased but soybean heights were not when the two crops were grown together. Again there was little difference among the three cropping combinations. Light penetration was much higher in corn and soybean rows than in the first cropping except in the corn with a high row population which provided more shading. The use of a shorter corn variety and a taller soybean variety, coupled with the drought, resulted in LER values lower than 1. Under these conditions intercropping was detrimental.

The third cropping had more favorable growing conditons; and, as in the first planting, there were no detrimental effects on corn yields nor corn height when grown with soybeans. Soybean yields were significantly decreased when soybeans were grown with corn. Soybean heights for the third planting are canopy heights due to lodging in all of the combinations. In general, like the first planting, there was little difference in the light which entered the various corn and soybean rows. Reduction in light penetration was also similar to the first planting with an average of 30% light entering the corn and soybean rows in the third planting. These soybeans also suffered from an attack of Cercospora leaf spot which was sufficiently severe to affect yields. LER values ranged from 1.12 to 1.35, reflecting a positive intercropping effect. The best treatment was the 30cm alternate rows under high population pressure and adequate rainfall (first and third plantings) the reductions in soybean yields were very similar. In the first planting with a tall corn and a short soybean, soybean yields were on the average 31% of the monoculture while in the third planting with a

Table 51. Corn and soybean heights when grown alone and together for three successive plantings.

Treatment	Plantings					
	First 77 days		Second 72 days		Third 77 days	
	Corn	Soybeans	Corn	Soybeans	Corn	Soybeans
	cm					
Corn alone	364	--	202	--	253	--
Soybeans alone	--	46	--	91	--	103
Corn & Soybeans:						
60 cm betw. rows	347	66	171	88	272	72*
30 cm betw. rows	360	61	165	88	269	79*
Same row - 60 cm	341	59	162	86	261	68*
LSD.(05)	24	3	14	7	23	35

Table 52. Solar radiation for a 12 day period (86 to 97 days after planting) in various corn and bean rows as compared to open field measurements.

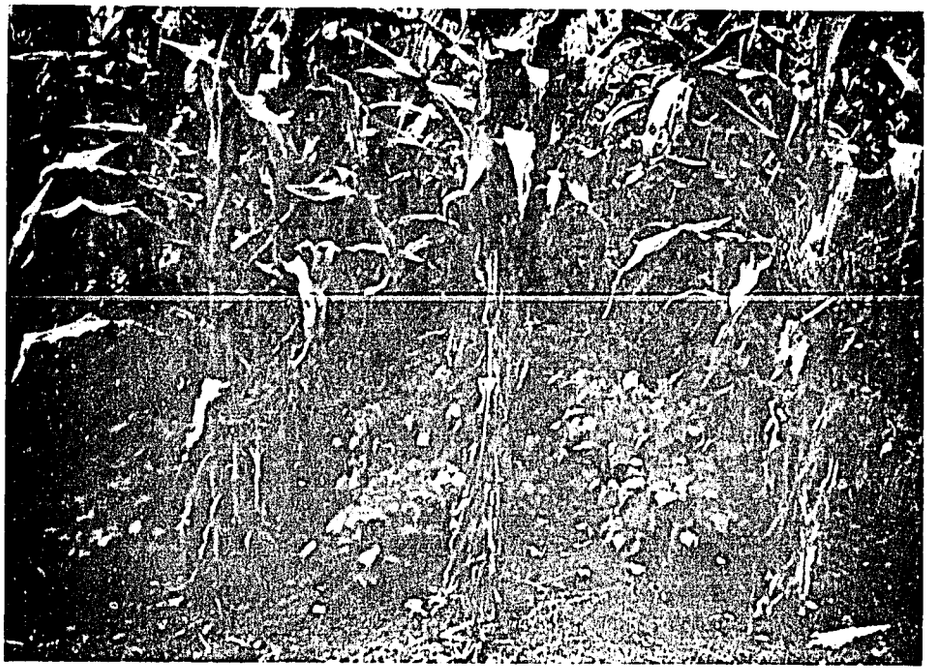
Pyranometer location	Planting		
	First	Second	Third
	g cal/cm^2/day		
Open field	343	395	449
60 cm between corn and soybean rows:			
Corn row	95	131	126
Soybean row	105	325	159
30 cm between corn and soybean rows:			
Corn row	89	385	122
Soybean row	93	360	140

shorter corn and a taller soybean, yields were 31% of the monoculture yields. Light penetration to the soybean row was also similar with 28% and 30% entering the first and third plantings respectively. This suggests a direct relationship between yields and the amount of light entering as was the case with artificial shade on rice in Peru.

In this experiment it appears that the switch in plant types occurred at the worst possible time. Jupiter soybeans being the taller variety, lodged when grown during the longer day lengths in the third planting. It would seem to be more logical to have the shorter soybean varieties growing during the longer days and vice versa for the taller soybeans.

There was an adverse effect on corn yields when grown with soybeans in the second planting probably due to the dry weather. It is interesting that the soybeans could outcompete the corn for the available soil moisture. Corn yields when grown with soybeans were only 21% of the monoculture, while soybean yields were 54%. Thus, the soybeans did relatively better during the dry weather than they did in the other two plantings. However, the 75% efficiency when combining corn and soybeans indicates overpopulation for the dry condition.

The gains in efficiency from the first and third plantings, which averaged approximately 56% and 22%, respectively, seem to justify further work for this combination. Future work should include treatments with a wider spacing between corn rows to allow more light penetration and air movement, perhaps employing the double corn row method used in El Salvador. Furthermore, consideration should be given the growth characteristics of the available varieties, especially soybeans.



Plant type of the species in combination affect their performance when intercropped. Top: the tall-statured corn variety used in the first planting severely depressed soybean production. Bottom: when a short-statured corn variety was used in combination with a taller soybean variety, soybeans severely depressed corn growth during a period of water stress.

COMPETITION STUDIES WITH CASSAVA

A simple experiment was conducted with two cassava varieties to determine the effect of heavy crop competition on root production and also to monitor nutrient concentration changes in various plant parts during root growth.

Cassava (cvs. Mangi and Valencia) was planted at CATIE on November 2, 1973 in $80m^2$ plots with plant spacings of 1 x 1m in the same location as the first experiment. Once the plants had established good growth (approximately two months) corn, beans and rice were planted in half of the plots. Plant populations per hectare were: corn 30,000, beans 200,000 and rice 60 kg seed/ha. These three crops were accommodated as best possible with beans and rice between cassava rows, and corn between cassava plants in the row. The three crops were used to see how they competed relative to each other and to create a severe population pressure on cassava. Before planting the short-term crops, a broadcast application of 100-200-200 of N-P_2O_5-K_2O was made; after their harvest, an additional 100 kg of N as ammonium nitrate per hectare was applied to the cassava.

Crop Yields

Yields of the corn, beans, and rice intercropped with cassava and the cassava checks are given in Table 53. It was thought that yields of the interplanted species may be better when grown with Mangi cassava because it has a deeper-lobed leaf than Valencia but this was not the case. Plant competition effects may have been too severe to permit this observation. There were no differences among yields of interplanted crops due to cassava variety. Both corn and bean yields were about 50% of what normally can be expected at Turrialba, but rice could not effectively compete with the other crops. Cassava root yields under intercropping for Mangi and Valencia were 34% and 39% of the monocultures, respectively.

Economic Interpretation

At present for the Turrialba area there are two prices for cassava, one being the local market price and the other the processor's for export. Good quality cassava can be sold at the high price. Local prices and gross returns per hectare are given in Table 54. At the high price, there is little difference in gross return between cassava grown alone and with other crops. At the low cassava price, it is more economical to combine cassava with other crops ($772 vs. $1148). When interplanted corn and beans were grown at nitrogen rates sim-

Table 53. Cassava, corn, beans, and rice yields when grown together and cassava yields when grown alone.

Crop	Cassava variety	
	Mangi	Valencia
	---------- tons/ha	----------
Corn (intercropped)	2.34	2.36
Beans (intercropped)	0.83	0.95
Rice (intercropped)	0.11	0.10
Cassava (intercropped)	9.0	12.7
Cassava monoculture	26.7	32.7

Table 54. Gross return of cassava grown alone and when grown with corn, beans, and rice.

Crop	Price	Gross return
	US$/kg	US$/ha
Cassava alone (processor's price)	0.052	1544
(market price)	0.026	772
Mixed cropping		
Cassava (processor's price)	0.052	564
(market price)	0.026	282
Beans	0.53	472
Corn	0.16	376
Rice	0.17	18
Total at high cassava price:		1430
Total at low cassava price:		1148

ilar to those employed in this experiment, returns of $1000 per hectare were obtained. Thus it appears that a farmer has various choices which would give him a good return. If quality could be guaranteed, cassava alone is a good choice. A lower competitive effect should allow cassava and beans to probably be the wisest choice as they are at present the two most economical crops for the area.

NITROGEN MANAGEMENT FOR UPLAND RICE

Three field experiments were conducted in the Pacific Coast of Costa Rica to determine the most profitable combination of nitrogen sources, timing of application and rates for upland rice. The experimental design, climate, soil properties and yields appeared in the 1973 Annual Report. The Pacific Coast of Costa Rica is an excellent upland rice growing region characterized by high rainfall during the growing season, young soils with good water holding capacity which respond only to nitrogen fertilizers and a high level of management, and the use of short-statured varieties. At Palmar Sur, no significant yield responses were obtained; the yield of check plots averaged 4.1 tons/ha. At Cascante, only negative yield responses associated with lodging were obtained, the yield of check plots averaged 5 tons/ha.

At Taboga, sharp positive responses were obtained, with the yields of check plots averaging 3 tons/ha. Maximum yields in the order of 5.9 tons/ha were obtained with several treatment combinations. When all the nitrogen was applied at planting, sulfur-coated urea was superior to urea or ammonium sulfate. When the nitrogen was topdressed half at tillering and half at panicle initiation, the superiority of sulfur-coated urea diminished. Urea and ammonium sulfate split in three applications produced identical response curves to those of sulfur-coated urea applied all at planting.

The apparent recovery of added nitrogen was calculated according to nitrogen uptake differences and is presented in Fig. 51. The average of the N sources were 31% for sulfur-coated urea, 28% for urea and 29% for ammonium sulfate. Applying all sources at planting averaged 18% recovery; splitting applications in two 36%, and splitting applications in three 33%. The highest recovery (63%) was obtained with 60 kg N/ha as urea split in halves. Some of these values reflect a very high efficiency of added nitrogen to rice.

A simple economic analysis was undertaken in order to determine the most profitable combinations. Two sets of prices were used: the 1973 prices prior to the effects of the energy

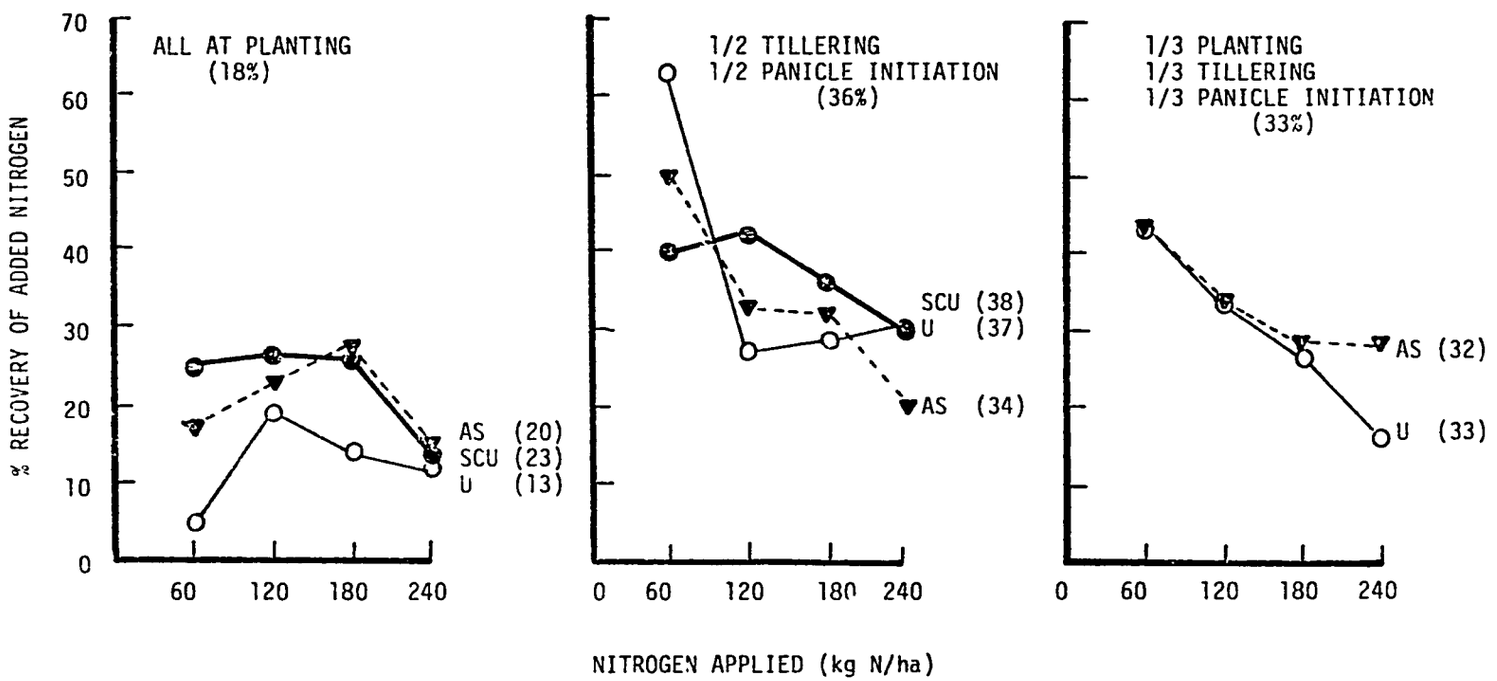


Fig. 51. Apparent recovery of added nitrogen as a function of sources and time of application for upland rice (CICA-4) variety in Taboga, Costa Rica.

crisis and the 1974 prices in which the cost of nitrogen as urea tripled, as ammonium sulfate doubled and the rice prices increased from U.S.$104 to $176/ha. Table 55 shows these increases and Table 56 the unit cost of nitrogen including labor and machinery needed for application.

The gross returns to nitrogen fertilization are shown in Fig. 52 for the two years. The overall effect of price increases from 1973 to 1974 was to increase the gross returns to fertilization in all treatments. The 69% increase in rice prices made rice growing more profitable in spite of the doubling or tripling of fertilizer nitrogen costs. At both price levels, several management treatments produced the highest economic returns without significant differences among them: Urea split in thirds and in halves, ammonium sulfate split in thirds and sulfur-coated urea all at planting or split in halves (all at the rate of 180 kg N/ha) and ammonium sulfate split in halves at 60 kg N/ha (Table 57).

The nature of yield responses, therefore, are quite variable in the area. When responses occur the farmers have several nitrogen management alternatives. Sulfur-coated urea incorporated at planting or split in two applications are equal to split applications of urea or ammonium sulfate both in agronomic and economic terms.

During 1974 a rice was again planted in Taboga, to be followed by an unfertilized sorghum plot in order to evaluate the residual effect of the different nitrogen treatment. The results are not available at the time of writing.

Table 55. Price-cost relationships in Costa Rica during 1973 and 1974.

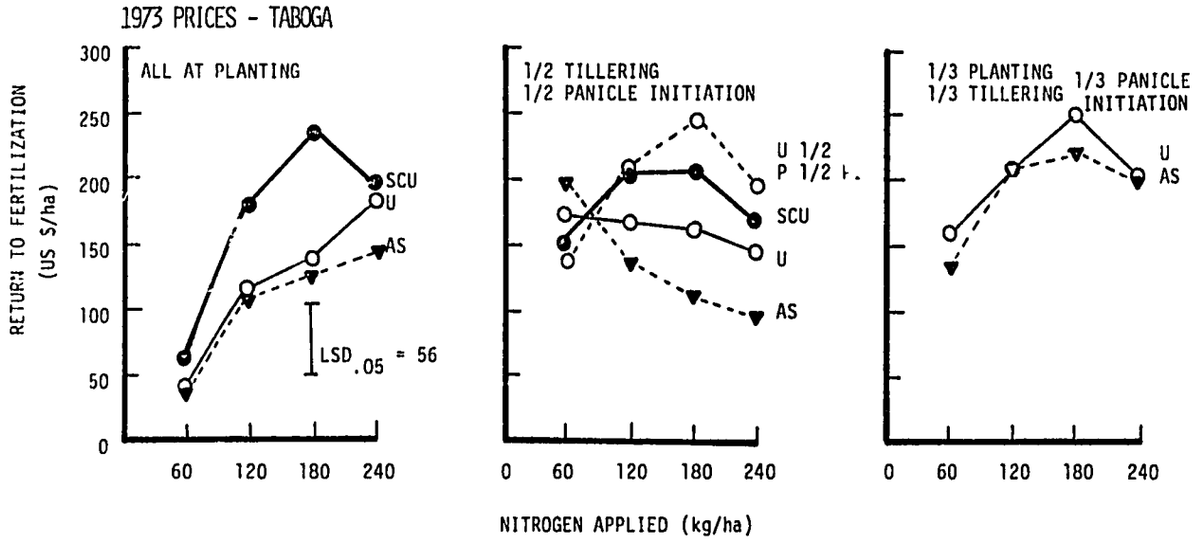
Material	1973	1974
	---------- US$/kg N or ton rice ----------	
Urea	0.22	0.66
SCU*	0.29	0.87
Ammonium sulfate	0.36	0.72
Rough rice	104	176

*Assuming 32% more than urea per kg N.

Table 56. Unit costs of nitrogen applications for upland rice in Costa Rica considering labor and machinery costs.

N Management	1973	1974	Increase
	----- US cents/kg N ----		%
All at planting:			
Urea	22	66	200
SCU	29	87	200
AS	36	72	100
1/2 Planting, 1/2 Panicle Initiation			
Urea	26	70	169
1/2 Tillering, 1/2 Panicle Initiation			
Urea	30	74	145
SCU	41	99	141
AS	48	90	88
1/3 Planting, 1/3 Tillering, 1/3 Panicle Initiation			
Urea	27	71	162
AS	44	84	91
Mean	34	79	133

Includes airplane topdressing cost of U.S.$38 per ton of fertilizer.



*Price of grain yield response - Cost of added nitrogen.

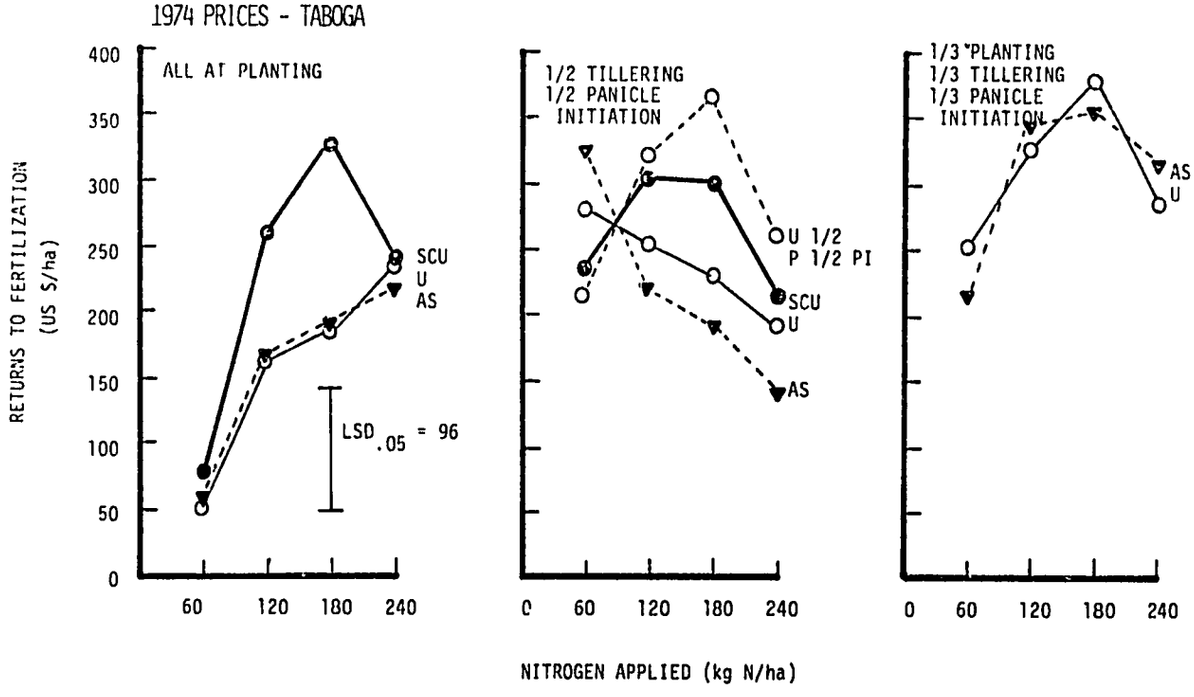


Fig. 52. Gross returns to nitrogen fertilization at 1973 (top) and 1974 (bottom) prices for upland rice in Taboga, Costa Rica.

Table 57. Most profitable nitrogen management combinations for upland rice in Costa Rica.

Source	Timing	Rate	Yield Response	kg rice* / kg N	Return to fertilization 1973	Return to fertilization 1974
		kg N/ha	ton/ha		------- US$/ha --------	
Urea	1/3	180	2.88	9	251	379
Urea	1/2 P	180	2.80	8	244	367
SCU	P	180	2.76	12	235	320
AS	1/3	120	2.54	25	211	346
SCU	1/2	120	2.40	12	202	305
AS	1/2	60	2.14	36	194	323
LSD.05			0.50		56	95

*Last rate increment.

Excellent upland rice can be produced in the Pacific Coast of Costa Rica with a wide variety of nitrogen management practices.

COPPER TOXICITY IN UPLAND RICE

Copper toxicity is a problem for rice production in several Central American countries. The affected sites were once used for banana production, and during that time, the Bordeaux mixture applied for disease control. Sufficient copper was spread on these areas that there now is a toxicity problem for rice production.

In the last report details of soil sampling and procedure for a greenhouse study were given, plus certain results presented. Since that time additional data has been obtained. Results are now presented concerning (1) soil Cu levels as extracted with the North Carolina double acid (0.050 N HCl + 0.025 N H_2SO_4) and (2) the average concentration of elements in rice plants.

The yield of dry matter in relation to the level of double acid extractable Cu for this greenhouse study is shown in Fig. 53. This solution extracted more Cu than the modified Olsen procedure reported last area. The overall relation between plant weight and soil Cu level, however, is very similar from the two methods.

No large consistent differences were found an elemental composition due to soil Cu level. Average concentration of a number of elements in rice plants grown on four soils is presented in Table 58. The main nutritional disorder indicated is the high Cu content. Some high iron and manganese values exist but these are not uncommon. They do indicate, however, that perhaps lime could be applied to reduce Cu uptake and the plants would still not become deficient in Fe or Mn.

The amount of dry matter seems to decrease rapidly if the plant copper is increased above 30 ppm (Fig. 54). This is a rough estimate of a critical toxic concentration of Cu in ice top growth. Undoubtedly there are other parameters that should be included for a more precise interpretation.

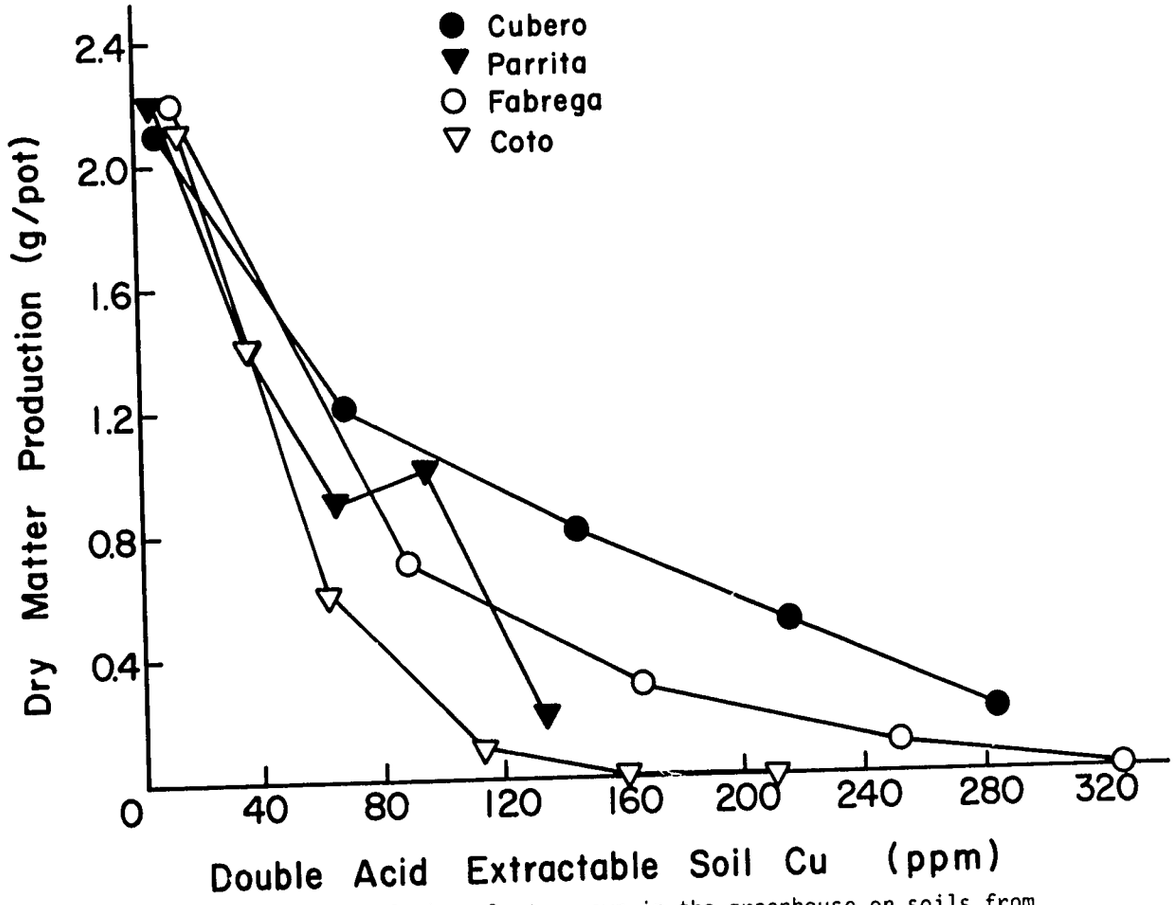


Fig. 53. Weight of rice plants grown in the greenhouse on soils from four locations in Costa Rica in relation to their levels of double acid extractable copper.

Table 58. Average concentration of several elements in rice plants grown on soils from four locations in Costa Rica in a greenhouse study.

Element	Location			
	Cubero	Parrita	Fabrega	Coto
Cu (ppm)	39	31	50	76
Fe (ppm)	126	143	516	651
Zn (ppm)	80	73	91	94
Mn (ppm)	3360	780	3210	680
Ca (%)	0.67	0.85	0.89	1.45
Mg (%)	0.31	0.35	0.33	0.48
K (%)	2.81	2.67	2.80	2.71
P (%)	0.30	0.34	0.39	0.44

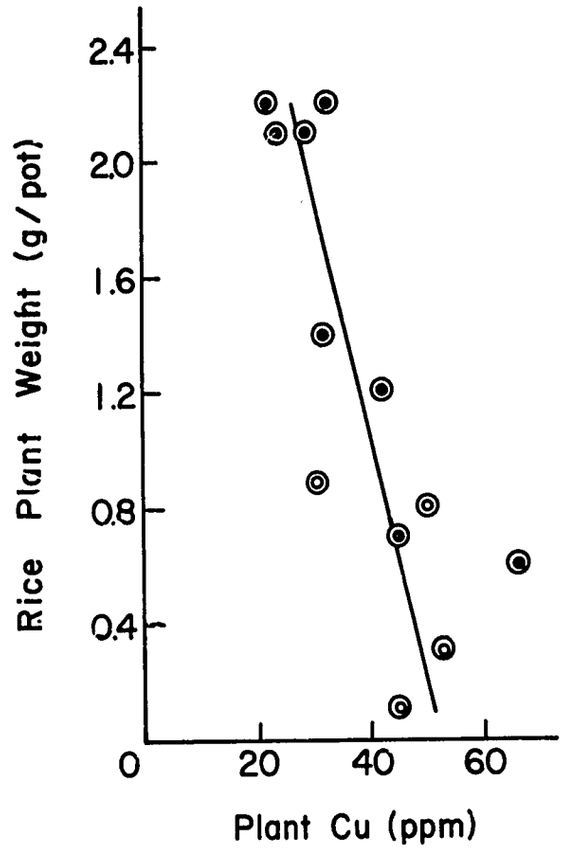
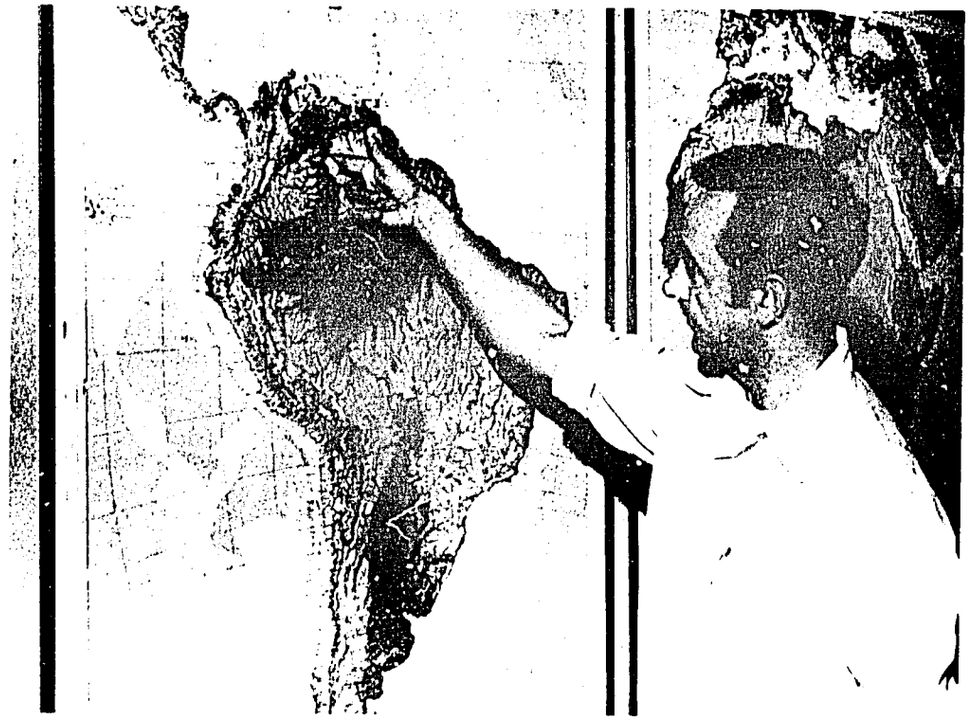


Fig. 54. Weight of rice plants grown in the greenhouse in relation to their copper concentration.

Typical copper toxicity symptoms in upland rice grown in Palmar Sur, Costa Rica. The chlorotic areas are spotty. The symptoms are similar to those of iron chlorosis.

SOIL CHARACTERIZATION AND MICROBIOLOGY



Mr. Leonidas Mejía indicates the location of his soil characertization studies, which provide basic data for future extrapolation studies.

To better understand and aggregate existing soil properties to facilitate extrapolation of research results, detailed soil characterization studies have been continued and expanded during the year. Emphasis was made on soil variability within specific landscapes. Studies were conducted at the Yurimaguas Experiment Station in Peru in western São Paulo State in Brazil, the Llanos Orientales of Colombia, the Maracaibo Basin and Orinoco Basin of Venezuela. Dr. S. W. Buol, Dr. R. B. Daniels, Messers. Edward J. Tyler, Igo F. Lepsch, Leonidas Mejía, Ramón Paredes and Richard Schargel participated in these studies. Mr. Fernando Munevar and Dr. A. G. Wollum completed the study of organic matter mineralization in Andepts of Colombia.

YURIMAGUAS EXPERIMENT STATION IN EASTERN PERU

The completed detailed soil survey map of the Yurimaguas Experiment Station has been put on an air photo base and is shown in Fig. 55. The mapped area consists of 420 hectares of which 145 hectares is recent flood plains and the remainder is dissected upland with a relief of approximately 10m. The detailed map consists of 15 soil mapping units which represent nine soil families according to the U. S. Soil Taxonomy System. There are five families mapped and represented as A, B, C, D, and G which are not correlated with series presently used by ONERN, the Peruvian soil survey agency. Seventeen profiles were described and 117 soil samples were collected for analysis. Chemical, physical and mineralogical analysis has been completed and the data compiled in Mr. Tyler's thesis.*

Soil Associations

A cartographically generalized soil association map of the area was prepared from the detailed map. The map is shown in Fig. 56 and the legend is in Table 59. The two major physiographic regions, flood plain and dissected uplands are divided by a scarp just northwest of the Shanusi river.

Association 1 occupies the Shanusi river's floodplains. All of the soils on the flood plain have higher base saturation and pH values than soils of the dissected uplands. They generally contain up to 15% feldspar in the sand fraction and considerable amounts of the

---

*Tyler, E. J. 1975. Genesis of soils from a mapping area in Yurimaguas, Upper Amazon Jungle of Peru. Ph.D. Thesis, Soil Science Department, North Carolina State University.

Fig. 55. Detailed map of the Yurimaguas Experiment Station.

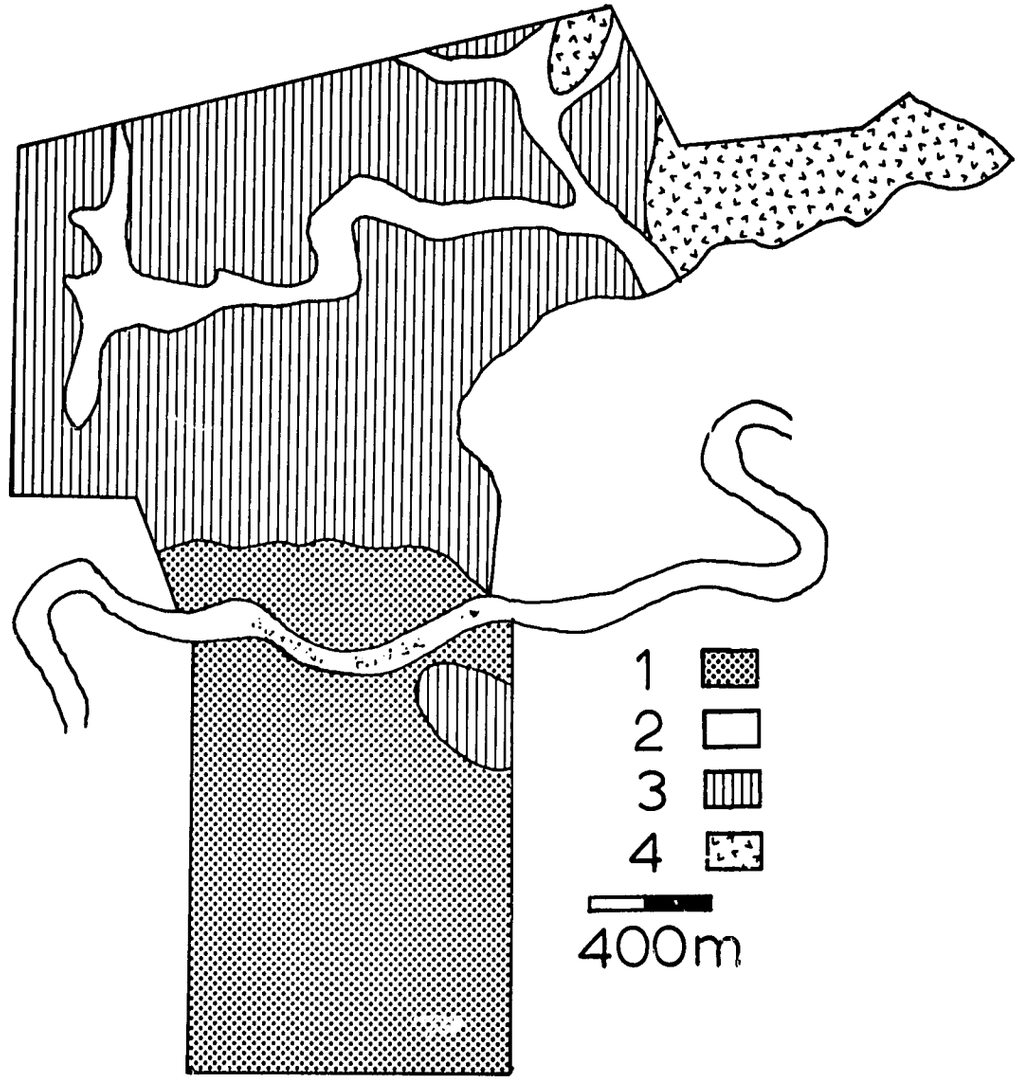


Fig. 56. Soil association map of the Yurimaguas Experiment Station.

Table 59. Map Legend for the soil association map of the Yurimaguas Experiment Station.

Soil Assoc.	Approx. Area	Detailed mapping symbol	Peruvian Soil Series	Soil phase % slope	Classification
1	145 has	Sa	Sanango	0-3	Typic Tropudalf fine loamy, mixed isohyperthermic.
		Ag	Aquajal	0-3	Typic Tropaqualf, fine loamy, mixed isohyperthermic.
		A	Unnamed	0-3	Aquic Dystropept, coarse loamy, mixed isohyperthermic.
		C	Unnamed	0-3	Typic Tropopsamment, mixed, isohyperthermic.
2	40	G	Unnamed	0-3	Typic Tropaquept, clayey, montmorillonitic, isohyperthermic.
3	200	YuA	Yurimaguas	0-3	Typic Paleudult, fine loamy, siliceous, isohyperthermic.
		YuB	Yurimaguas	3-8	Typic Paleudult, fine loamy, siliceous, isohyperthermic.
		YuC	Yurimaguas	8-16	Typic Paleudult, fine loamy, siliceous, isohyperthermic.
		YuD	Yurimaguas	16-35	Typic Paleudult, fine loamy, siliceous, isohyperthermic.
		ShA	Shanusi	0-3	Typic Paleudult, fine loamy, siliceous, isohyperthermic.
		ShC	Shanusi	8-16	Typic Paleudult, fine loamy, siliceous, isohyperthermic.
		D	Unnamed	8-16	Typic Tropaquept, coarse loamy, siliceous, isohyperthermic.
		B	Unnamed	0-3	Typic Tropaquent, coarse loamy, siliceous, isohyperthermic.
4	35	PuA	Pucallpa	0-3	Aquic Paleudult, fine loamy, siliceous, isohyperthermic.
		PuC	Pucallpa	8-16	Aquic Paleudult, fine loamy, siliceous, isohyperthermic.
		YuD	Yurimaguas	16-35	Typic Paleudult, fine loamy, siliceous, isohyperthermic.
		B	Unnamed	0-3	Typic Tropaquent, coarse loamy, siliceous, isohyperthermic.
		G	Unnamed	0-3	Typic Tropaquept, clayey, montmorillonitic, isohyperthermic.

montmorillonitic clay minerals. Soils in this area change greatly in texture from one place to another and range from sands to clays. Similar changes occur with depth in most profiles containing lithologic discontinuities.

The Tropudalfs and Tropaqualfs are the most intensively used soils of the area. The Tropudalfs are located next to the Shanusi river. They have more rapid internal and external drainage than the Tropaqualfs which are located further from the river. The Tropopsamments are excessively drained. The Dystropepts are usually composed of contrasting texture and are often stratified. There are some small oxbow lakes of swamps in this area.

All of these soils have properties which depend on the deposition of materials left by a meandering river system. This accounts for the horizontal and vertical variation in texture of the soils. Pedological processes have resulted in the formation of clay skins in the finer textured soils. Gleying and sesquioxide concentrations are formed in the poorly drained soils.

In the dissected uplands there are three associations, two of which are undulating uplands and the other a valley floor. Soil Association 2 consists predominantly of Tropaquepts but many varied inclusions are found. This association is located in the deep valleys of the dissected uplands. These valleys are wide, nearly flat and contain small but perennial meandering streams. The area is about the same elevation as Association 1. These soils are frequently used for rice and bananas while the stream is used as a water supply and for fish.

Soil Association 3 occupies the largest areal extent on the station and consists of eight mapping units and four taxomonic families. Well-drained Typic Paleudults comprise most of the association. The experimental fields are located on this association. Typic Paleudults are found on all hilltops and most of the side slopes. Coarse loamy families of Tropaquepts are also found on the side slopes and Tropaquents are found in the small drainageways. Except for some side slope positions the soils are very acid and contain mainly quartz, sand kaolinite, smectite. and interstratified clay minerals. This association is generally less dissected than the following one. Soil Association 4 consists of the imperfectly drained Aquic Paleudults on the hilltops slopes. The small drainageways contain Tropaquents. The Aquic Paleudults have finer texture than the Typic Paleudults and contain montmorillonite and interstratified clay minerals causing slow internal soil drainage. The high CEC of the clays and the low pH combine to make subsoil exchangeable aluminum contents very high. There appears to be a lithologic discontinuity in many of these pedons.

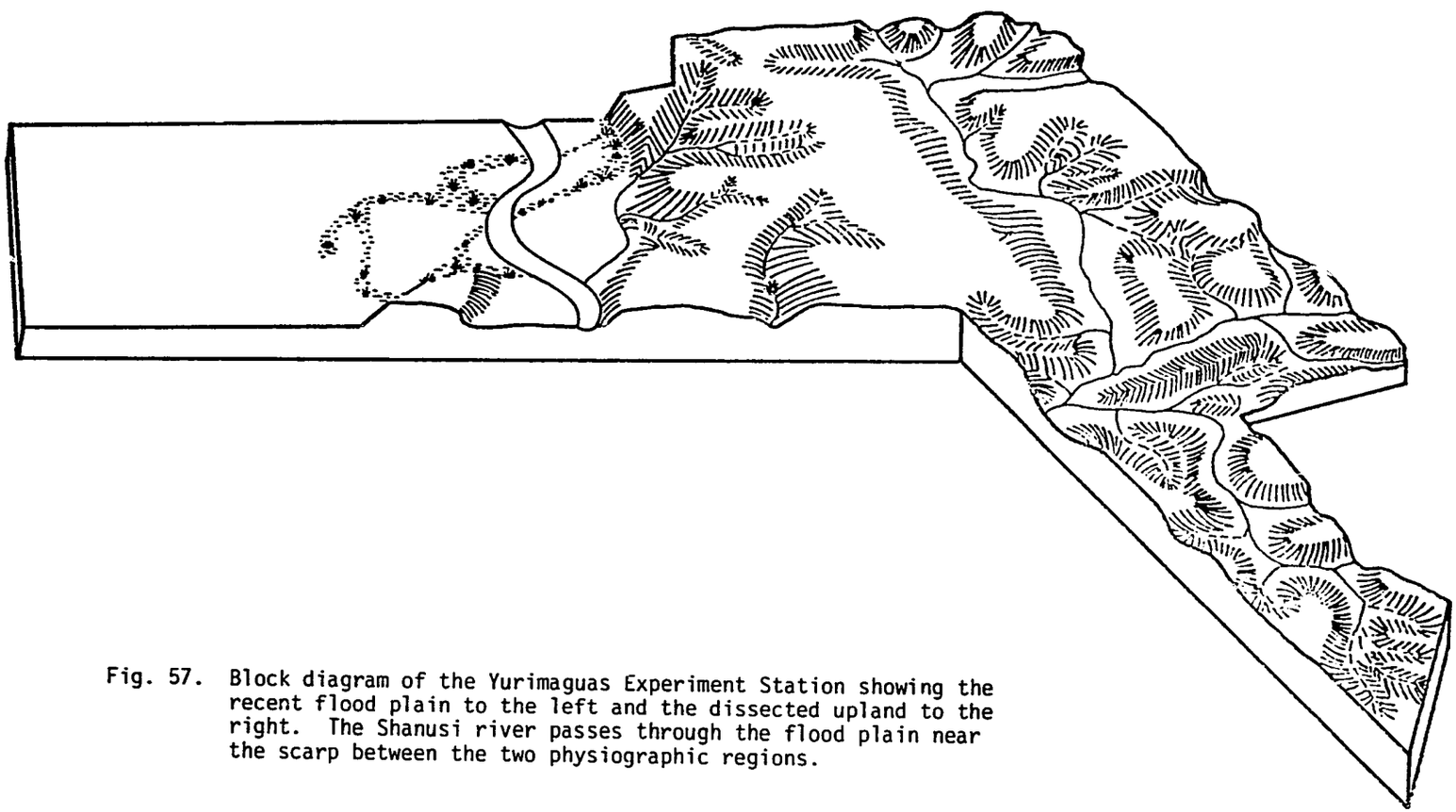


Fig. 57. Block diagram of the Yurimaguas Experiment Station showing the recent flood plain to the left and the dissected upland to the right. The Shanusi river passes through the flood plain near the scarp between the two physiographic regions.

The hilltops throughout Associations 3 and 4 are approximately the same elevation as can be seen in the block diagram (Fig. 57). The soils of Association 4 are finer in texture than those of Association 3. It is impossible to predict which soil will be present from one hill to the next. In profile Y25 (Aquic Paleudult) in Association 4 and in wells of Association 3, lithologic discontinuities have been found.

Genesis Implications

Lithologic discontinuities, stone lines and horizontal textural changes found in the uplands suggest that the parent materials were of fluvial depositional origin and probably very similar to the recent flood plain. Rejuvenation of the river system that deposited the upland materials resulted in dissecting the upland and lowering the water table.

The high rainfall and lush vegetation along with the lower water tables has allowed for removal of bases which were probably present in the initial materials on all hilltops and some side slopes. The pH and base of the hilltops is always low. The existence of ground water closer to the surface on side slopes has caused higher base saturation and pH than is found on the flat tops. This is illustrated in Table 60. The pH and base saturation is particularly high where the side slope cuts a clay lens which causes high amounts of water to move laterally adding bases to the soil. These clay lenses have low internal hydraulic conductivity probably because of the high amounts of montmorillonite clay present.

For the upland soils the clay usually consists of about 40% kaolinite with the remainder consisting of montmorillonite and interstratified minerals. Thus, many soil properties can be closely related to the amount of clay present in the profile. The effective cation exchange capacity and plasticity index used to determine engineering properties both increase as clay content increases and are well correlated (Figs. 58 and 59). This suggests that because of the uniformity of clay minerals of the upland soils on the station that the percent clay can be used as an indicator of soil properties.

Variation of the upland soils seems to be the most closely related to the amount of clay present in the profile. The effective cation exchange capacity increases as the amount of clay increases (Fig. 57). The plasticity index used to determine suitability for engineering purposes also increases with clay content (Fig. 58). This suggests a uniform clay mineralogy for the uplands of the Station and that the percent clay may be a good indicator for predicting soil properties.

Table 60. Mean percent base saturation and pH at 100cm depth for three landscape positions.

Position	No. of Profiles	Mean % Base Saturation	Mean pH
Upland tops	7	3.6	4.2
Side slopes	3	20.6	4.6
Flood plains and valleys	6	45.5	4.9

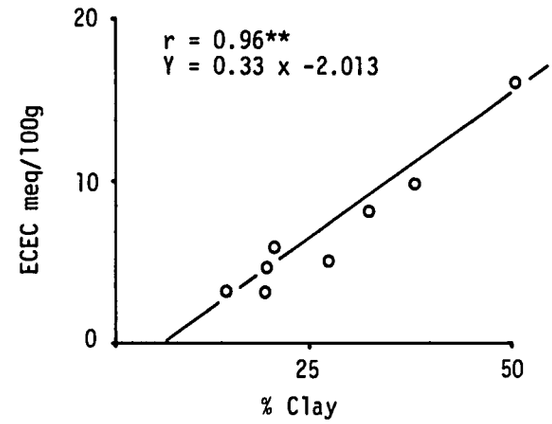


Fig. 58. Relationship between effective cation exchange capacity with percent clay for selected horizons from upland soils Y25, Y17, and Y21.

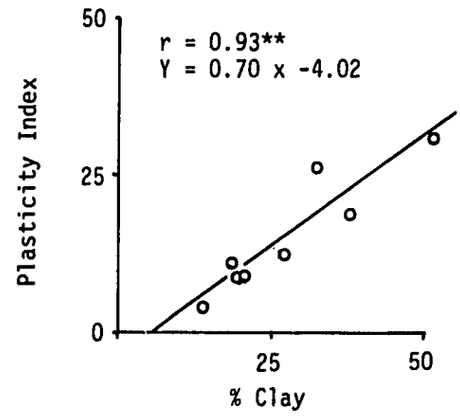


Fig. 59. Relationship of the plasticity index to percent clay for profiles Y25, Y17, Y21, from upland soils.

OCCIDENTAL PLATEAU OF SAO PAULO STATE, BRAZIL[1/]

To determine soil-geomorphic relationships in an Oxisol-dominated soilscape and to relate soil characteristics to high level production management, a study area, comprising 7,084 hectares was located in the Echaporã county, about 320 km northwest from Campinas, São Paulo, Brazil. The area comprises a small plateau surrounded by scarp and gently undulating hills. A block diagram is shown in Fig. 60. The altitude ranges from 500m to 700m above sea level. The climate is subtropical due to altitude. The bedrock is either hard sandstone, sometimes with calcium carbonate cement, or sandy loose surficial deposits. The vegetation ranges from semi-decidous tropical forest to "cerrado." Coffee, corn, upland rice pastures occupy more than half of the area.

The field work comprised detailed geomorphic surface mapping and soil mapping. Both extensive soil mapping unit sampling and detailed soil profile sampling were conducted. A total of 104 sites were sampled with auger, mostly at depth of 0-20cm and 60-80cm. Nine soil profiles were sampled in detail on toposequences. Laboratory characterization of these samples were done both at the Instituto Agronômico de Campinas and North Carolina State University.

Five major geomorphic surfaces were identified and mapped in the area. Fig. 61 shows how they are related on two cross sections: Surface I, the top of a small plateau, is the oldest surface. Surface II is younger than Surface I. Surface IV is younger than Surface III; Surface V, around the scarp and around the creek valleys is the youngest surface in the area. The relative ages between Surface I and III were not easily seen but it seems that Surface III is either the same age as Surface II or immediately younger.

Seven soil mapping units were identified in the area. Their positions on the landscape are shown in Figs. 60 and 61. Soils contrast on many of their characteristics, mainly base saturation and exchangeable acidity. At least four soil orders are found in the area: Oxisols, Ultisols, Alfisols and Mollisols. Some relationships between these soils and the geomorphic surfaces are also shown in Figs. 60 and 61. Generally, the soil pattern follows the

---

[1/]This work is being conducted by Igo F. Lepsch and is mostly financed by the Fundação de Amparo a Pesquisa de Estado de São Paulo and Instituto Agronomico de Campinas. AID funds have been used for travel to the study area by Drs. S. W. Buol and R. B. Daniels.

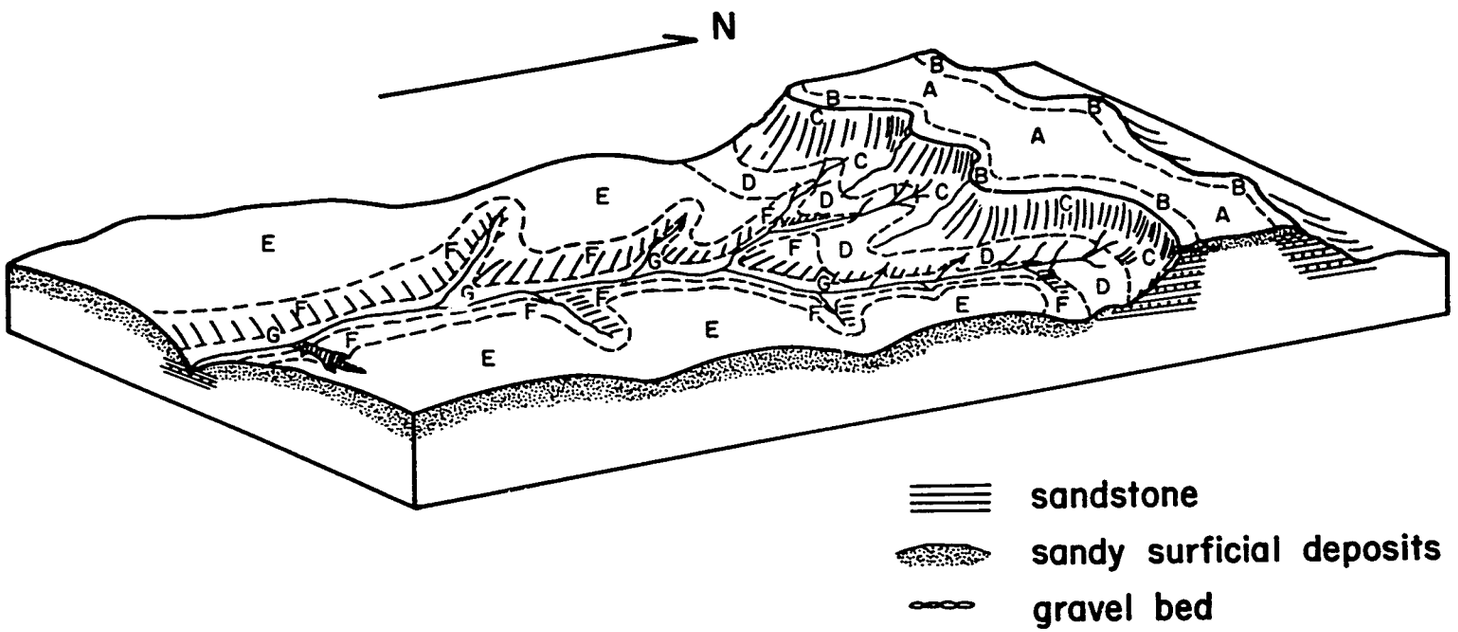


Fig. 60. Block diagram of the study area showing the position of the soil mapping units in relation to landscape features (A and B-Oxisols; D, F and G = Ultisols; B = Alfisols; C = Mollisols.

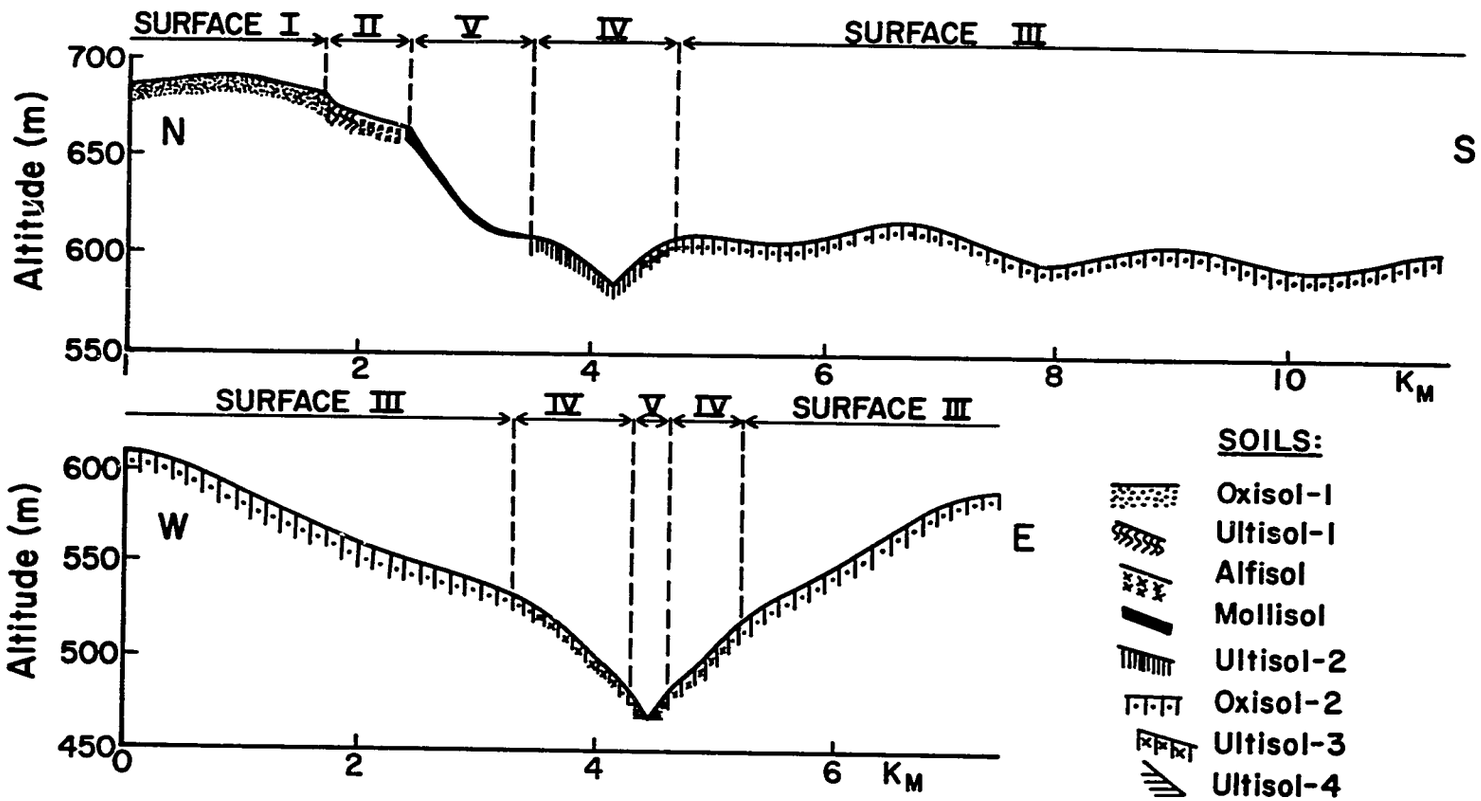


Fig. 61. Cross sections N-S and W-E showing geomorphic surfaces and soil distribution.

geomorphic surface pattern but the boundaries do not necessarily coincide exactly with the boundaries of one geomorphic surface. The relationship showed in the cross section if Fig. 61 always repeats in the area studied. This shows that once soil-geomorphic surface relationships are understood they can be very useful in predicting soil boundaries while doing soil survey.

Data also show that Oxisols occur on the oldest and more level surfaces. Ultisols and Alfisols have developed on the younger side slopes. The Mollisols develop on the steeper, shallow parts of the side slopes were calcareous sandstone is near the surface or up slope.

Further work includes sand and clay mineralogy of selected profiles and statistical correlation between soil map and geomorphic surface map units. The project is planned to be completed by August 1975.

LLANOS ORIENTALES OF COLOMBIA

Mr. Leonidas Mejía completed a large portion of the characterization studies of nine profiles in a 900m transect through a shallow depression ("Esteros") in Carimagua, Colombia. All of the profiles have a slight clay content increase with depth but all topsoil and subsoil textures were silty clay loam or silty clay. The amount of water-dispersible clay was 4% or less in all B horizons. Moisture retention values decreased rapidly between 0.1 bar and 0.3 bar tension and less rapidly between 0.3 bar and 15 bar tension. Percent clay content estimated by (15 bar water percent) x (2.5) was usually less than percent clay determined by pipette analysis. pH values were negative in all horizons, usually by about 1 pH unit. Exchangeable Al contents decreased with depth in all profiles and corresponding base saturation and exchangeable base contents increased are noted with depth. Organic carbon contents were highest in the surface horizons of the poorly drained profiles nearest the "Esteros" reaching over 5%. Well drained profiles contain over 2% organic carbon in surface horizons. C/N ratios were about 20 in surface horizons and decreased with depth. 2:1-2:2 intergrade and kaolinite are the most prevalent minerals in the clay faction. Some gibbsite was detected, but the determination of amorphous material is not yet completed. Quartz is the dominant (90%) fine-sand size mineral. Thin sections have been prepared from samples of the major horizons and are now being studied. Complete presentation of these data are planned in Mr. Mejía's M.S. Thesis in 1975.

MARACAIBO BASIN OF VENEZUELA

Mr. Ramōn Paredes has almost completed chemical and physical characterization of nine profiles representing udic, ustic and aridic moisture regime in the Maracaibo basin of Venezuela. The characterization data is summarized as follows: over 90% exchangeable Al saturation is frequent in soils of the udic moisture regime. Little exchangeable Al is present in the aridic moisture regimes. Organic carbon contents are higher in the udic area and decrease in the ustic and aridic areas respectively. pH values are negative, usually by about 1 pH unit, in all samples. Exchange properties vary little and indicate that all soil materials probably have a similar origin or pre-soil weathering.

Mineralogical and micromorphological studies are in progress and should be completed by mid 1975.

ULTISOLS AND OXISOLS OF VENEZUELA

The physical-chemical properties and weathering trends of eleven soil profiles of Oxisols and Ultisols from Venezuela are being compared with Ultisols from temperate regions by Mr. Richard Schargel.

The profile samples are representative of soils which occupy considerable area in the lowlands of Venezuela. Although presently they are of limited or no use, due to their low natural fertility, they are an important potential resource for agricultural development in the future. Information provided through this research is expected to help in the identification of their utilization and in the transference of technology.

Three profiles are located in the plains (Llanos) belonging to the northern part of the Orinoco basin. They have developed from alluvial sediments derived from the Andes and Coastal mountain ranges. These soils have an ustic moisture regime with rainfall varying between 1200 and 1800mm. Two are under savanna and one under forest vegetation, presently under pasture.

Three profiles are located on the northern edge of the Guayana shield, derived from acid igneous rock materials. These soils presently have an ustic moisture regime with rainfall between 1500 and 2000mm. Two are under savanna and one under forest vegetation.

Five profiles are located in the upper Orinoco basin. Two are derived from basic igneous rocks, one from acid igneous rocks and two from alluvial sediments mostly derived from

acid igneous rocks. These soils have an udic moisture regime with rainfall between 3000 and 4000mm. Similar soils on North Carolina have not yet been selected.

ORGANIC MATTER MINERALIZATION IN ANDEPTS

Volcanic ash soils usually have high contents of organic matter. The rates of organic matter mineralization are lower in volcanic ash soils as compared to other types of soils; consequently, nitrogen is frequently deficient for plant growth in these soils.

Several hypotheses have been suggested to explain the low rates of organic matter mineralization in volcanic ash soils. These include a lack of available carbon for energy and microbial growth and low available phosphorus and inorganic nitrogen. To test these hypotheses the following study was conducted.

Surface horizons of four volcanic ash soils from Colombia were studied: La Ceja (Typic Distrandept), Tibaitatá (Andic Aquic Eutropept), Facatativa (Typic Placandept) and San Jorge (probably a Dystrandept). The chemical analyses of the soils showed that Tibaitatá is the least acid and has a higher effective cation-exchange capacity and base saturation than the other three soils. Mineralogical analysis revealed that the clay fraction of the study soils is dominated by amorphous aluminosilicates. Small amounts of kaolinite are present in the Tibaitatá soil, as well as less amorphous materials than in the other three soils. Tibaitatá soil was found to have a relatively low P fixation capacity whereas the other soils have a very high capacity to fix phosphates.

Incubation studies were conducted under aerobic conditions to evaluate the effect of different C, N, and P treatments on microbial respiration and nitrogen mineralization. The main results and conclusions of the microbiological studies are the following:

Carbon dioxide data showed that soil C mineralization is probably not increased by additions of readily available C to these soils. This is based on the fact that the slopes of the lines from CO_2 evolution from glucose added to 3000 ppm are not significantly different after added C had been respired.

Additions of readily available C to the soils caused either net immobilization of N or a decrease in N mineralization with respect to unamended soils. Representative data are given in Fig. 62. It was concluded that the lack of energy and C for microbial growth does not seem to be limiting factor for organic matter mineralization in volcanic ash soils.

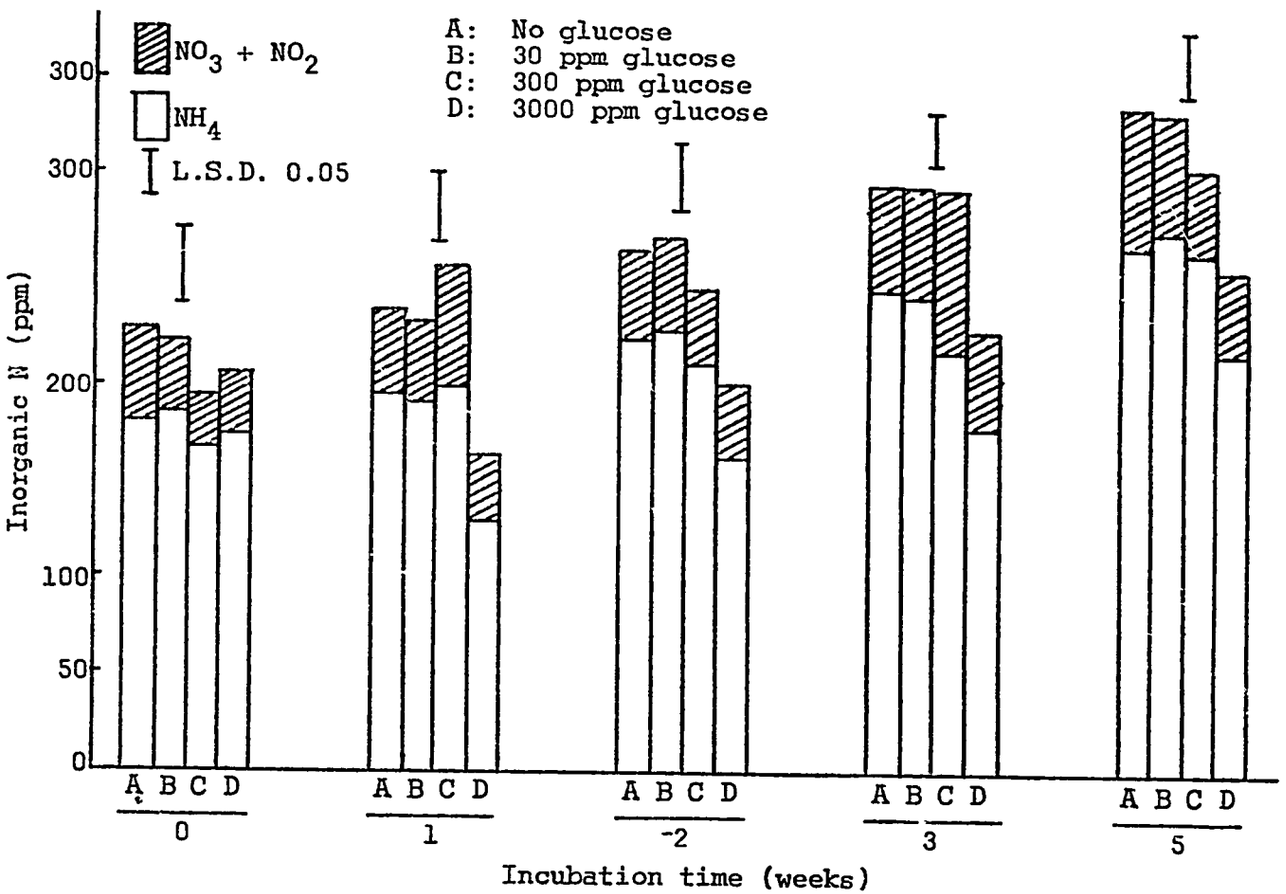


Figure 62. Change in inorganic N content in La Ceja soil after incubation with the indicated rates of glucose

Phosphorus additions from 400 to 2400 ppm P as $Ca(H_2PO_4)\cdot H_2O$ increased the rate of C mineralization and utilization of readily available C added to the soils. The level of P addition that caused the greatest increase in N mineralization was 2400 ppm P (Fig. 63). In soils of volcanic origin P availability for microbial growth probably limits the rate of mineralization of both C and N.

Inorganic N added to one of the soils at the rates of 20, 80 and 200 ppm increased the amount of soil N mineralized and seemed to enhance the effect of P on N mineralization. Readily available C added to the soil decreased N mineralization even when high levels of inorganic N and P had been added (Fig. 62).

A comparison of the effect of $Ca(H_2PO_4)_2\cdot H_2O$, KH_2PO_4 and $CaCl_2\cdot 2H_2O$ on soil C and N mineralization showed that the increase in N mineralization caused by additions of $Ca(H_2PO_4)$. H_2 may be in part the result of the added Ca. Calcium phosphate, KH_2PO_4 and $CaCl_2\cdot 2H_2O$ clearly differed in the way they changed soil pH. Calcium chloride increased the inorganic N content of the soil without increasing microbial respiration; therefore, its effect was thought to be of a nonbiological nature. The effect was accompanied by a drastic decrease in soil pH. Additions of 100, 200, 400, 1200, and 2400 ppm P as KH_2PO_4 increased microbial respiration in two soils differing in amorphous clay content and P fixation capacity. Microbial respiration was increased in a fashion that did not show relation with the P fixation patterns of the soils.

In two instances it was observed that the rate of mineralization of soil C was higher for soils having lower content of amorphous clay minerals than for soils richer in them.

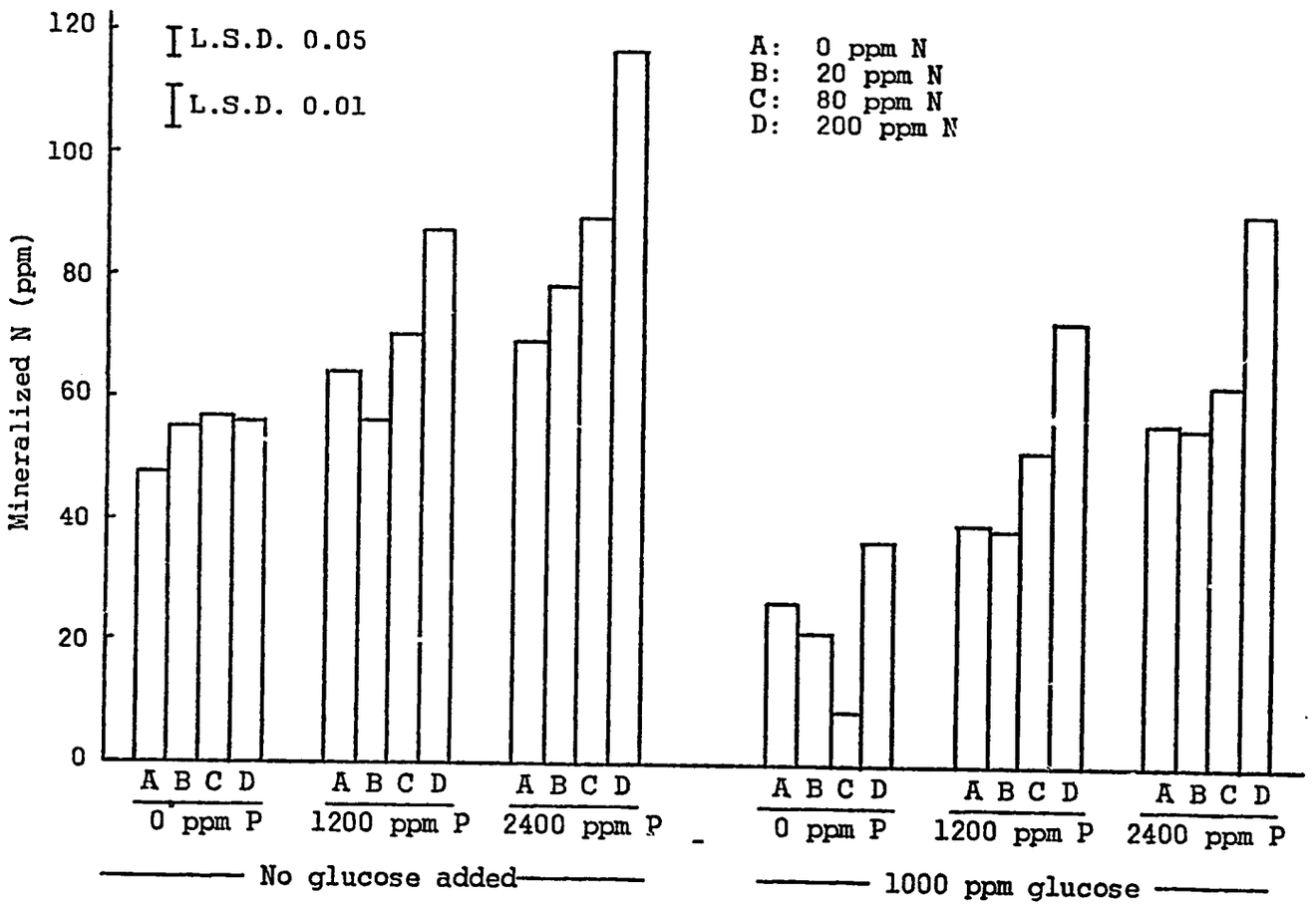
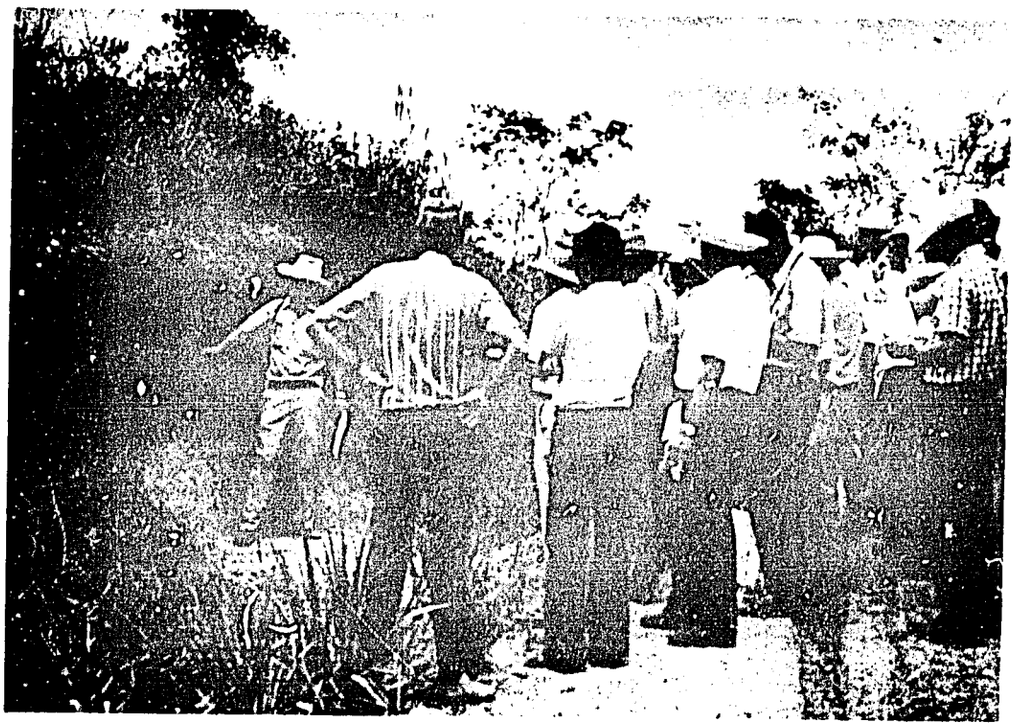


Figure 63. Nitrogen mineralized after incubating San Jorge soil for 30 days with the indicated treatments

FERTILITY CAPABILITY SOIL CLASSIFICATION SYSTEM



Soil profiles, such as this Ultisol from Peru can now be classified according to their fertility characteristics.

The Soil Fertility Capability Classification (FCC) System was first proposed by Dr. S. W. Buol in 1971 as a means for bridging the gap between the subdisciplines of soil fertility and soil survey. The original philosophy was to draw up a classification system that would encompass information having direct effects on soil-plant-fertilizer interrelations. Such a classification would be a technical system designed for the use of fertility specialists. The overall effect would be the aggregation of soil units for fertilizer management purposes by use of criteria that are more meaningful to soil-plant-fertilizer interactions than criteria used in the natural classification system. Such a system would eventually provide a mechanism for facilitating the transfer and extrapolation of fertility research data and fertilizer management practices.

The first comprehensive report on the development of this system was presented at the Seminar on Soil Management and the Development Process in Tropical America held in Cali, Colombia, during February 1974 (Buol et al., 1974). The system employs parameters that research had already proven to have the most direct and effective influence on crop production. Three levels of generalization or categories were established; the type, the substrata type, and the condition modifiers. The type and substrata type are based solely on the texture of the surface and underlying material to a depth of 50cm. Condition modifiers indicate chemical or physical properties, usually within the plow layer, which impose specific fertility limitations. Thirteen condition modifiers are recognized. A specific condition modifier implies that the soil factor is expressed to a degree which still severely restrict management options.

The format was presented and described in the 1973 Annual Report. No changes in parameters or their definitions were considered necessary during this year.

The first evaluation indicated that as a system of soil classification, FCC was elastic enough to encompass any soil chosen from a large geographic spectrum. More interesting was a preliminary economic analysis of a limited data set for potato experiments in the Sierra of Peru conducted by Dr. R. K. Perrin (1973 Annual Report). This analysis suggested that the FCC units, into which the sites classified, not only had their own individuality but the crop response to phosphorus fertilization could have caused a greater gross return over the blanket recommendation had fertilizer recommendations been based on FCC units. A further

economical enhancement could also have been obtained if soil test recommendations were made in conjunction with the FCC units.

These results encouraged further testing of the system. Dr. M. A. Granger and Mr. R. A. Pope were responsible for this task. To do this, reliance was placed on the use of the vast amounts of fertilizer trial data already in existence in various parts of the world. Access to such data was first obtained in Brazil through the auspices of the cooperative FAO/ANDA/ABCAR program conducted as a joint effort of the Food and Agriculture Organization of the United Nations, the Associação Nacional para Difusão de Adubos and the Associação Brasileira de Crédito e Asistencia Rural.

The data set consists of 4110 fertilizer experiments conducted on a wide variety of crops from 1969 to 1973. Experimental plots were adjacent to cooperating farmer's field in the Cerrado region of Goiás and Minas Gerais States. After analysis and on-site evaluation most of the sites were eliminated because of extremely wide yield fluctuations which could not be attributed to fertilized response. A total of 532 sites were selected for final use. They included 248 experiments on upland rice, 205 on corn, 45 on field beans, 31 on cotton and 13 on potatoes.

The experimental design was usually nine treatments:

0-0-0	2-1-1	1-1-0
0-1-1	1-0-1	1-1-2
1-1-1	1-2-1	1-1-1 + lime

Unit applications of N, P_2O_5, and K_2O in kg/ha were 45-45-40 for corn and 30-45-30 for upland rice. The standard lime treatment was 1 ton/ha.

The soils are classified in the Brazilian system as Red-Yellow Latosols and Dark-Red Latosols which roughly correspond to the Haplustox and Acrustox great groups of the Soil Taxonomy. The climate is characterized by a five to seven month dry season. The "d" condition modifier applied to all the soils in the area. This modifier has been omitted from consideration in further data analysis within the set. The data was used to 1) Classify the soils in which fertilizer response data was generated into FCC units, 2) Examine the behavior of the FCC units under different cropping environments.

SITE CLASSIFICATION OF BRAZILIAN EXPERIMENTS

Dr. Granger then travelled to Brazil and classified each site by direct observation, soil sampling, or from existing data when such data was available. This was conducted in close cooperation with FAO/ANDA/ABCAR and EMBRAPA staff. The results appear in Tables 61 and 62. Clayey soils "C" and loamy-over clayey "LC" were the most common. They accounted for 65% and 35% of the total population respectively. The only other type substrata type combination found was sandy over loamy "SL" and this accounted for less than 0.5% (Table 61).

Only six condition modifiers were identified. These were "e" (low cation exchange capacity, "a" (aluminum toxic), "h" (acid), "i" (iron-fixing P), "k" (K deficienty), and "d" (dry season) of which "d" was a universal modifier. Modifiers "e", "i", and "k" occurred alone or in combination in 58%, 54% and 51% of the sites respectively. The modifier "a" occurred in 40% of the sites either alone or in combination with others while very few of the sites (11%) bore the "h" modifier. Only 9% of the sites had no condition modifiers. Thus, many of the experimental sites had low cation exchange capacities in their surface horizon, suggesting the need for low but frequent applications of fertilizers. Many had sufficiently red surface color to warrant the "i" modifier indicative of phosphorus fixation by iron components. Aluminum toxicity and potassium deficiencies are also fertility problems associated and indicated in these soils.

Some 50 fertility capability units were identified but only twelve accounted for as much as 64% of the total population. These twelve units are shown in Table 62 as the most common fertility capability units.

BEHAVIOR OF FCC UNITS AT DIFFERENT YIELD LEVELS

The manipulation of the 542 fertilizer response experiments was accomplished by the Linear Response and Plateau (LRP) model developed by Waugh, Cate and Nelson. The absolute yield without fertilizers (0-0-0) was designated as the "check" yield. The <u>intercept</u> yields are the average of the threshold yields obtained at the zero level of each nutrient (0-1-0, 1-0-1 and 1-1-0). The <u>plateau</u> yield is the maximum yield obtained in the flat part of the response curve. It is the average of the individual N, P and K plateau yields. Thus, the check intercept and plateau yields refer to three general levels of fertility.

Table 61. Type-modifier combinations in the experimental sites.

Condition Modifier Combinations	Type-Substrata Type			
	C	LC	Sl	Total
	No. of experimental sites			
none	223	153	0	376
e	48	66	0	114
ea	93	62	0	155
eh	16	29	0	45
ei	185	16	0	201
ek	147	82	7	236
eak	263	217	12	492
eai	155	69	0	224
ehk	41	68	0	109
eik	104	62	0	166
ehi	14	12	0	26
ehik	17	52	0	69
eaik	360	180	0	540
aik	46	14	0	60
ai	50	8	0	58
ak	19	27	0	46
a	47	38	0	85
h	32	48	0	80
hi	56	8	0	64
hk	12	16	0	28
hik	16	8	0	24
ik	147	44	0	191
i	505	76	0	581
k	56	84	0	140
Total	2652	1439	19	4110

Table 62. Most common Fertility-Capability units found.

FCC	Frequency and Distribution	
	No.	%
Ci	505	12
Ceaik	360	8
Ceak	263	6
C	223	5
LCeak	217	5
Cei	185	5
LCeaik	180	4
Ceai	155	4
LC	153	4
Cek	147	4
Cik	147	4
Ceik	104	3
TOTAL	2639	64%

Table 63 summarized the yield differences between individual FCC parameters by crop. For example, the notation: C > LC indicates that the check yields of cotton were 47% higher in clayey soils (C) than in loamy-over clayey soils (LC). Table 63 shows that yields of all crops were much higher on the "C" (clayey) soils than on "LC" (loamy-over clayey) or on "SL" (sandy-over loamy) soils. In the case of potatoes no comparison was possible because all experiments classified as LC. The type substrata type classes, therefore, separated effectively yield and yield response differences.

Evaluation of the modifiers encountered whether alone or in combination did not result in as distinct a separation as did the type and substratatype separation. Table 63 compares the yield differences in these soils which have the modifier (1) and those which do not (0).

Assessment of the individual "e" modifier came closest to predictability. Its significance as a limiting factor in terms of crop growth diminished quite readily with the availability of adequate plant nutrients. Though its use in the system is primarily an indicator to the frequency of application of cationic nutrients it was assessed as another limiting factor. Table 63 indicates the diminishing significance at higher levels of fertilizer application (plateau yield level) and only rarely (in upland rice) was there no difference in yield between soils with and without this modifier. In all other cases the absence of the "e" modified on a soil invariably resulted in higher yields. Thus, these results may be construed as an indication that the "e" modifier is not only a justifiable parameter but also a valid one.

Table 63 shows a comparison in the behavior of different crops grown on soils with and without the "a" moidifer. Crops very sensitive to aluminum toxicity such as cotton were most severely affected and the results show that the lack of aluminum toxicity resulted in as much as 70% higher yield than the presence of aluminum toxicity as defined by the "a" modifier. Rice, beans, and corn, however, did not always show adverse effects to the presence of aluminum toxicity. This is perhaps due to their relatively higher aluminum tolerance and considerable varietal difference. Potatoes showed small positive and negative responses to aluminum toxicity. It is well known that potatoes are substantially tolerant to aluminum and even respond positively to small increments of aluminum in soil solution. The "a" modifier seems a valid parameter for crop susceptible to aluminum toxicity. Its limits should be refined in terms of individual crop or varietal tolerance expressed as percent Al saturation.

Table 63. Effects of individual FCC parameter on check, intercept and plateau yields by crop. Numbers indicate the % yields difference between the two parameters.

Crop	Yield levels	Type-Substrata type	Modifiers (0 = absent, 1 = present) e	a	i	k
COTTON	Check	C > LC	0>1	0>1	0<1	0>1
		47%	16%	70%	4%	46%
	Intercept	C > LC	0>1	0>1	0>1	0>1
		35%	17%	68%	2%	52%
	Plateau	C > LC	0>1	0>1	0<1	0>1
		39%	12%	62%	5%	47%
UPLAND RICE	Check	C > LC > SL	0>1	0>1	0>1	0>1
		8%; 77%	24%	26%	40%	10%
	Intercept	C > LC > SL	0>1	0>1	0<1	0<1
		10%; 36%	16%	6%	21%	3%
	Plateau	C > LC > SL	0=1	0>1	0<1	0<1
		9%; 33%	0%	10%	7%	7%
POTATOES	Check	LC	0>1	0<1	0>1	0>1
			71%	4%	81%	39%
	Intercept	LC	0>1	0>1	0>1	0>1
			37%	13%	46%	4%
	Plateau	LC	0>1	0<1	0>1	0<1
			36%	2%	41%	5%

Table 63. (Continued)

Crop	Yield levels	Type Substrata type	Modifiers (0 = absent, 1 = present) e	a	i	k
BEANS	Check	C > LC	0>1	0>1	0<1	0>1
		33%	27%	16%	20%	17%
	Intercept	C > LC	0>1	0<1	0<1	0<1
		35%	19%	8%	32%	15%
	Plateau	C > LC	0>1	0<1	0<1	0<1
		33%	6%	11%	28%	20%
CORN	Check	C > LC	0>1	0>1	0>1	0>1
		1%	14%	11%	14%	13%
	Intercept	C > LC	0>1	0=1	0>1	0>1
		7%	12%	0%	17%	7%
	Plateau	C > LC	0>1	0<1	0>1	0>1
		1%	6%	5%	20%	15%

The "h" modifier has been defined as an intergrade between "a" and none. Thus, the absence of an "h" modifier in an FCC unit implies that the soil has either no limiting acidity or it has enough to warrant an "a" modifier. Evaluation of the "h" modifier by this analysis was not possible.

The "i" modifier with its connotation of problems associated with high P-fixation by iron did not behave as consistently as envisoned. In fact the predicted behavior was realized only in the potato and corn experiments for all levels of fertilizers (Table 63). Even so it should be understood that the presence of "a" as an additional modifier might also serve to complicate the analysis of crop response to this individual modifier.

Another parameter that did not behave as expected was the "k" modifier. For every crop the unfertilized plots not designated by the "k" modifier gave higher yields than those with the notation. At the intercept and/or plateau levels of upland rice, potatoes and beans, the relationship does not hold.

This cursory analysis of grouping yields by FCC categories shows the effectiveness of the type-subtype, the "e" and "a" modifiers in separating soils. They also show the need for improvement in the "i" and "k" modifiers.

Dr. Granger noted several factors in the data set which limit the use of these data for statistical evaluation of FCC--fertility response relationships. Site care was often inadequate; damage by animals, disease and other pests often occurred, but was not noted. Severe drought occurred in some areas in 1970, but is not noted in the data. In addition, there is no replication at a site during a given year; often a site was used in only one year out of three. The lack of this information precludes assessment of what must have been a large error component.

Previous work on the FCC system (1973 Annual Report) has demonstrated well defined, statistically significant relationships between FCC parameters and fertilizer response. These results were made possible by the high quality of the experimental work from which the data were derived. Response data of this quality will be difficult to obtain for a large enough number of sites to provide a complete evaluation of the FCC system by standard statistical approaches. Evaluation of the system cannot, however, be accomplished without considering a wide spectrum of soils. This will make it necessary to use less desirable data for at least part of the assessment. In those cases when uncontrolled variables contributed heavily to

variability, the presence of trends like those in the Brasilian data must be given more weight than in the more conventional work.

Economic Evaluation of the Fertility Capability Classification System

There are two questions of interest with respect to evaluation of the FCC for management decisions. The first is whether the resulting soil classes allow one to develop more profitable recommendations that would an alternative set of classes, or perhaps no classes at all. The second question is whether the individual soil variables involved have a significant effect on crop response to fertilizers. Answers to the latter question can lead to improvements in the construction of classification systems.

Ultimately the best evaluation of the above questions can be provided by the profit-prediction criterion, but this analysis is not yet complete. However, the results of regression analysis of the FCC and its variables provided useful insights complementing those reported in the preceeding section. Two rather elementary regression models were applied to the Brazilian corn data discussed in the preceeding section. The data from all experimental plots were pooled. Yields were first regressed on FCC type and modifier variables as dummy variables, plus applied nutrient variables and interaction variables between FCC variables and applied nutrients. In the second model, yields were regressed on continuous variables corresponding to the factors determining the FCC modifier variables when possible. For instance, instead of the variable "e" (which is equal to one for soils with CEC 4 meq/100g, and equal to zero otherwise) we regress yields directly upon CEC.

The results of these regression analyses are summarized in Table 64, and as will become clear, they are generally consistent with the results previously presented. With respect to the effect of the variables on fertilizer response, simple analysis of means revealed little. The regression analysis shows, however, that of the classification variables, only "a" (aluminum toxic or, its continuous proxy, Al saturation) had a significant effect in reducing the response of corn to nitrogen and phosphate. Also, the continuous variable (soil test K) had a significant but negligible negative effect on potash response. The remaining effects were not statistically significant. These results indicate that for these data, only aluminum content is significantly correlated with fertilizer response. Application of the profit predictability criterion will yield further evidence on this point. The Brasilian soils were in

Table 64. Regression analysis of the effect of FCCS classification variables and proxy variables on corn yields and response to fertilizer in Brazil.

Soil variable	Check yield	Response per kg of: N	P_2O_5	K_2O	Check yield effect of: Type	a	h	i	k	CEC	Al Satn.	i	soil test K
	kilograms of grain per hectare												
Soil Class Variables:													
FCC Type C vs LC	-814*	+4.0	b	-4.4	+990**	-308	b	+1063**	+ 93				
FCC Modifiers: e	-473*	-3.0	0.0	+3.5		-501*	b	-253	-166				
a	+730**	-88*	+5.3	b			b	-645	+320*				
h	-126	4.6	-10.3	b				b	b				
i	-634**	b	1.6	b					+ 44				
k	-256	b	b	+3.5									
Proxy variables:													
Clay (vs loam) texture	+524**	-1.1	b	-0.7						-1784**	+257**	+715**	+12**
CEC (per meq/100g)	-269	+0.4	-1.0	-3.7							- 12	b	b
Al (per 1% Al saturation)	-26**	-14.0**	+10.0*	b								- 33	3**
i (FCC modifier)	-395*	b	+4.5	b									b
Soil test K (ppm K in soil)	-17**	b	b	-0.06*									

b/ Not estimated

*, ** - Significantly different from zero at the 20% and 5% levels of significance, respectively.

in general not very responsive to fertilizer and these results may not hold true for more responsive soils.

The second question posed above is whether the soils should be grouped into FCC classes for analysis or whether they should be pooled for fertilizer management decisions. One method of pooling the soils is to estimate a generalized response function, so that the optimum amount of fertilizer can be determined as a function of soil test variables. The regression on proxy variables (reported in the lower half of Table 64) is such an equation. This second equation explained about as much yield variation as did the first, with a similar number of significant coefficients, suggesting that pooling of all FCC classes may be satisfactory for management decisions. This issue can best be determined with the profit prediction criterion.

Other results of interest are provided by the regression analysis. With few exceptions, the estimated effects of classification variables on check yields support the results of means comparisons presented in the previous section. In addition the interaction effects (reported in the right-hand columns of Table 64) agree in sign with the earlier-reported results. The only results which appear unusual are the effects of C vs. LC soils and the interaction of this factor with "e". The clay soils alone are estimated to yield 814 kg/ha less grain than LC soils. However, in conjunction with "e", yields are estimated to decrease by another 473 kg/ha, plus the interaction effect of 990 kg/ha, for a net difference of 300 kg/ha of LCe soils over Ce soils. This large negative effect of C alone was not apparent in the means comparison, nor was it borne out by the second regression reported in Table 64.

In summary, the regression analyses provide some statistical evaluation of the usefulness of the FCC and related variables. These results suggest that only aluminum saturation is significantly related to fertilizer response in this data set and that pooling of all soil classes might be as effective for fertilizer management as the FCC breakdown. Most of the FCC classification variables, however, were shown to be significantly related to check yields.

The magnitude of the uncontrolled variables in the data used could be considered as intolerable for research but realistic of farmer fields. The consistent response frequency trends between FCC groups suggest that this technique has promise as a tool to evaluate the usefulness of management practices in non research, farmer field settings.

COMMUNICATION OF RESULTS

A group of soil scientists from several countries are briefed on research in progress at the Amazon Jungle Station in Yurimaguas.

The effectiveness of this research program should be measured by the generation of information not previously available to soil scientists and policy-makers in developing countries. As this information becomes available the ultimate effect will be measured when farmers adopt the new recommended practices.

The program's philosophy is to disseminate its results as quickly as possible to an audience of working soil scientists and administrators. Dissemination has been accomplished through 1) Technical publications, including the Annual Reports, 2) Mailing of such publications in the appropriate language to the desired audience 3) Presentation of the results during scientific and policy-making meetings upon invitation from developing country authorities 4) On-site demonstrations to scientists. Efforts in this direction expanded in 1974.

In addition, a description of the research program in general terms was prepared by the U. S. Information Agency. Newspaper articles have appeared in the leading national newspapers of several Latin American countries. Specific newspaper articles about research results have appeared in Peruvian and Brazilian newspapers.

PUBLICATIONS

The following articles were published by the project staff in scientific journals, books or as theses:

Lepsch, I. F. and S. W. Buol, 1974. Investigations in an Oxisol-Ultisol toposequence in São Paulo State, Brazil, Soil Sci. Soc. Amer. Proc. 38(3):491-496.

Lopes, A. S. 1975. A survey of the fertility status of soils under "Cerrado" vegetation in Brazil. M. S. Thesis, North Carolina State University, 138 pp.

Oelsligle, D. D. 1975. Accumulation of dry matter, nitrogen, phosphorus and potassium in cassava (Manihot esculenta Crantz). Turrialba 25:85-87.

Sanchez, P. A., C. E. Seubert, E. J. Tyler, C. Valverde, C. E. Lopez, M. A. Nureña, and M. K. Wade. 1974. Investigaciones en manejo de suelos tropicales en Yurimaguas, Selva Baja del Perú, pp. II-B-1-II-B-37. En: IICA: Reunión Internacional sobre sistemas de Producción para el Trópico Americano (Sistemas de Uso de la Tierra). Instituto Interamericano de Ciencias Agrícolas, Lima, Perú.

Sanchez, P. A., S. W. Buol. 1974. Properties of some soils of the Upper Amazon Basin of Perú. Soil Sci. Soc. Amer. Proc. 38:117-121.

The following manuscripts have been accepted for publication in the indicated conference proceedings.

Buol, S. W., P. A. Sanchez, R. B. Cate, Jr., and M. A. Granger. Soil Fertility-Capability Classification: A technical classification for fertility management. Seminar on Soil Management and the Development Process in Tropical America, CIAT, Cali, Colombia (In English and Spanish), Mimeographed, 24 pp.

Salinas, J. G. and P. A. Sanchez. Conceitos atuais sôbre as relações solo-planta en relação a toleranza a baixa disponibilidade de fósforo. Presented at the Symposium on Breeding Plants for Tolerance to Toxic Aluminum and Manganese in Soils, Sociedade Brasileira de Genetica, Recife, Brasil (In Portuguese and English), Mimeographed, 36 pp.

Soares, W. V., E. Lobato, E. Gonzalez and G. C. Naderman, Jr. Liming of soils associated with the Brazilian Cerrado. Seminar on Soil Management and the Development Process in Tropical America, CIAT, Cali, Colombia (In English and Spanish), Mimeographed, 37 pp.

The following reports were prepared at the request of cooperating country institutions for their use:

Sanchez, P. A., A. S. Lopes e S. W. Buol. 1974. Centro de Pesquisas dos Cerrados-Projeto preliminar sugestão (Cerrado Research Center-Preliminary proposal). Prepared for EMBRAPA, 64 pp.

Tyler, E. J. y S. W. Buol. 1974. Propiedades de los suelos de Yurimaguas en relación a las alternativas de localización del futuro aeropuerto internacional. Prepared for the Peruvian Ministry of Agriculture, 8 pp.

MAILING LIST

All publications continue to be sent free of charge to whoever requests to have his name included in the mailing list. At the time of writing a total of 491 individuals and institutions were receiving this service. Of these 251 are from Latin america, 103 from the United States, 29 from Asia, 27 from Africa, 21 from Europe and 60 on campus.

CONFERENCES AND SYMPOSIA

Much of the communications process is accomplished by participating in scientific and policy-making meetings. Program staff members were invited to participate in a series of key conferences in various countries in 1974. A short description of these activities follows.

Feb. 14-20, Cali, Colombia: Seminar on Soil Management and the Development Process in Tropical America. Several members of this research contract and colleagues from cooperating institutions participated in this regional seminar organized by the University Consortium on Soils of the Tropics, AID, CIAT, the Colombian and the Latin American Societies of Soil Science. These included Drs. McCants, Sanchez, Oelsligle, Naderman, Wolf and Granger. Three written papers based on these program results were presented on fertility-capability classification, soil moisture studies in Puerto Rico and Brazil and liming of soils associated with Brazilian Cerrado.

The post-Seminar tour carried an average of 40 leading soil scientists from different countries of Latin America, Asia, Africa, Europe and the United States to the Yurimaguas and Brasília experiment stations. The ongoing work was presented by Dr. P. A. Sanchez, Ing. M. A. Nureña, Mr. C. E. Lopez and Mr. M. K. Wade in Yurimaguas and by Drs. G. C. Naderman, W. Goedert, Mssrs. W. V. Soares, M. N. Camargo, J. M. Wolf, E. Gonzalez and R. S. Yost in Brasília. This provided an opportunity for these scientists to have first hand contact with our experimental objectives and results.

Feb. 25-27, Turrialba, Costa Rica: Conferencia sobre Sistemas de Producción Agrícola para el Trópico (Conference on Tropical Agricultural Production Systems). This conference organized by our host institution CATIE, had the objective of discussing the formation of a Central American cropping systems research program. Dr. Sanchez chaired the section of agronomic aspects and drafted the recommendations on this subject. Dr. Oelsligle presented some of his field results and actively participated in the discussions. The eventual outcome of this conference was the awarding of the Cropping Systems Research Contract to CATIE by AID/ROCAP.

June 10-15, Lima, Peru: Reunión Internacional sobre Sistemas de Producción para el Trópico Americano (International Meeting on Production Systems for the American Tropics). This IICA-sponsored meeting brought together an interdisciplinary team of scientists and development officials from the six Amazon countries (Bolivia, Brazil, Colombia, Ecuador, Peru and

Venezuela) to discuss the development of the region. The results of the Yurimaguas project were presented in Spanish to an audience of scientists and policy-makers from the Amazon Jungle region by Dr. Sanchez.

July 10-17, Recife, Brazil: Simpósio sobre Melhoramento de Plantas para Resistença a Condições Noçivos de Alumínio e Manganês no Solo (Symposium on Breeding for Varietal Tolerances to Toxic Soil Aluminum and Manganese). Two papers were presented by the project staff at this symposium which was co-sponsored by the Brazilian Genetics Society and the Brazilian Association for the Advancement of Science. Dr. Naderman presented the results of the liming and moisture studies, and Dr. Sanchez presented the review of soil-plant relations affecting tolerances to low soil phosphorus availability.

July 17-18, Campina Grande, Paraíba, Brazil: Intensive Short Course on Research with Meteorological Data and Utilization of Water Resources. Dr. Naderman gave two 90 minute presentations of the principal concepts and methodology involved in the fertility-moisture research orientation of the Brasília project in Portuguese to 25 participants of this short course sponsored by EMBRAPA, Utah State University and other institutions concerned with the development of the Northeast Brazil.

July 22-24, Lima, Peru: Primer Congreso Nacional de la Ciencia del Suelo (First National Soil Science Congress). Dr. Sanchez was one of the keynote speakers in this meeting with the topic "Management of Tropical Soils." The Spanish version of the 1973 Annual Report of the Amazon Jungle was distributed. Mr. C. E. Lopez was co-chairman of the Jungle soils section.

Sept. 18 and 25, Brasilia, Brazil: Conceitos Críticos sobre Fertilidade e Agua para Agricultura en Areas do Cerrado (Critical concepts Regarding Fertility and Water for Agriculture in areas of Cerrado). This consisted of two lectures in Portuguese by Dr. Naderman to an Agronomy class at the University of Brasília.

Oct. 21, Brasília, Brazil: Pesquisa sobre Solo e Nutrição de Plantas para Agricultura no Cerrado (Research on soils and plant nutrition for agriculture in the cerrado). This lecture was given in Portuguese by Dr. Naderman. This was one of ten presentations in a series of conferences on recent developments in crop and soil technology sponsored by the University of Brasília. About 100 persons attended.

November 10-15, Chicago, Illinois: American Society of Agronomy Annual Meetings. The following papers were presented by the project staff. The abstracts are published in the

1974 issue of "Agronomy Abstracts."

1. "Nitrogen management of rice in Costa Rica." A. Cordero, D. D. Oelsligle, A. Romero, L. D. Lara and P. A. Sanchez.

2. "Combining corn and soybeans for increased food production in the tropics" by A. M. Pinchinat and D. D. Oelsligle.

3. "Fertilization of forage sorghum in El Salvador" by D. D. Oelsligle, J. Dimas, E. de la Peña and G. Greibel.

4. "Effects of the addition of readily available carbon, phosphorus and inorganic nitrogen on the mineralization of nitrogen in some Andepts of Colombia" by F. Munevar and A. G. Wollum II.

5. "Effects of land clearing methods on crop performance and changes in soil properties in an Ultisol of the Amazon Jungle of Peru" by C. E. Seubert and P. A. Sanchez.

6. "Management research on Peruvian Amazon soils utilizing Sechura rock phosphate" by C. Valverde.

7. "Rates and depth of incorporation of limestone to correct aluminum toxicity in an Oxisol of Central Brazil" by E. Gonzalez, E. J. Kamprath, G. C. Naderman, Jr. and W. V. Soares.

8. "Adverse soil-water conditions and corn production in Central Brazil" by J. M. Wolf, G. Levine, G. C. Naderman, Jr. and E. Gonzalez.

9. "A survey of the natural fertility status of Brazilian soils under Cerrado vegetation" by A. S. Lopes and F. R. Cox.

Seminars were given during the year at the Brasília Experiment Station primarily for local colleagues by Messrs. Gonzalez, Wolf, Pruntel, Yost and Bandy concerning the results and methodology of their work.

A seminar on the Yurimaguas project was presented by Dr. Sanchez upon invitation by the Universidade Federale Rural do Estado do Rio de Janeiro on July 1. Discussions on possible extrapolative work at their jungle station in Amapá were held. The entire project was presented to the EMBRAPA staff in seminars by Drs. Kamprath, Naderman and Sanchez on July 9 in Brasília.