9310525 (5)
PD-AAC-886-1
Microfiche
P 6/25

CLASSIFICATION

PROJECT EVALUATION SUMMARY (PES) — PART I

Report Symbol U-447

1. PROJECT TITLE	2. PROJECT NUMBER	3. MISSION/AID/W OFFICE
Agro-Economic Research in Tropical Soils	931-0525.11	DS/AGR

1915 / 953
#1

136p

4. EVALUATION NUMBER (Enter the number maintained by the reporting unit e.g., Country or AID/W Administrative Code, Fiscal Year, Serial No. beginning with No. 1 each FY) 1

[X] REGULAR EVALUATION [ ] SPECIAL EVALUATION

5. KEY PROJECT IMPLEMENTATION DATES

A. First PRO-AG or Equivalent FY 69
B. Final Obligation Expected FY 80
C. Final Input Delivery FY 80

6. ESTIMATED PROJECT FUNDING

A. Total $ 3,631
B. U.S. $ 3,631

7. PERIOD COVERED BY EVALUATION

From (month/yr.) Feb. 1977
To (month/yr.) Mar. 1979
Date of Evaluation Review March 30, 1979

8. ACTION DECISIONS APPROVED BY MISSION OR AID/W OFFICE DIRECTOR

A. List decisions and/or unresolved issues; cite those items needing further study. (NOTE: Mission decisions which anticipate AID/W or regional office action should specify type of document, e.g., airgram, SPAR, PIO, which will present detailed request.)	B. NAME OF OFFICER RESPONSIBLE FOR ACTION	C. DATE ACTION TO BE COMPLETED
1. Determine which unit within AID will manage and fund project.	DAA/DS/FN Tony Babb	04/06/79
2. Prepare updated project paper.	DS/AGR John Malcolm	03/30/79
3. Prepare PIO/T - Extension through 12/31/80.	DS/AGR John Malcolm	04/06/79
4. Arrange for an orderly transfer of the activities to USAID/Lima and the Government of Peru.	DS/AGR John Malcolm	10/01/80
5. Conduct a terminal review.	DS/AGR John Malcolm	12/31/80

* Utilization and Review contained herein have already been abstracted as a #17.

9. INVENTORY OF DOCUMENTS TO BE REVISED PER ABOVE DECISIONS

[X] Project Paper
[ ] Financial Plan
[ ] Logical Framework
[ ] Project Agreement
[ ] Implementation Plan e.g., Critical Network
[X] PIO/T
[ ] PIO/C
[ ] PIO/P
[X] Other (Specify) PAF
[ ] Other (Specify)

10. ALTERNATIVE DECISIONS ON FUTURE OF PROJECT

A. [X] Continue Project Without Change
B. [ ] Change Project Design and/or [ ] Change Implementation Plan
C. [ ] Discontinue Project

11. PROJECT OFFICER AND HOST COUNTRY OR OTHER RANKING PARTICIPANTS AS APPROPRIATE (Names and Titles)

John L. Malcolm — John L. Malcolm 4/2/79
Soil and Fertilizer Specialist
DS/AGR

12. Mission/AID/W Office Director Approval

Signature
Typed Name Dean F. Peterson — Sign 4/3/79
Date

PROJECT EVALUATION SUMMARY (PES) - PART II

Agro-Economic Research in Tropical Soils 931-0525.11

13. This project was evaluated in depth by Drs. Douglas Caton, Howard Sprague and Omer Kelley, December 1976 through February 1977. They found the research of high caliber and many of the results ready for adaptation studies under farm conditions. Dr. Dean Peterson visited all of the field research sites in June 1978 and concluded that the project was answering questions critical to successful sustained farming of tropical soils, and should be continued.

When, because of DSB budget difficulties, it was announced that the project would have to be terminated, the three missions and host governments of the three countries in which the project was active made strong pleas for continuation. During two extensions, the possibility for Mission and/or LAC support and management of the project was explored. Only USAID/Lima foresaw sustained support for the project and then only beginning in October 1980. DSB has decided to provide both financial and management support for the project until USAID/Lima can assume these functions in FY 1981.

14. The evaluation is based on continuing contact with the project and the assessment of the field missions and Ministries of Agriculture of the host governments. No formal evaluation since completion of the one in 1977 was required, since the problems were all related to AID funding, management and documentation.

15. Inputs: There has been one negative factor. The uncertainty of continued support and short-term project extensions have made it impossible to assign the planned and desired number of soil scientists to the field. Some relaxation of the policy on overseas assignments under contracts approaching their terminal date is clearly needed.

16. Outputs: The outputs have come according to plan. Each success has shown new problems or the need for additional data. For example, meeting the full nitrogen, phosphorus and potasium needs of the crops led to rapid exhaustion of the magnesium and boron supplies. These two elements can be furnished at a very modest cost. The residual value of phosphates was much higher than anticipated and the full return on the heavier applications has yet to be realized. Treatments which would have been discarded as wholly uneconomic, if the tests had been abandoned after three years, are now clearly profitable as well as technically successful. A copy of the technical report on work at Yurimaguas is attached.

17. Lessons Learned: Two major lessons come from this project. The first is that short duration soil research will almost certainly lead to invalid conclusions, but persistent and well-managed research will show realistic paths to sound management. The second is that the forward planning process within AID has become an impediment to meeting development needs rather than

an assistance. It will take almost two years to arrange transfer of funding and management responsibility for this project to USAID/Lima. Even though the Mission is ready to assume both roles, the documentation and programming processes are too formidable to allow a more rapid changeover..

DS/AGR:JMalcolm:kb 4/2/79

TRIP REPORT

June 30, 1978

NAME:	Dean F. Peterson, Acting Deputy Director, DS/AGR
PERIOD OF TRAVEL:	June 6, 1978 - June 21, 1978
ITINERARY:	June 6 - Washington to Bogota, Columbia June 7 - Bogota to Cali June 8 - Cali to Bogota, Bogota to Lima June 9 - Lima to Yurimaguas, Peru June 11 - Yurimaguas to Lima June 13 - Lima to Brazilia June 16 - 17 - Brazilia to Santa Cruz, Bolivia June 19 - Santa Cruz to La Paz June 20 - 21 - La Paz to Washington
PURPOSE:	Familiarization with CALI and CIP. Review and familiarization of North Carolina State and Cornell University soils work in Peru, Bolivia and Brazil. Discussions with AID Peru and AID Bolivia on water and agricultural programs.
DISTRIBUTION:	AA/DS, S. Levin, T. Babb, C. McGraw DS/AGR, L. Hesser, K. McDermott, F. Williams DS/AGR, Division Chiefs TSWM Staff LAC, DR/RD, J. Balis

TABLE OF CONTENTS

		Page
I.	Introduction	3
II.	CIAT	3
III.	Yurimaguas	5
IV.	USAID Peru and Peruvian Agencies	6
V.	International Potato Center (CIP)	7
VI.	Brazilia Center for Research on Agriculture for the Cerrados (CPAC)	7
VII.	Santa Cruz - Bolivia	9
VIII.	USAID - La Paz	10

I. Introduction

I was accompanied by Dr. John Nicholaides, Department of Soil Science, North Carolina State University and Dr. David Bouldin, Professor of Soils, Cornell.

The Cornell project on tropical soils terminates effective July 31, 1978, but has been extended until February 1, 1979 without additional funding. The North Carolina State Project terminates December 31, 1978 These projects addressed questions of management of the oxisols and ultisols of the tropics, the largest soils reserve in the world--perhaps 800 million hectares. They were started in August 1, 1977 (Cornell) and June 1970 (North Carolina). While of great depth and having generally excellent climate for agriculture these soils generally suffer greatly from infertility. Their importance is stressed in "The World Food Problem" issued by the President's Science Advisory Committee in 1967 and by the National Academy of Science World Food and Nutrition issued in 1977. Research on how to manage these soils has been minimal. They are extensive in Bolivia and Peru as well as most other Latin American countries, Africa and Asia.

AID and the Joint Research Committee of the BIFAD is considering a CRSP in soils. Present AID research efforts and university continuity needs to be conserved through this transition. In addition to review of this project, the trip provided the opportunity for me to make a first time visit to CIAT and to CIP and to the AID missions in Peru and Bolivia.

Recommendation: With the closeout of the NCSU and Cornell projects, the prospective soils CRSP project perhaps 2 years away and the fact that these research efforts will not come under the prospective soils service grants, scheduled closure of these two projects will close out management research efforts on these two important soils groups and interrupt the continuity and capability of Cornell and North Carolina State University. An effort should be made to continue these projects. If Bolivian and Peru Missions or LA Bureau are unable to program this work at this time but desire the programs continued, DS/AG should explore possibilities for "gap-filling" central support.

II. CIAT

Contacts Made

K. O. Rachie, Associate Director
Pedro Sanchez, Livestock Program
G. A. Nores, Economics
J. H. Cock, Cassava program
A. V. Schoonhaven, Beans program
J. Gonzalez, Rice program
F. Kramer, Training program
J. Halliday, Soil Microbiology
L. A. Leon, Fertilizer - IFDC

W. F. Fenstar, Fertilizer - IFDC
J. G. Salinas

Narrative

After an overnight stay in Bogota we arrived at Cali at 0730 on June 7 and, following breakfast at CIAT, we began the program with an interview with Kenneth Rachie, in the absence of the director general. Dr. Rachie outlined the programs of the center emphasizing CIAT's roles in research, training and outreach. The Center has 58 scientists, 12 are stationed at outreach posts. Major programs are: Beef (2 scientists); Beans (12 scientists); Cassava (10 scientists); Rice (linked to IRRI - 4 scientists); Maize (linked to CIMMYT - 2 scientists; Swine (2 scientists - phasing out). About 1100 persons have been trained at various levels. The beef program is already cooperating with 38 institutions.

Beef - Pedro Sanchez

This program is headed by Pedro Sanchez. It is focused on an approach to oxisol and ultisol management through beef production. Beef is widely used even by poor people in Latin America. The program focuses on pasture management. Major topics include soil classification, germ plasm selection, aluminum toxicity tolerance, soil fertility, pasture agronomy, rhizobia and economics.

Under natural conditions, even though rainfall may be 1000-1500 mm or more carrying capacity may be of the order of 1 animal for 10 hectares. Improved grazing of the oxisol, ultisol lands seems like an innovative approach to first stage development of this extensive resource.

Cassava - James Cock

In contrast to English-speaking country perceptions, cassava is not a low prestige crop in Spanish and Portuguese literature. It is grown on poor soils in 80 countries. The world production is around 110 million tons annually. CIAT's program focuses on variety improvement. More than 2,500 varieties are maintained in clones. Problems include adaptation to acid soils, insect and disease resistance and plant architecture for maximum production. Cassava is very common in mixed or intercropping systems.

Rice - J. Gonzalez

Rice (mainly upland) is pervasive in South America which is self-sustaining. Central American and Caribbean are short. Problems include disease, blast particularly and weeds. Components of the program include breeding, agronomy , international/regional trials and training.

Beans - A. Schoonhaven

Program is only 4 years old. Recent appearance of hybrids are of interest. Program is limited to Latin America but work is not now conducted in the humid tropics. Potential is 4000 - 6000 kg/ha. Bean/maize association is important. Diseases are a problem and this is being attached through breeding.

Training - F. Kramer

About 200 post-graduate level persons per year are provided an average of 5 months training. Dissemination is the objective. Two types of programs are offerred: Production and Research, thesis research, PhD and MS level, are offerred in cooperation with US, European and Latin American Universities.

Microbiology - J. Halliday

CIAT collects rhizobia for forage legumes. Information is computerized. Performance and effectiveness are linked to cultivar. 800 strains have been collected for one species alone.

III. Yurimaguas

Contacts Made

Loren Schulze, USAID, Peru
Reuben Mesia, Chief, Yurimaguas Sub station for Agriculture Research
Dale E. Bandy, Asst. Prof. of Soil Science, North Carolina State University, Project Leader, International Project on Tropical Soils, Yurimaguas

We were taken by International Potato Center (CIP) airplane from Peru to Yurimaguas early a.m. June 9 returning June 11 p.m. Yurimaguas is the fartherest upstream amazon port.

This site is in the Amazon jungle judged typical of the low altitude selva on ultisols. Normal practice is slash-burn. Fertility lasts about 2 years. Below about 10-15 cms, aluminum toxicity is acute. Rain is 2,000 - 2,200 mm, but is bi-seasonal with two dry periods in December-January and June-July. Due to limited root penetration droughts of 3 days or more are hazardous to crops. The program started in 1972 to 1) learn if tropical rain forests can be mechanically cleared, 2) determine the fertility status of these soils, and 3) establish whether or not they can be permanently cultivated. Experimental results show 1) that mechanical clearing is unacceptable because of soil compaction and exposure of subsoils having aluminum toxicity, 2) that liming (1.5 T/ha) plus P, N and K along with minor elements are essential to continued farming. Phosphorus is critical;

timing is necessary to obviate aluminum toxicity. Experiments include maize variety trials, fertilizer levels, management practices, effect of slope and water table, intercropping, kudzu green manure as a substitute for forest return, and composting. The maize experiment is part of the national program on maize. There is a CIAT experiment on beef pasture. Principal crops are upland rice (3.5 T/Ha), maize (4.5-5.0 T/Ha), soybeans (2.5-2.7 T/Ha), peanut (3.0 T/Ha)*, cassava, plantains, farmers plant a wider variety including pineapple, beans, etc.

Under North Carolina's efforts a very creditable soils laboratory has been installed and a staff of 18 field workers and 5 technicians trained. Peruvian government officials have become increasingly interested and the Yurimaguas substation has received an increasing commitment. Immediately prior to our arrival, several high officials of the government spent several days at Yurimaguas. With over population on the coastal side, Peru is becoming increasingly interested in the vast Amazon selva. In this remote area, Bandy has done an exceptional job of scientific management.

The station has now initiated a farmer demonstration program. A number of farmers were interested in this program, but because of limited personnel, the program has been limited to 12 farmers. They will each try 3 levels of technology, one of which is the traditional intercrop. One of these farms was visited at a site several kilometers from Yurimaguas by river boat. He is essentially a subsistive farmer who sells occasional surpluses in Yurimaguas for commercial essentials.

While there is a good basic laboratory and a capable Peruvian interest it seems unlikely that this effort will be maintained without outside resident technical assistance. My information is that this may be the only significant work being done on the soils of the lower selvas (ultisols) in the Amazon. While the social and economic difficulties of utilizing this resource may be great, Peru is facing exceptional population and economic problems. Great as the socio-economic difficulties may be, they cannot be approached rationally without realistic technological alternatives. This project seems to be sorting these out and appears to have Peruvian government support.

IV. USAID Peru and Peruvian Agencies

Contacts Made

Mack H. McClenden, Rural Development
Ted Olsen, (TDY on contract) Utah State University
Carlos Valverde, Ministry of Food and Agriculture. In charge of Ag Research in CRIA (region) I and of all soil research in Peru. La Moliva
Efram Balte, Director General for Planning for Food and Agriculture

*Numbers in parenthesis refer to yields under nominal fertilizer and practices.

Mr. Yeager, the Mission Director along with Loren Schulze had conflicting schedules out of Lima. Our visit and interests were discussed with Mr. McLanden. Because of his TDY, Mack, of course, was unable to speak very much about Mission concerns. I made it clear to him, I think, that continuation of the Yurimaguas effort would require mission initiative and probably mission funding.

Our visit with Valverde centered on a critique of the Yurimaguas project.

Ted Olsen outlined the water management experiments. These are carried out on the La Molina campus on Min Ag fields and at two other field sites outside of Lima. Cooperation between Min Ag, the University at La Molina and Utah State appears to be outstanding. Olsen has an adjunct academic appointment with the University so can direct theses, etc. An agronomist, now associated with CIP, is being added to the Utah State team. Olsen also discussed the more general project under CID management which is centered in Huancayo. Here irrigation is supplemental in a high mountain valley. Results of the general water-soil-crop-fertility interactions under the Utah study are utilized.

V. International Potato Center (CIP)

Persons Contacted

Kenneth Brown, Director Regional Research and Training
A. R. Page, Director of Research

We were given a general briefing of the CIP program and inspected the laboratories. The center is also located at the La Molina campus which permits close interaction with the contiguous university and soil group of Min Ag. High points of interest to me were the efforts on using true seed*, tissue culture propogation, the large amount of work done through contractors (principally universities), the extensive outreach program and the large number of researchers (about 50) in comparison to the budget. The San Ignacio project is only one of several rural development projects of the COMITE. USAID, through CID has an irrigation agronomist stationed at Santa Cruz.

VI. Brazilia Center for Research on Agriculture for the Cerrados (CPAC)

Persons contacted

Elmar Wagner, General Director, CPAC
Wenceslau J. Goedart, Technical Director, CPAC
Delmar Marchetti, Administrative Director, CPAC
A. Raul Da Silva, Agronomist, CPAC
Edson Lobato, Soils scientist, CPAC
Dale Ritchey, Soils, Cornell University

*Seeds do not transmit most viruses, however the genetic heterogeneity is very large so true breeding will await selection and development of homogeneous lines.

Jot Smyth, Soils, North Carolina State University
Walter Couto, CIAT, in residence at Brazilia

This station is located 30 or 40 kms outside of Brazilia. Soils are typically oxysols. The venture started as a small station in 1965 and emerged as a full-fledged center in 1975 under EMBRAPA. Cornell and North Carolina State started cooperation in 1972-1973. Apparently this cooperation was a factor in the eventual founding of the center. The station contains 2000 hectares and the scientific staff totals 85, 15 international (non-Brazilians), laboratories and facilities are very good but not sumptuous. Some $5 million laboratory equipment is being provided by Japan. I don't know if it is donated or purchased.

These soils are said to be representative of some 125 million hectares in Sough America; 105 million, in Africa; 25 million in Asia. The land which cost $3/ha in the Brazilia region 3 years ago now costs $100-$150. Clearing and initial liming and phosphorus add $300.

The Center's program includes soil, water and crop management, resources inventory and farming systems. The February drought makes for a high risk, but there are possibly cropping strategies, using planting dates, and shorter season varieties which might finesse this critical period where irrigation is not available.

On the second day of the visit we inspected two ventures where the Center's technology is being extended to the field. The first is a state-managed cooperative venture in which farmers are given tracts (300 ha) under a lease arrangement but must follow cropping patterns laid down by this Ag. Except for some excellent irrigated potatoes land was fallow due to dry season. Land in the Federal District is not privately owned. A large farm (12,000 ha) was visited in an adjacent state. Farmers' strategy here is to grow annuals, soybeans, on land with slopes under 1%; perrenial crops on slopes 1%-5% and graze steeper lands. The extensive central eroded peneplane of Brazil. Three levels of erosion surfaces are exposed. These differ in chemical makeup and drainage. Rainfall is about 1600 mm with 6 months summer dry period. There is also a short dry period in February which is very damaging if longer than about 8 days. This year it lasted 42, a record. While natural residual nitrogen seems high, subsoil aluminum toxicity and phosphorus fixation are critical initially and the fossil nitrogen will eventually have to be replaced. Phosphorus needs do not seem as large as have been previously reported and large initial application can be maintained by annual residual applications. Irrigation is a possibility for a small percentage of the area.

Normal procedure is to bring land into production by clearing of scrub followed by upland rice, followed by natural pasture, but grazing capacity is low (1 cow/10 hectares). With timing and fertility this can be increased by 10-15 times.

The center has ded that there are excellent yield potentials for most crops inheat, soybean, rice, maize and sorghum as annuals and cassas, coffee, forests and beef perrennially or biennially. FarmSousa-Lima, grew 4,000 ha of soybeans this year and will plaha under fertilized pasture also. He has his own variety c soybeans and pasture grasses. Sausa-Lima, a farmer amaler from South Brazil purchased the property in 1972 ansperations in 1974. He says he was persuaded to tackle the Cerlem, by Norman Borlaug.

Besides technologhe extent to which Cerrados of Brazil will be developed to wels of productivity is clearly demand limited. The Cerever, seems to have excellent potential for developing techno managing these soils. This technology is scale-neutral, itbe transferrable, and there is a potential for internationalg. The Center probably does not need AID support, but conID-linkage for training and information would be in AID'st.

CIAT maintains a: liaison scientist, Walter Couto, as part of its beef prog:

VII. Santa Cruzla

Persons Co:

Miguel Rojctor, Committee for Public Works (COMITE)
Ing. JorgeChief of Natural Resources, COMITE
Ing. Carloiez, Director, CIAT*
Ing. Eduarosa V., Soils
Ing. Recor V. Program coordinator
Ing. Agr. uilera
Ing. Hecto J.
Lic. Juan andivar
Lic. OscarV.
Lic. Javido B.

Santa Cruze and Santa Cruz city (pop. 150,000) is the largest in Bolivhe Southwestern extremity of the Amazon basin. While farming an city is reasonably sophisticated, outside of the immediate an subsistence, slash burn and marginal. The province has a soil revenues earmarked for development under the COMITE. CIAbrmed to develop the agricultural technology. Focus of interesiated to the North Carolina project is an area near San Ignacio 1,000,000 hectares, population 20,170, 73% small, poor farmology is partly Cerrado and partly humid forest. Objective was tc urban migration of sub-subsistence farmers.

*Not the CGIAR c

Strategy was to develop some market economy around peanuts as an oil seed cash crop; however, peanuts failed after the second year. Other possibilities include soybeans, tobacco, coffee and citrus. Using extrapolations from Yurimaguas and Brazilia, NCSU has given technical help through TDY for somewhat more than a year. Problems seem to be fairly easily solved and 300 farmers are ready to enter demonstration programs. CIAT has requested NCSU to place a scientist in residence. Apparently the mission is willing but could not program before FY 80.

VIII. USAID - La Paz

Persons Contacted

Frank Kimball, Mission Director
Richard Peters, Soil Scientist, RD staff, USAID
Boyd Wennergren, Chief, Consortium for International Development
Allen Le Baron, CID
David James, CID

Unfortunately Dan Chaij, rural development officer was on TDY to Washington and only a courtesy visit with the director was possible. The program was discussed generally with the CID representatives and with Mr. Peters. If the Mission is interested in further assistance to the Santa Cruz program from DSB it will need to make its wishes known.

NORTH CAROLINA STATE UNIVERSITY | AT RALEIGH
SCHOOL OF AGRICULTURE AND LIFE SCIENCES

DEPARTMENT OF SOIL SCIENCE
BOX 5907 ZIP 27650
PHONE: (919) 737-2838

June 19, 1978

Dr. Dean F. Peterson
TA/AG/SWM
Agency for International Development
Washington, D. C. 20523

Dear Dr. Peterson:

As per Dr. Pedro Sanchez' instructions, I am enclosing one MAP OF TROPICAL AMERICAN SOILS (Mapa de Suelos de America Tropical) for your information and utilization.

Sincerely,

Dawn M. Silsbee

(Mrs.) Dawn M. Silsbee, Secretary
Tropical Soils Research Program

Enclosure

ATTACHED

MAPA DE SUELOS DE
AMERICA TROPICAL
GENERALIZACION TAXONOMICA-CARTOGRAFICA
ELABORADA EN BASE AL MAPA MUNDIAL DE SUELOS DE LA FAO
LEYENDA
ALFISOLES
ARIDISOLES
MOLISOLES
OXISOLES
SPODOSOLES
ULTISOLES
VERTISOLES

UTILIZATION REVIEW AND EVALUATION
TROPICAL SOILS RESEARCH PROGRAM
CORNELL AND NORTH CAROLINA STATE UNIVERSITIES

Report Prepared by

Douglas Caton, Agricultural Economist
Howard Sprague, Agronomist
Omar Kelley, Soils Scientist

February 22, 1977

OVERVIEW AND RECOMMENDATIONS

A. Overview

1. The Oxisols and Ultisols represent the largest area of land in the world that either is not farmed or only partially utilized. There are some 1,600 million hectares of such soils of which approximately 800 million hectares are arable. (There were 167 million hectares farmed in the U.S. in 1976, of which 150 million were harvested.) Seventy percent of this land has sufficient precipitation for year-round crop production (3 crops/yr.). Thirty percent has a wet-dry cycle with sufficient precipitation for at least one crop per year. Most of these soils are found in the savannas and forests of Latin America, Africa and South Asia, and some 48 LDCs are involved. These countries are estimated to have a population of 1.6 billion people by the year 2000. If these soils can be brought under production, it is estimated that most of these lands and production would be handled by small farmers.

2. It appears that solutions have been found to the slash/burn type of agriculture so that continuous cropping can be conducted on these soils.

3. The major soil problems preventing crop production in the past have been identified. There are differences in the degree of severity of these problems, but they appear to be universal where ever these soils occur. These problems are:

a. Very low phosphate availability (and high phosphate fixing capacity) and low Ca, Mg, and K.

b. High Al solubility, and high acidity.

c. Low water availability.

4. Over the some 400 years of farming the Oxisols and Ultisols of Puerto Rico, something appears to have happened that makes them much more productive than the same soils found in Brazil, Colombia, Peru, and Ghana. If the same results should be experienced in these other areas, the effect on world food production would be tremendous. It would be so large that the exact impact is not possible to predict with present knowledge.

5. It is now known that there are major differences in species and varieties of crops in their tolerance to soluable Al and to low available phosphorus. This could set the stage for a completely new concept in low energy cropping systems.

6. Very little knowledge exists on efficient cropping systems on these soils in the tropics. The roles of grass and legumes in such croppping systems have not been studied, let alone evaluated.

7. Long term requirements and effects of varying levels and placements of P and lime are not known. The same is true for the other fertilizer elements even though they are of less economic importance. (Ca, Mg, N, K, and certain minor elements.)

8. Crop production on these areas will face most of the problems that occur in other farming areas. A very severe problem has arisen with respect to water erosion which appears to be both universal and severe on these soils.

9. Effective utilization of the research results will depend upon how well the results are communicated to the farmer, and upon the determination of which practices and farming systems are economically viable. The results achieved indicate lower per unit costs and increased farm income opportunities, but so far the research has not determined the cost-returns relationships that exist among alternatives.

10. Traditional ways and modes of supplying information on improved agricultural science and technology offer the opportunity for utilization, but effective transmission of research results into practice depends upon making utilization an integral part of research.

11. The research-training-information transfer network as outlined appears to offer a framework and an opportunity to blend and harmonize research and utilization into a unified whole with a focus on economically viable farming systems.

12. The present field locations offer an excellent opportunity to expand basic knowledge on tropical soils, but these additional considerations are also involved: (a) an on-the-ground survey needs to be made of the soils information requirement in Africa, Asia, and Central America, (b) the focus on utilization needs to be sharpened and directly integrated with the research as a commensurate operation of the program.

B. Recommendations

1. That the research at the field locations, with their indigenous cooperation, be continued, at the same time work should begin on a revised research-utilization program under the network concept.

2. That an immediate review and assessment be made of the need to broaden and strengthen the program by mounting a greater effort on land use classification and soil problem survey, starting with Africa and Central America.

3. That the farm system concept be brought more to the forefront as the integrating unit of analysis of both soils research and agro-economic assessment, and that the economic evaluation component of the program be strengthened as rapidly as possible.

4. That a search be made on alternative sources of soil fertility than purchased inputs be incorporated into the program; that is, a search for tolerant plants, inclusion of organic materials in the soil, and the use of legumes in the multiple cropping or crop rotation.

5. That the soils program of Cornell and North Carolina State University be tied in more directly in a coordinating fashion with the work of the International Research Centers, and that ways to include the contributions of EMBRAPA and the University of Puerto Rico in the network be explored out.

6. That a practical format be found for rapidly upgrading the human factor on soils problems in Africa and South and Central America, as well as continuing essential graduate training.

7. That the known technologies on information transfer be used in evolving an information utilization system that will effectively tie farming systems and research together, e.g.,

the development and formalizing of definite strategy for transferring crop production information to the farm.

TABLE OF CONTENTS

I. Introduction

A. Purpose of the Review

B. Utilization Overview

1. Overview

2. Utilization Impact Potentials

II. Importance of Tropical Soils in Agricultural Production

A. Description

B. Productivity Potentials

III. Review Procedures

A. Background

1. Soil Fertility in Humid Tropics--Cornell University

2. Agronomic-Economic Research--North Carolina State University

B. Procedure

IV. On-Campus Research Review and Evaluation

A. Cornell University

1. Introduction

2. Narrative Summary

B. North Carolina State University

1. Introduction

2. Narrative Summary

3. Highlights of 1975 Annual Report

a. Savannas

b. Amazon Jungle

c. Central America

d. Extrapolation Studies

e. Collaborating

V. Review and Evaluation of the Cornell and North Carolina Field Programs

A. Puerto Rico

B. Brazil

C. Peru

D. Colombia

VI. Evaluative Comment on the On-Campus and Field Research of Cornell and North Carolina State University

1. Introduction

2. Physical and Chemical Properties

3. Fertility Response Measurement

4. Varietal Differences

5. Cumulative Effects of Liming

6. Residual Effects of Liming

7. Available Soil Water

8. Continuous vs. Shifting Cultivation

9. Problems Involved in Utilization of Research

10. Evaluation of Problem Identification

a. Soil Characterization

b. Classification According to Soil Fertility

c. Efforts to Converting Shifting to Continuous Cropping

d. Low Energy Technology

e. Managing Soil Acidity

f. Phosphorus Management

g. Plant Breeding

11. Agro Economic Analysis Relative to Economically Viable Farming Systems

VII. LDC and AID Utilization of the Findings and Achievements of the Tropical Soils Research Program

A. Problem Identification

B. Utilization Capacity

C. The Research Argument

D. Evaluation Comment on Future Research and Utilization Strategy

Appendices

Appendix I -- Soil Fertility in the Humid Tropics

Appendix II-- North Carolina State University Tropical Soils Program Summary and Future Outlook

Appendix III -- Proposed Review Format Cornell and North Carolina Tropical Soils Projects

Appendix IV -- Photos

UTILIZREVIEW AND EVALUATION
TROPIILS RESEARCH PROGRAM
CORNELL AND CAROLINA STATE UNIVERSITIES

Douglas Caoward Sprague, Omer Kelley

I. Introduction

A. The Purposee Review

The utilizaeview of the Cornell and North Carolina State tropicls research programs was made at the request of the Soi Water Division, Office of Agriculture, Technical Assisbureau, Agency for International Development. The purf the review was to sum up the status of research inion on major tropical soils problems, and to explore the opities for increasing its utilization. The evaluative contexhe probable technical contribution of the research infonto more economically viable agricultural production sin the tropics, for oxisols and ultisols which are thminate soil groups.

The review alt with procedures being followed to increase the adaptearch and information transfer capabilities of the Lin enhancement of the human resource, particular attention d to graduate training, and to the establishment of "corf competency by both Universities

on tropical soils problems, on-campus and overseas. For purposes of the review, LDC research and planning staff and graduate students affected by the program were collectively considered as an extension of the core group.

B. Utilization Overview

1. Overview

Section IV of this report contains the review team's evaluative comment and judgement on the potential impact areas, and on the significance on LDC food, nutrition, and rural development goals of the research on tropical soils. Section V's primary evaluative focus is on development of viable farming systems as the necessary means to identify soils information needs and to measure production benefits. A farming system format also permits identification of the contribution to total benefit relationships of complementary information on plants, animals, pests, weeds, water, and farm production practices.

The evaluation made treats soils information utilization in both its direct and indirect senses, e.g., fertilizer recommendations vis-a-vis graduate student training; by type of information (fertility, moisture, soil structure);

and by kind of user (research institution, farmer, planner). One part of the section on utilization deals with the mechanisms and process dimensions of information transfer; and a concluding part deals with the possible evolvement of a research and information transfer network on tropical soils as a utilization strategy. A part of the strategy might be to also engage in this process the emerging research and institutional strengths of LDCs, such as EMBRAPA of Brazil, on a southern hemisphere basis, or more world-wide.

2. Utilization Impact Potentials

These potentials include:

a. Increase world's cultivated land by 50%, and due to multiple cropping possibilities, increase world food production by a substantially higher figure.

b. Improve the well-being of millions of small farmers who are either settled in the acid Oxisol and Ultisol areas or who will migrate to them in search of a better life.

c. Avoid widespread ecological damage by suitable selection of which lands to use for crop and pasture production and which should be left untouched.

d. Permit orderly national level planning by translation of agronomic data into economic models.

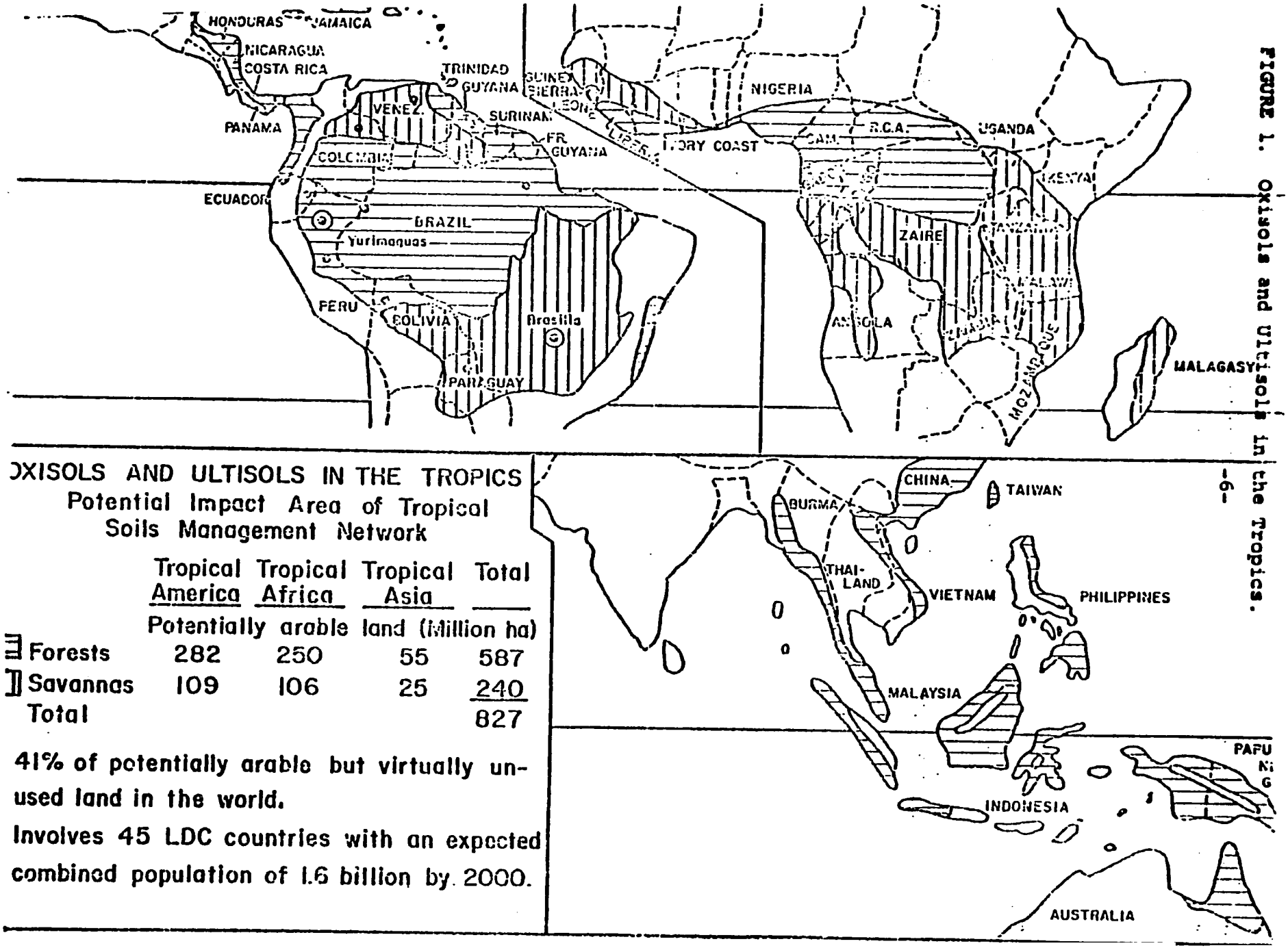
II. The Importance of Tropical Soils in Agricultural Production

A. Description

The largest block of potentially arable but virtually unused land lies in the vast tropical forest and savanna areas with acid Oxisol and Ultisol soil groups. In these areas food production is rising at a slower rate than human reproduction. These regions comprise approximately 1600 million hectares, of which 827 million are potentially arable. The largest continuous regions are in the interior of South America and in Africa, with smaller but important areas in Indonesia and South Asia. Figure 1 shows the geographical extent of the impact area, which covers 48 less developed countries with a projected total population of approximately 1.6 billion people by the year 2000.

Agriculture in the tropics first developed in areas of high-base status soils. These soils—now called Alfisols, Vertisols, Mollisols, and certain Entisols and Inceptisols—cover approximately eighteen percent of the tropical land area. Because of their relatively high fertility the impact of the Green Revolution programs has been mainly limited to areas with high-base status soils, particularly those that can be irrigated.

FIGURE 1. Oxisols and Ultisols in the Tropics.



OXISOLS AND ULTISOLS IN THE TROPICS
Potential Impact Area of Tropical Soils Management Network

	Tropical America	Tropical Africa	Tropical Asia	Total
	Potentially arable land (Million ha)			
Forests	282	250	55	587
Savannas	109	106	25	240
Total				827

41% of potentially arable but virtually unused land in the world.

Involves 45 LDC countries with an expected combined population of 1.6 billion by 2000.

These soils have generally developed from alluvium, sediments, or volcanic ash rich in calcium, magnesium, and potassium. They present slight to no acidity problems and require practically no investment in lime. Nitrogen is the most commonly limiting nutrient. Phosphorus deficiency, micronutrient disturbances, and moderate salinity problems occur, but these can be easily corrected.

A larger group of soils in the tropics are of low-base status and are highly leached. They are classified mainly as Oxisols, Ultisols, some Inceptisols, and sandy Entisols. They cover approximately fifty-one percent of the tropics in vast areas in the interior of South America and Central Africa and smaller areas of the hill country of Southeast Asia. These soils are commonly deficient in bases, and often present aluminum toxicity problems. The ubiquitous deficiency of phosphorus is often difficult to correct because phosphorus fertilizers are "fixed" by reaction with iron and aluminum oxides. Micronutrient and sulfur problems are common.

Correcting these nutritional problems usually involves substantial investments in fertilizer and lime. On the positive side, they generally possess excellent physical properties which facilitate tillage.

A third majoical soils grouping consists of high-base status soilsd Aridisols, which occur in tropical deserts and occupy aborteen percent of the tropics. The availability of irrigand nitrogen are the principle limiting factors. wnen prcirrigated, and free of salinity problems, these soils :come extremely productive

B. Productivitvtials

Soils of thecs can make a major and sustained contribution toward wood production when they are well understood and economirealistic management systems are applied. Most of the ements in the near future can be expected from increasilds in the high-base status soils, but in the long run thgement of the low-base status soils is the larger issue.

Also, unlikeic plant breeding problems, many problems concerning soe site-specific, and recommendations have to be compatible arming practices at the local levels. Therefore, more sites eded for practical soil management research. This was deated at a recent seminar on soil management in Colombiaa delegate from Nigeria recommended that burning should benated in clearing tropical forests, while work in Peru demted the dramatic fertilizing benefits

from ash derived from burning. This apparent discrepancy was explained by the fact that the ash raised the soil pH from 6 to 8 in Nigeria, causing iron deficiency, while in Peru the ash raised the soil pH from 4 to 4.5, supplying needed bases to the soil.

III. Review Procedure

A. Background

Previous projects which provided a basis for the soils research under these two projects were the NCSU Soil Fertility Testing Project (AID/csd-287) with work in fourteen Latin American countries, and a concurrent bilateral project in Peru. The current Latin American program is a direct outgrowth of these two projects. Expansion in the development of research and teaching on tropical soils was supported at Cornell and North Carolina State University by 211(d) grants authorized in November 1970. Three other universities, Hawaii, Prairie View A&M and Puerto Rico also participated in the Tropical Soils Consortium supported by 211(d) grants.

The minutes of the Research Advisory Committee Meeting, April, 1970 summarized the main objectives of the AID financed research on tropical soils as including:

a. Agronomic-economic evaluation

b. Characterization of soils (chemical, mineralogical and physical properties)

c. Soil fertility—soil chemistry studies (nitrogen, phosphorus, lime, and micronutrients)

d. Soil moisture regimes

Later, on December 3-4, 1973, RAC recommendations on the Cornell and North Carolina research projects were as follows:

1. Soil Fertility in the Humid Tropics—Cornell University

   . . . (2) the expansion of the research to a third area in Africa be implemented if possible as the Puerto Rico activity is phased down or as more financial resources become available.

   Subsequently, in 1974, Cornell University developed a soils-agronomic project with the Ghana Soil Research Institute to determine soil fertility limits on food-crop production on the Ultisols of the humid forest zone.

2. Agronomic-Economic Research on Tropical Soils—North Carolina State University

   Recommendation: That: (1) emphasis be intensified on integrating the agronomic and economic phases; (2) overall experimental design and methodology be refined to assure the applicability of results from specific sites to broadly generalized systems.

   Thereafter, North Carolina State University also expanded its work to: (1) analysis methodology

to evaluate "economically-sound soil and fertilizer farm management practices;" (2) the use of soil characterization information to extend experimental results; (3) developing evaluation models for technically and economically sound farming systems; and (4) developing design and testing procedures to determine site specific adjustments to generalizable recommendations.

B. Procedure

The on-campus and field reviews were preceded by three initial steps: (1) a review of AID file documents on the research contracts, (2) preparation of a concise summary of the soils research, including an appraisal of utilization, by each University (appendices I and II), and (3) a review of tropical soils information needs with the Regional Bureaus.

The discussions with the regional bureaus can be summarized as follows:

1. That soils research be set up and conducted on an "up-to-date" basis with respect to production and farm management problems and evolvement of more effective farming systems, for all farmers, but with special reference to the small farmer.

2. That an information basis be created which can provide continuous information on soils problems and solutions for planning and farm management decisions.

3. That research be conducted which will, as its ultimate product, help insure continuous and economically viable farm productivity in the light of expected population growth.

The on-campus reviews were held at Ithaca (December 2-4, 1976) and Raleigh (December 6-8, 1976). The field reviews were conducted in Puerto Rico (December 10-12, 1976) and Brazil, Peru, and Columbia (January 3-15, 1977). The review format used and the review work plan are attached as appendix III.

The review hypotheses were as follows:

1. That the research is providing an indexing and classification of the agricultural production problems with respect to the oxisols and ultisols of the tropics.

2. That the research has established "working" agricultural systems models for both intensive and extensive agricultural systems.

3. That the research is extending into incorporation of bio-systems (organic matter, plant selection, and cropping systems) and into moisture regimea (rainfall and supplemental irrigation)

4. That evaluation procedures and testing mechanisms have been formulated to extrapolate (extend) the research conclusions and generalizations to: (a) other areas and regions in a comprehensive manner and (b) in terms of an "agronomic-economic" evaluation model, the cropping system and economic considerations involved.

IV. On-Campus Research Review and Evaluation

A. Cornell University

1. Introduction

The soils research of Cornell University is directly related to the soils research of the University of Puerto Rico, North Carolina State University and the University of Hawaii in a number of ways. The Oxisols and Ultisols fertility and acidity work in the University of Puerto Rico is correlated with the research of these universities, particularly with NESU in Brazil. The Brazil, the Cornell and North Carolina research are joint, with Cornell giving more emphasis to fertility, particularly nitrogen, and to soil moisture; whereas, the NCSU project places more emphasis on the broader aspects of soil management and on economically viable cropping systems.

The Cornell (and the NCSU) project is directly agriculture-development oriented, with emphasis on four interrelated objectives: (1) the factor and dimensions of soils (physical—chemical—bio-agronomic), (2) cropping patterns basic to evolving "model" (representative) farming systems, (3) evaluation and extrapolation of methodology, and (4) diffusion and utilization of methods and technology.

2. Narrative Summary of the Cornell Soils Research

Cornell has identified constraints relating to the effective use of Oxisol and Ultisol great soil groups that occupy very extensive land areas of the tropical and subtropical zones of the American hemisphere, Africa and Asia. For the most part, these soils are now either lying idle or support very low levels of agricultural use. However, they have terrains and climates that should support substantial agricultural production if soil constraints can be alleviated.

Cornell has made substantial progress in gaining a specific understanding of the physico-chemical soil properties that affect soil productivity. Somewhat surprisingly for this climate, the water relations of these soils have been found to limit crop-plant productivity. These relations have been quantified as to the limited soil storage of rainfall and the partial unavailability of water due to the presence of toxic soluble aluminum in the soil profile, that inhibits root occupation and functioning. The related content of the cations—calcium, magnesium and potassium—has been studied, in the context of meeting nutrient requirements of crops.

The supplies of essential phosphorus and nitrogen to provide nutrients at levels needed to support crop growth at economic levels have been studied in terms of such fertilizer

applications, in relation to the soil water regimes and presence of soluble aluminum (at toxic levels) that characterize these soils. Significant correlations have been made between soils of Puerto Rico, Brazil, Ghana and New York.

There has been less done on the biological aspects of these soils, but initial work has been done on the native supplies of soil organic matter—its abundance, contribution to the cation exchange capacity of these tropical soils, and nutrient-supplying power for crop growth. Also, very useful information has been carried through preliminary stages on relatively large genetic differences found between strains of maize (pure lines and hybrids) on root tolerances to soluble aluminum and ability to make growth with limited supplies of calcium, magnesium and potassium. These exploratory studies suggest the possible utility of studies on regularly recurring additions to the soil of fresh organic matter supplied by growing adapted tropical grasses and legumes in rotation with crops. This procedure might replace the traditional slash-and-burn fallow systems, thus, permitting continuing cropping of the same land. Similarly, the growing of adapted legumes to make regular additions of nitrogen to the soil offers opportunity for periodic replenishment of nutrient nitrogen without recourse to expensive nitrogen fertilizers. The studies on use of nitrogen fertilizer by crops have been shown to follow surprisingly similar patterns on soils in New York, Puerto Rico, Brazil and probably Ghana.

Sufficient basic data has been acquired in the short period covered by this research project, to indicate the following sequential steps in devising ultimate soil utilization procedures. These steps are postulated as follows: (1) identification of the primary constraints; (2) dealing with these major constraints simultaneously by suitable soil treatments; (3) selection among the possible alternatives (of those that are economically feasible); and (4) field testing to determine their actual contribution to continuing land productivity, without soil deterioration.

There has been an effective combination of on-campus and tropical field research activities. The on-campus contribution has been: (1) the intellectual planning and direction by the senior scientists; (2) the use of existing laboratories, growth chambers and greenhouses for the types of studies that cannot be conducted in the developing countries because of lack of facilities and skilled technicians; and (3) the college courses and instruction for training graduate students in preparation for conduct of thesis research in the tropical countries where the target soils are located.

The field work has included direct measurements on soils and crops grown on experimental sites and collection of samples for laboratory, growth chambers and greenhouse studies mostly conducted on the campus. The design of the field

experiments has been made on campus, and the statistical analyses of data from field studies also have been made on campus. The use of on-campus expertise and facilities has been a direct contribution of the University. There has been effective direct participation of senior staff in the field work itself, ensuring a high quality research effort.

The following commitment of man-months of effort on this research indicates the useful combination of campus capabilities with field activities:

For the Year 1975-1976 (as being indicative)

Cornell	On-Campus (man-months)	Field Research in LDC's (man-months)
Professional and Senior Staff	31	17
Laboratory & Technicians	12	0
Graduate Students	24	20
Clerical	9	0
Labor	--	51
Consultants	6	2
	82	90
Puerto Rico Subcontract		
Professional		6
Clerical/Technical		12
Labor		36
		54
GRAND TOTAL	82	144

Thus, with a minimum of expenditure for physical facilities, a strong research program has been mounted by combining the existing facilities on campus with the field in LDC's where the problems exist.

Overview of field research has been the continuing responsibility of the professional and senior staff resident at Cornell but with periodic visits to the field sites. The same graduate students who enroll for degree courses on campus, actually conduct the field research under the general direction of the on-campus professors. Thus, both the professional and graduate students are in close association throughout the full term of graduate training, and the quality of the research is that required in a first-class university.

The soil and water management problems in tropical and subtropical regions are many faceted and certain types of problems have wide significance whereas others are strongly site oriented. The types of research efforts are as varied as the problems. Researchers are needed to make effective progress on all crucial problems involving the development of the basic resources of land and soil, climate and vegetation. These are so extensive and the probable practices and procedures likely to be useful are so varied that there is little justification for duplication of effort

between internationicultural research institutes, the programs of interna agencies (UNDP-FAO, World Bank, etc.) and bilateral progrıch as AID contracts), other external assistance agencies

The mportant consideration in selecting the area of research efs whether such research will constitute a fundamental contrı of the individual nation to meet urgent food production reqnts, and foster long-term agricultural development, and enne most prudent use of natural resources to meet human needsırdinal requirement is that the improved productivity not be/ed to the detriment of the producer on the land. By and la is the long-suffering, neglected, but indispensible compof the national population. He should not be "milked" to suppes basic goals, for without the producers' contributions, otherts of national development may either be impossible or se\constrained. Improved productivity of the land is a neces:Research designed to enhance productivity should focus on conts as to land, soil, water, that affect agricultural product

B. North Carolina State University

1. Introduction

The NCSU program combines the essential elements of soils-agronomic economic research, including training and institution building at the country level. The North Carolina program also is formulating utilization and information transfer concepts and methods to involve extension and farming operations.

NCSU has interested highly qualified staff and graduate students in the soils program, plus building on ten years of experience of their Latin America soils "fertility" project, and seventeen (17) years of institution building, teaching, and research experience in Peru.

2. Narrative Summary

The research format is focused on four primary objectives. The first three of these are centered on developing economically-sound soil management systems for: (1) acid tropical savannas, (2) tropical rainforests, and (3) intensive intercropping systems. The field research activities to achieve each of these objectives are based in Brasilia, Brazil and Yurimaguas, Peru. Some work is also being done in Central America. The fourth objective involves assembling information and assessing methodologies on extrapolating research results.

Three main activities are performed to achieve these objectives: Soil characterization studies, to determine the soil properties of little-known tropical areas along with basic greenhouse and laboratory studies designed to understand certain basic concepts not presently understood. A second activity is the development of a fertility-capability soil classification system as a practical tool for grouping soils with similar fertility limitations and thus, to bridge the gap between the subdisciplines of soil survey and soil fertility. The third activity is development of an extrapolation strategy. This activity involves economic interpretation of the data gathered in a way which evaluates the profitability of the soil management systems proposed and at the same time provides physical coefficients for implementation recommendations as follows:

3. Highlights from the Annual Report for 1975

a. Savannas

The long-term residual effects of liming and fertilizer applications on Oxisols of the Cerrado of Brazil provided additional information, as most experiments completed their third year after establishment. Original applications of 2 to 8 tons/ha of lime incorporated deep (0-30 cm) were able to maintain from

72 to 97 percent of the maximum corn yields. Shallow (0-15 cm) lime incorporations did not perform as well. Chemical analysis suggests a considerable movement of exchangeable calcium and magnesium below the zone of applications.

Phosphorus management continues to be the most crucial fertility parameter for developing economically-sound systems. The long-term residual phosphorus experiment, now in its fifth consecutive crop, shows that a broadcast initial application of 80 kg P_2O_5/ha as superphosphate followed by band applications at the same rate before each planting produces about 80 percent of the yields obtained by a massive initial broadcast application of 1280 kg P_2O_5/ha. The residual effect of cheaper sources of phosphorus continued to show the good performance of high reactivit rock phosphates. With time, the low reactivity Araxa rock phosphat increased its effectiveness dramatically. Termofosfato, a thermal alteration of Araxa fused with magnesium silicate, continued to perform as well as superphosphates.

The residual studies of zinc fertilization show that an initial rate of 9 kg Zn/ha is sufficient to maintain maximum corn and sorghum yields three years after applications.

A methodology for screening varieties for joint tolerance to aluminum-toxicity and low available soil phosphorus levels was developed in the greenhouse and tested successfully in

the field. Several varieties of corn, beans, wheat, sorghum and rice were identified as showing joint tolerance to the two most adverse factors of Cerrado soils. When tested in the field, they approached maximum yields at much lower levels of lime and phosphorus applications than the sensitive variety. For example, the tolerant sorghum variety, Taylor Evans Y-101, produced 6 tons/ha of grain with only 1 ton/ha of lime applied 3 years before, with a 50 percent aluminum saturation in the top 30 cms. The susceptible variety RS-610 produced the same yield with 4 tons/ha of lime and 20 percent aluminum saturation in the top 30 cms. Many maize varieties developed under acid conditions in southern Brazil exhibit joint tolerance to aluminum toxicity in low available soil phosphorus levels in sharp contrast with CIMMYT's Mexican maize varieties developed under calcareous soil conditions. These results have stimulated national breeding programs of corn and sorghum to include joint tolerance as breeding objectives. Coupled with other management practices identified earlier, such as deep liming, combination of broadcast and banded phosphorus and cheaper sources of phosphorus, the identification and use of tolerant varieties will make economically feasible the opening of new acid savanna areas for intensive crop production.

Crop physiology during water stress periods was better understood through growth analysis monitoring leaf area

index, soil temperature, soil water use, transpiration rates, stomatal resistance to water loss, leaf water potential, root distribution, yields and nutrient uptake. These measurements confirm the superiority of deep liming as a better way to utilize soil moisture during water stress periods in corn. Upland rice, however, did not benefit from deep liming probably because of its greater tolerance to soluble aluminum levels.

Mulching corn with grass reduced soil temperature by 2-3 degrees Centigrade in both seasons while a black plastic mulch increased soil temperatures by that amount. Both mulches decreased water stress. Coupled with deep liming, grass mulch during the hot rainy season and black plastic mulch during the dry season increased yields significantly.

b. Amazon Jungle

The continuous cropping experiment suffered a severe yield decline during 1975 even when levels of fertilization and liming considered adequate were applied. The causes for this decline were not related to age after clearing or to climate. They were identified as insufficient rates of fertilization and liming, poor germination and initial stands, soil compaction and increased insect attacks.

Soil analysis confirmed that the fertilization rates applied in 1972 are no longer adequate. Nutrient requirements

increased as the soil approached a new equilibrium level. Magnesium and potassium deficiencies occurred and also an imbalance between calcium, magnesium and potassium. The residual effect of phosphorus applications was shorter than expected. Poor germination and initial stands of rice were corrected by selecting fungus-free seeds and controlling insect attacks. Soil compaction problems became evident and were corrected by mulching and/or herbicide applications to minimize manual weeding. When fertilizer applications were increased (to 180-160-150 kg/ha of N, P_2O_5 and K_2O plus 50 kg MgO/ha, 24 kg S/ha, 3 kg Zn/ha, 3 kg Cu/ha, 1 kg B/ha and 0.1 kg Mo/ha) pests were controlled and mulches and herbicides used to diminish soil compaction, the yields increased again. Next year's annual report will show upland rice yields of over 3 tons/ha, corn yields of over 4 tons/ha and soybean yields of over 2 tons/ha. Preliminary economic analysis shows that these fertilization rates are profitable.

Research on multiple cropping combinations showed that five basic crops (corn, rice, cassava, peanuts and soybeans) could be grown on the same land during one year, producing about 30 percent more food and net income to the farmers than when the crops were grown separately.

Although the response to lime is great in these acid, jungle Ultisols, the residual effect of lime applications is not as long as that observed in the savanna Oxisols. Continuously humid weather, the use of $Ca(OH)_2$ as the lime source and the rapid increases in exchangeable aluminum a few months after liming are some of the reasons why. Incorporating lime with a hoe, or simply raking it on the surface, gave very favorable responses and opened practical possibilities in small farming systems where mechanization is difficult.

Mulching or incorporating guinea grass or kudzu in the soil increased crop yields significantly over four successive crops, and prevented yield declines in unfertilized fields. Mulching decreased soil temperatures by about 5 degrees Centigrade, prevented compaction, conserved soil moisture and decreased weed growth. Green manure applications did all of the above except for decreasing soil temperatures. When crops were intensively fertilized the yield response to these residue applications diminished.

The responses to sulfur, magnesium, potassium and micronutrients were also identified and quantified. This led to the formulation of recommended fertilization rates which increased corn and soybean yields dramatically.

Field adaptation of Irish potatoes to the lowland tropics was conducted with germplasm and supervision of the International Potato Center. The preliminary results show considerable promise.

c. Central America

Research on multiple cropping systems showed that a corn-cassava intercropped system in the Atlantic coast of Costa Rica (on Allisols) produced as much yield of both crops per hectare as two hectares of monoculture. In the ubiquitous corn-beans relay intercropped system practiced throughout the region, results showed that nitrogen applications to the beans after doubling the corn yields increased bean yields significantly and economically. The efficiency of nitrogen applications to upland rice in the Pacific coast of Costa Rica showed an optimum application rate of 110 kg N/ha. A thorough study of dry matter and nutrient accumulation by cassava was completed during the year. It provides basic data for the understanding of this basic food crop. Phosphorus fertilization studies in the Altiplano and Pacific coast of Guatemala showed that no massive phosphorus applications are needed to produce adequate corn and wheat yields. Producing intensively fertilized forage sorghum during the rainy season in El Salvador to provide silage for dry season feeding of livestock was proved to be economically sound.

d. Extrapolation Studies

The first formal version of the Fertility-Capability Soil Classification System was published. It is presently being used in Colombia, Venezuela, El Salvador and tested in other countries, including the United States. Its applicability to Colombian data was tested. Problems were found in several regions related to the use of the parameter designed to identify high phosphorus fixation by iron compounds. It was found that phosphorus fixation could be predicted by the clay content of Oxisols and Ultisols or by the product of percent clay x percent of free Fe_2O_3.

Soil characterization studies were conducted in areas with very little prior information in the interior of South America. A toposequence study in the Llanos Orientales of Colombia indicates that these soils are classified as Oxisols and that they differ only slightly in their chemical and mineraological properties, except for organic carbon which seems to be closely related with soil moisture regime. A second study in the Occidental Plateau of Sao Paulo State, Brazil shows that most soil variation was related to parent material and geomorphology. In this region Oxisols, Ultisols and Mollisols occur in close proximity. A third savanna region in the west coast of the Maracaibo Lake in Venezuela, showed

that soils varied from Aridisols to Alfisols and Ultisols, depending on soil moisture regime. Basic studies also began on the relevance of yellow and red soil colors on iron oxide composition and management implications. Characterization of Oxisols and Ultisols of the Venezuelan savannas and Amazon Jungle is also in progress. At the request of the Ministry of Food, soils of the Jenaro Herrera colonization project in the jungle of Peru were collected for characterization.

A study trip through Nigeria, Ghana and Upper Volta permitted a comparison of jungle and savanna soil conditions between these areas of West Africa and South America. The similarities in soil management problems are very close in both jungle areas, although the West African regions visited have less soil fertility problems and more soil physical problems than in the Amazon Jungle. The similarities in vegetation are very striking between the Cerrado and the Guinea savannas of Ghana. However, the soils are totally different and require completely different approaches. A study of the effects of burning the soil itself rather than the vegetation was conducted with an Ethiopian soil in order to gather a basic understanding of the "guie" system of shifting cultivation practiced in that country.

The economic interpretation project terminated its initial phase of analyzing already existing data, finding the most appropriate models for arriving at fertilizer rate recommendations. A new phase was started in late 1975 consisting of interpreting and analyzing data produced by our program in Yurimaquas and Brasilia as a basic tool for linear programming and sector analysis studies.

e. Collaborating Institutions and Individuals

The research reported is conducted in cooperation with several national institutions, involving a high degree of collaboration.

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

In the Amazon Jungle of Peru, field research is conducted at the Yurimaguas Experiment Station which is part of the Centro Regional de Investigaciones Agropecuarias del Nor-oriente of the Ministeria de Alimentacion. Supporting laboratory work is conducted at La Molina. The Direccion General de Investigaciones of the Ministry has assigned Dr. Carlos Valverde as project leader, representing Peru. Dr. Valverde has been very effective in expediting administrative matters with the Peruvian Government. The International Potato Center plays a major role in providing administrative and logistical support. In turn, the program grows its potato trials at Yurimaguas as the lowland tropical station, for adapting potatoes to the region.

In Central America, joint projects are conducted with the Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE) at Turrialba, Costa Rica; the Ministries of Agriculture of Costa Rica and El Salvador and the Institutio de Ciencias y Techologia (ICT) of Guatemala. Activities are also linked with the International Soil Fertility Evaluation and Improvement Program (ISFEIP). Logistical support is provided by CATIE. Program plans are coordinated with the ROCAP offices of AID in the region.

Several extrapolation studies are also collaborative in nature. Data for evaluating the Fertility-Capability

Soil Classification System has been provided by EMBRAPA, the Instituto Colombiano Agropecuaria, Instituto Geografico Agustin Codazzi in Colombia. Soil characterization studies have been conducted with partial financial support in the form of scholarships for graduate students from the USAID Mission to Colombia, the Ministerio de Obras Publicas of Venezuela, the Fondo de Amparo a la Pesquisa do Estado de Sao Paulo, Brazil.

To fully appreciate the significance of the NCSU program (and that of Cornell), one must first compare (a diagnostic comparison is convenient) "traditional" with "system" oriented research. The first is static in make-up and is task oriented. The second is problem oriented and dynamic in make-up. The first case says that we will work on a particular problem in a particular place and assume the findings (conclusions) will at least have some kind of general properties. The second case says we will first determine the general properties that have to be met in a systematic way; these determine the primary problems, and, since we will have to get back to the problems we have identified in good order, we will have to have a vehicle to get us there (the agricultural systems model).

On this feature of the research a common methodology needs to be worked out jointly by Cornell and NCSU.

For example, in Ghana, Cornell may have been extrapolating a methodology per se rather than an integral of a production system; that is, the trade-off may well have been between the projection of a research design (learned from the experience, of course), vs. more time devoted to integration of practices into farming systems in Puerto Rico as the laboratory.

V. Review and Evaluation of the Cornell and North Carolina Field Research Program (excluding Ghana and Central America)

A. Puerto Rico

1. Introduction

The subcontract with Puerto Rico is advantageous to both Cornell and Puerto Rico. It provides Cornell with easy access to oxisols and ultisols in the tropics, to field test the research findings on such soils carried out in laboratories, greenhouses, and growth chambers at Cornell. It also is a convenient testing ground for concepts on soil and water management, before transfer to underdeveloped countries (Ghana, etc.) where oxisols and ultisols occur. The search for additional constraints on various soil types (3 for oxisols, and 3 for ultisols) has provided new insights; and preliminary studies have accelerated progress toward the ultimate goal of developing productive farming systems.

Puerto Rico has benefitted by a significant enlargement of its total soils research program, the opportunity for prompt utilization of effective management practices, enhancement of the status of agricultural research in the government hierarchy, and the training of staff by association with Cornell's senior scientists.

The subcontract has provided a mutually beneficial association which should be continued.

2. Physical-Chemical-Biological Problems

The constraints on oxisols and ultisols for sustained productivity generally have been confirmed on the Puerto Rico members of oxisols.

3. Utilization

Utilization of research findings may apparently be rapidly achieved through the Agricultural Extension Service. A recent reorganization, when completed, will combine agricultural research, extension, and teaching within the designated departments. All of these are to be transferred to Mayaguez as soon as feasible.

Some aspects of the research, those dealing with individual treatments or practices, may be transmitted to farmers, but will require economic interpretation. For improved farming systems, the appropriate research has not yet been done. For effective work, it is imperative that "tolerant" varieties that are high yielding be identified for each crop to be included in the farming system. This has not been done. Soil management and improvement practices that are economically feasible, to insure reasonable profitability of the system, should be evaluated.

Before utilization can effectively occur, essentially a complete reformulation and a developmental policy attitude toward the rural sector will have to take place. In cross-section, and in the cosmic makeup of agriculture, the rural economy of Puerto Rico represents the developmental situation found in many other developing countries. Agriculture has been victimized by a policy emphasis which has been placed on industrial and urban development ahead of agricultural development. As a consequence, the productivity and employment opportunities have both steadily decreased, particularly over the last 40 years. Puerto Rico now imports more than a billion dollars a year of food items, the majority of which the country could provide for itself under the right policy and developmental climate. Therefore, before the technology available to increase yields and to broaden the cropping base will be used, fundamental changes will need to be made in the incentive climate for agriculture.

The combination of various rates of liming, and of nitrogen and phosphorus fertilization, are now being studied in rotations on 3 oxisol soil types and ultisol soil types. The effective use of legumes to supply nitrogen is an additional management factor under study.

It should be reiterated that the field results from Puerto Rico have been of short duration and further research is needed to provide a sound basis for revamping country agricultural systems. These results must also be correlated with those from Brazil, Peru, Colombia, and Ghana before drawing final conclusions. As noted earlier, the Puerto Rico soils seem to be substantially more productive than those in the other regions noted. The significance of this status requires further study.

4. Soil Productivity Considerations

The productivity of several Puerto Rico soils has been shown to be strongly influenced by the supply of water in the soil profile to meet plant needs, the supplies of available phosphorus and the supply of available zinc. Supplemental irrigation effectively corrected limited water supplies. Phosphate fertilization corrected deficiencies in this element, and relatively small amounts of zinc were sufficient. When these deficiencies were corrected, the subsoils were as productive as the top soils.

Substantially higher yields of corn and beans were produced by "tolerant" strains or varieties of these crops than by most traditional varieties or "sensitive" strains that had been introduced. Sorghum behaved much like corn, but total yields were

lower, even for tolerant strains. Detailed studies confirmed that the principal factors were those in the soil, rather than climate (other than water), pests, and management factors.

Nitrogen fertilizers were generally needed, and were most effective when applied as sidedressings when the crop was 8 to 10 inches tall. Nitrogen fertilizer responses were similar to those reported in temperate climates. The feasibility of supplying nitrogen by growing leguminous species in the farming system has not yet been studied. The practice of using heavy applications of nitrogen fertilizer on beans appears to be uneconomic. Further research is needed on effective inoculation to produce good nodulation of bean roots, so that external nitrogen supply is not a limiting factor in growth. Such data would provid guidance on culture of other food grain legumes, green manuring legumes, and forage legumes. Fertilizer responses on sweet potatoes and cassava were conclusive on Puerto Rico soils.

The constraints on oxisols and ultisols for sustained productivity generally have been confirmed on the Puerto Rico members of oxisols and ultisols, as falling into 3 categories: the physical constraints include deficient water supplies for crops caused by rapid water loss by excessive soil drainage even in the rainy season, and low water-retention capacity caused by the

unique structure of the soil in which fine particles are aggregated with large continuous channels between aggregates.

The chemical constraints include: (a) strong soil acidity; (b) high content of soluble aluminum (manganese in some soils) that is toxic to many plant types; (c) low content of phosphorus, and the rapid conversion of fertilizer phosphate to aluminum phosphate that has low solubility; (d) very low cation exchange capacity, with very limited contents of calcium and magnesium; and (d) a frequent deficiency in one or more of the micro nutrients essential for plant growth (zinc, copper, boron, molybdenum). The alleviation of these constraints by fertilizers and soil amendments not only requires the addition of suitable chemicals, but the method of application, amounts, and timing of treatments with respect to crop plant needs are important.

The biological constraints include the barriers to root development and occupation of the soil profile and this differs with species and with varieties (cultivars) within species. Tolerance to strong acidity and high levels of soluble aluminum (or manganese) is necessary for good soil occupation by crop roots, and for effective utilization of water contained in the soil profile. Sensitive varieties of the same crop species may produce only 10 to 50 percent as much growth as tolerant species. There are great

differences also between crop species; corn and beans are far more sensitive than upland rice or cassava.

A significant research finding is that crop yields generally are substantially higher on oxisols and ultisols in Puerto Rico than those reported for Brazil or Peru. A theory that should be tested is whether long continued farming and improved treatments (practiced for many decades in Puerto Rico) have substantially changed these soils from their native state. Will such improvement occur on newly reclaimed lands (Cerrados of Brazil, Ilanos of Colombia, or the ultisols of Peru and Ghana) if well managed over extended periods? Sustained research is needed to evaluate this possibility, since the reward would be continuing productivity—the antithesis of shifting cultivation that has been traditional.

Other biological aspects include the possibility of replenishing the organic matter content of the soils by roots of soil-improving crops (grasses and legumes), and thus improving moisture-supplying power of the soil profile as well as the cation exchange capacity responsible for contributing plant nutrients in available form. The use of leguminous crops and green manures to supply nitrogen in lieu of nitrogen fertilizers has only begun to receive research scrutiny.

A unique characteristic of oxisols and ultisols in Puerto Rico is the luxuriant growth of weeds and native legumes whenever crop land is allowed to stand idle. These responses strongly indicate productive potential, but research is needed to understand the phenomena and utilize the revealed principles for growth of economic crops.

B. Brazil

1. Introduction

The research on the CPAC experiment station near Brasilia is sited on Oxisol soils of the subgroups Dark Red Latosols, and Red-Yellow Latosols. Laboratory facilities of CPAC are excellent and fully accessible to the NCSU-Cornell staff and graduate assistants. Field assignments are adequate and logistical support is good. The review team had excellent discussions by Dr. Elmar Wagner and Dr. Wenceslau Goedert, Director and Associate Technical Director, respectively, of CPAC, as well as Dr. Dale Ritchey, coordinator for the NCSU-Cornell project. Five of the research assistants made presentations on research dealing with phosphorus, liming and soil acidity, nitrogen, zinc, potassium, magnesium and calcium. Field inspections were made of crops growing under the several kinds of soil treatments. This field research is on soils

that are fairly representative of some 183 million hectares of land in Central Brazil that now are largely undeveloped.

These oxisols have smooth to rolling topography; they are deep and well-drained, but strongly acid, high in soluble aluminum that is generally toxic to crop plants, and quite low in fertility. These soils also are seriously deficient in water-holding capacity so that crops suffer from drought even in the rainy season when periods without rain extend beyond 3 or 4 days. Although limited field research began in 1969, most of the significant findings have occurred since 1973. The basic nature of soil properties and deficiencies of oxisols are now known and treatment for alleviation of the several constraints have now reached the stage where continuing productivity is judged to be feasible. However, further testing is needed to develop the most economical methods of soil treatment and cropping practices, and to prove that sustained productivity is likely under rational farm management. The current status of research provides a sound basis for further exploration and development of economically sound farming practices. Termination of research at the current stage of development would probably sacrifice the present significant breakthrough, since exploitation by development of utilization practices remains to be done.

2. Physical-Chemical-Biological Problems

Excessive soil acidity may be corrected by liming. The amounts necessary, depth of mixing in the soil, and frequency of liming, differ as to costs for different soil types. The benefits for various crop species and varieties show wide differences. Lime treatments generally correct deficiencies in calcium required by tolerant species, and the use of dolomitic lime corrects deficiencies in magnesium as well as calcium. Liming at appropriate rates also reduces the amounts of soluble (toxic) aluminum, which makes possible good yields of tolerant species of crops. The economic feasibility of correcting soil acidity to non-toxic levels of aluminum for sensitive crops, such as maize, is yet to be determined.

Low phosphorus status of all oxisols is a major constraint. In conjunction with liming, the application of superphosphate has permitted high crop yields, but the benefits are substantially better for tolerant crop species (viz., upland rice, cassava, and soybeans), than for sensitive species. A most promising situation is that rock phosphates (costs one-fourth of superphosphate is made soluble by interaction with these acid soils, and release enough phosphorus to support satisfactory crop yields. However, there are significant differences with different sources of rock phosphate, and these are currently being tested. Also, there appear to be substantial differences between crop species, and between

varieties of the same species, in their "feeding power" for slowly soluble forms of phosphorus.

Some progress has been made in evaluating the tolerance or sensitivity of plant materials to the combination of high acidity and soluble aluminum with low-phosphate supplies, but the comprehensive evaluation of all major crop species, and of the available varieties of each species, is only beginning. This promises to be equally important with soil treatment in developing continuing productivity of the oxisols.

The oxisols are inherently low in supply of essential plant nutrients, and these researches have dealt with nitrogen calcium, magnesium, potasium and zinc as well as phosphate. Satisfactory methods of correcting these deficiencies are known, but data on the least costly and most profitable treatments are still being explored. Particular importance rests on the use of legume species to replenish the supply of nitrogen (through fixation of nitrogen in root nodules), and this depends on findings to be made on the residual soil nitrogen resulting from growing legumes in rotation with non-legumes.

The correction of deficient water supplying power of oxisols is related to the limited occupation of the acid soil horizons by crop roots and by the inherent low capacity of soil

to retain water in the soil profile. Cropping practices must cope with this problem. It is estimated that 5 to 10 percent of the Brazilian oxisols may be irrigated by local water supplies that can be developed, and the economics of such irrigation must be evaluated. Liming, in an appropriate manner to reduce soil acidity, also increases root occupation of the soil. The possibility of increasing the water-holding capacity of the soil profile by periodically growing adapted forage grasses and legumes that replenish soil organic matter to the depths of such occupation, remains to be explored. This would constitute a significant contribution that can now only be speculation based as indirect evidence.

The following activities that should build on the factual base created by research to date, should be given high priority in a continuing program:

1. Tropical Soils—Characteristics and management. To validate the concept of continuing productivity, and to explore new methods of soil improvement.

2. Soil Conservation—Water erosion constitutes a universal hazard that will assume greater significance as lands are farmed. Nothing

has been done to apply basic knowledge of erosion control to these soils.

3. Pest Management—Particularly, weed control and control of root nematodes are important second generation problems to be solved.

4. Farm Economics—The influence of improved technology on the cost of production per unit of commodity, must be developed to guide development of farming systems.

5. Farming Systems—The choice of crops and of adapted varieties, when combined into systems, must be evaluated in terms of profitability of candidate systems.

6. Tolerant Plant Species—There must be a comprehensive evaluation of all climatically adapted crop plant species, and of varieties within each species, to determine their tolerance of soil acidity, toxic aluminum, and slowly available phosphate, which are inherent in all oxisols. From the limited data at hand, this type of research gives great promise.

7. Supplying Nitrogen through Legumes—This is the means available to farmers, to meet crop plant needs for nitrogen by inclusion of legumes in the rotations. The legumes (food grains, oil seeds, forage species) should be profitable as crops, and also provide substantial residual soil nitrogen for other crops.

8. Replenishing Soil Organic Matter—The native supply of soil organic matter may be replenished by selected rotations that include plant species that make deeper root occupation and provide residual organic matter that will increase water-holding capacity, as well as supply essential nutrients released by root decay.

All of the above types of research are needed to insure sustained productivity of oxisols, as needed for permanent agriculture. It is estimated that a total of 7 graduate assistants, 2 full-time consultants, and 3 part-time consultants would adequately staff such a program at the present research station.

C. Peru

The experiment station at Yurimaguas is representative of the Ultisols of the tropics in Latin America, Africa, and Asia. It was selected with the objective of determining whether the traditional slash-burn system of management could be replaced with systems of continuous productivity. The ultisol regions have much higher rainfall than oxisol regions and the native vegetation is composed of trees and heavy understory plants. The slash-burn method of farming permits crop production for only two or three years after clearing, followed by long periods of non-use during which native vegetation re-occupies the land. Development of continuously productive farming systems would increase the quantity of arable land by 5 to 10 times that of slash-burn methods.

Ultisols are deep, well drained, highly acid throughout the soil profile, high in toxic aluminum, and very low in phosphorus. They are deficient in fertility, particularly calcium, magnesium, potassium, and in certain trace elements. The soil profile has low water-holding capacity, and crop species may suffer from moisture shortage when periods for more than three or four days are without rain.

Although the current research program has been continued for only four years, some definite conclusions may be drawn as follows:

1. Clearing the jungle by mechanical means, versus hand clearing and burning, was strongly in favor of traditional practices. Bulldozing was much more costly, and it resulted in substantial reduction in productivity, probably because the ash from burning was not left on the land. Slash and burn for new clearings is low energy, labor intensive, compatible with development by local small farmers.

2. Liming. Liming is essential for all crops, but some acid-tolerant crops require less lime for full production than sensitive crops. (Maize is sensitive). Deep liming supports greater initial production, but repeated liming to depths of 4-6 inches eventually proves adequate. Liming improves phosphate efficiency, and supplies calcium also. The effect on depth of root penetration has not been observed to date.

3. Phosphate fertilizers are universally required, but tolerant species are more easily satisfied than sensitive species. Rock phosphate may be substituted for fertilizer superphosphate, although the latter gives more prompt response.

4. There have been new clearings made each year beginning 1974, so that results of 1, 2, and 3 years of cropping were obtained in 1976. The use of lime and fertilizers has successfully maintained crop yields for 3 years, in contrast to steady decline where lime and fertilizers were not used. The crops included upland rice, cassava, soybeans, peanuts and maize. Maize yields have not reached desirable levels, for unknown reasons. These tests must be continued to prove sustained productivity for longer periods.

5. Guinea grass and tropical kudzu grow luxuriantly when phosphate is applied. They appear tolerant of strong soil acidity, high soluble aluminum, and limited storage of soil moisture. Tests in which such forage plants are grown in rotation with tilled crops should be conducted to determine their contribution to sustained productivity.

6. Mulching row crops with guinea grass or tropical kudzu, appears to reduce water stress, probably because of lower evapo-transpiration losses of soil water.

7. This research has been very productive in development of a knowledge base for ultisols, at relatively low costs. It has been recognized as being important for planning agricultural development in the upland selva (jungle) of Peru. There are frequent visitors to these research fields, including representatives concerned with development of these extensive lands. The research findings are considered applicable to all types of development, with emphasis on small farmers who predominate in most ultisol regions.

8. The root occupation of soil horizons by different crop species, and of individual varieties within species, has not been explored to date. This would be useful in selecting crops to be included in trial farming systems, since extensive root systems are doubtless associated with higher yields.

9. The possibility of replenishing organic matter to the depth that perennial grasses and legumes occupy the soil profile is promising, since such replenishment would improve water supplying power of soils, and serve as an enlarged reservoir for plant nutrients. A nearby field of sugar cane, now producing a 10th ratoon crop, offers an opportunity for

evaluating the potential for soil improvement through plant roots.

10. There appears to be a significant opportunity for extending the current accumulated knowledge of soil improvement and crop improvement, to the production of foods on home gardens. There is virtually no production of vegetables at present, to supplement the present limited diets. There appear to be adequate local markets to absorb produce grown in excess of family food needs. The following crops are suggested for preliminary trials: tomatoes, onions, eggplant, green pepper, squash and pumpkin, melons, cucumbers, radish, cabbage, true sweet corn, cowpeas, pigeon peas. Research is needed to select crops best suited to ultisols. Varieties of each crop, that are tolerant of ultisol conditions, should be sought.

11. Since there is substantial local livestock production for milk and meat, additional research to identify forage grasses and legumes species suited to these soils is warranted to supplement previous work with a few annual crops.

12. The foregoing studies should develop sufficient data on production with improved technology to undertake the assembly of enterprises into farming systems and estimates as to the profitability of such svstems.

13. To implement the proposed expansion of research, it is estimated that the staff should be enlarged by 3 additional graduate assistants, and 3 part-time consultants. Root studies, vegetable production and pest control should receive attention.

D. Colombia

Although the tropical soils research contracts are not inclusive of Colombia, observations were made there that have a bearing on such centrally funded research.

1. ICA (Instituto Colombiano Agropecuario) is a government agency that includes research and development for agriculture. There has been a sharp drop recentl in the government's effort in agricultural research. The stated justification is that research has been largely done and emphasis may be diverted to actual production. This illustrates an uninformed concept

that agricultural production problems are quickly solved, and research may be deemphasized. The example of developed nations may well serve to create a better understanding by LDCs of the continuing role of research in agricultural production and development.

2. CIAT (Centro Internacional de Agricultura Tropical). This excellent institution has concentrated its efforts on three major commodities—cassava, beans, and livestock production. There are excellent interdisciplinary teams working on the various aspects of these three commodities. In extended conversations with soil scientists at CIAT and visits to field experiments it was emphasized that there is no intention of undertaking basic soils research in depth, along the lines of the tropical soils research contracts with Cornell and NCSU.

This type of commodity specialization applies to all international research centers. The several disciplinary researches are pursued to the extent that they meet the needs of a specified commodity

but no further. It is essential that the research commitments of these institutes be understood to exclude the type of research covered by the Cornell and NCSU contracts. There is little or no duplication of effort between these institutes and the AID soils research contracts.

VI. Evaluative Comment on the Cornell and North Carolina State University On-Campus and Field Research Program on Tropical Soils

1. Introduction

The review under this section applies to the work of both NCSU and Cornell. Each university has conducted research on its home campus. In the field, Cornell has been involved in Puerto Rico, Brazil and Ghana, and NCSU has been involved in Brazil, Peru and Central America. The research in Brazil by NCSU and Cornell is truly a joint project.

Basically the efforts expended on campuses at both universities are of the laboratory and greenhouse type. All field work was done in the tropical locations. Frequent joint planning and review sessions were held, so all scientists learned and advanced together.

The laboratory analyses of soils, and the greenhouse and growth chamber testing of plant performance are essential parts of the research program, but must be done where these facilities are available and where skilled operators are present. Such activities are impossible in the field situations where the constraints are found. The most effective utilization of total resources is to use the existing facilities at the university for laboratory analysis and plant testing under controlled conditions, with the field

testing done in tropical locations; but where both functions are under the direct control of the senior scientists and are carried out by graduate assistants who move from the campus to the field as the program evolves. This has been done by the contractors.

Laboratory analyses of soil samples that have been subjected to various treatments in the field, and the interaction of soils with chemical soil amendments provided basic information on the changes in their suitability for crop growth. The growth chambers and greenhouse testing of crop seedlings provide rapid screening of large numbers of strains or varieties as to their adaptation to the soil conditions. On the basis of such screening, field t ls have been made of the more promising strains. Such field trials have demonstrated that the use of aluminum-tolerant strains, that also have ability to grow at low soil phosphate levels, permits growing acceptable crops where sensitive strains of the same crop fail.

When these projects were first undertaken, the prime questions were whether or not tropical soils could support continuous food crop production. Up until this time, there was little evidence that food crops could be grown on these soils and many attempts to grow such crops had ended in failure. There were those who argued that aluminum toxicity would prevent crop growth and

any attempt to correct the aluminum problem would either be too costly or would bring about other problems, such as micro element deficiencies that would in fact be worse than the original problem.

These projects soon identified the major problems of these soils (oxisols and ultisols) and demonstrated that substantial improvement in crop production could be achieved. Major problems of the tropical soils under evaluation were:

a. Extremely low nutritional status, especially phosphorus (and very high phosphorus-fixing capacities), but also including calcium, magnesium and potassium.

b. High amounts of acidity and soluble aluminum.

c. Low water availability of the soils due to:

(1) High levels of toxic soluble aluminum

(2) Low water-holding capacity

2. Physical and Chemical Properties of Tropical Soils

A most important area of inquiry is that of understanding the physical and chemical properties of soils, their morphology and general classification and to determine the similarity of the properties over the broad land area represented by these two important soils. Hence, both Cornell and NCSU have put considerable

effort into this aspect of the problem. They have found, for example, that similar soils are found in parts of the Northeast United States, and particularly in the Southeast United States. They agree that the basic nature of the problems on these soils is the same in the United States, South America, Puerto Rico, or Africa. The degree or extent of the soil constraints may well vary with specific site conditions, but in general the nature of the problem is the same. (For further information, see annual reports and published references.) For example, Cornell working on nitrogen response found quite similar results on soils in New York, Puerto Rico and Ghana (see Figures 2 and 3).

Valuable information has been gathered on soil properties in tropical Latin American regions, which had little or no previous soils information. For the first time a coherent picture of the soils resources and variability in the interior savannas and jungles of Guyana, Venezuela, Colombia, Peru and Brazil now is available. Characterization of several sites in Central America was also accomplished, as was comparison of soil properties and management strategies between savanna and jungle areas of South America and West Africa.

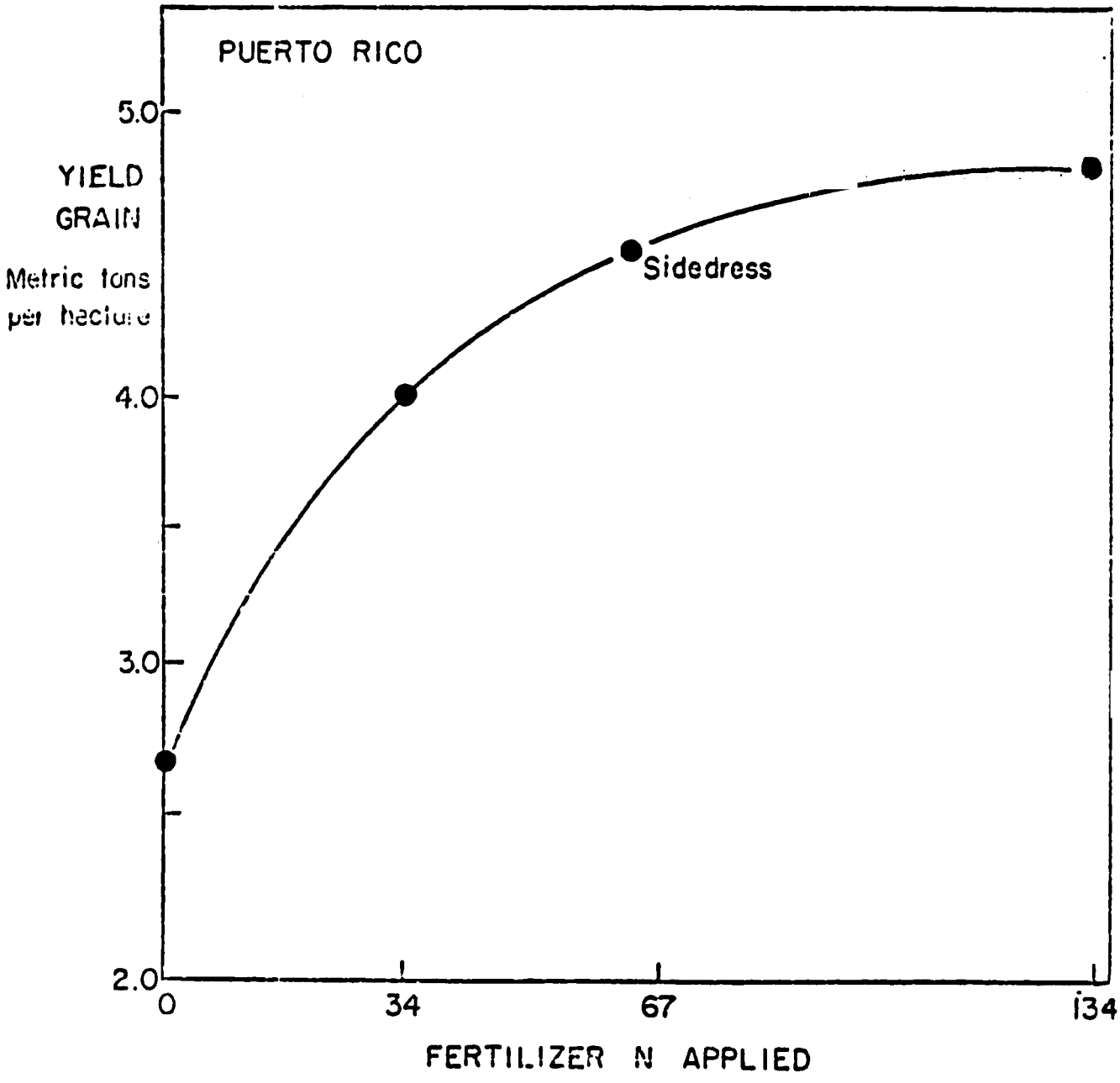


FIGURE 2. Grain Yield Response to Nitrogen: Puerto Rico.

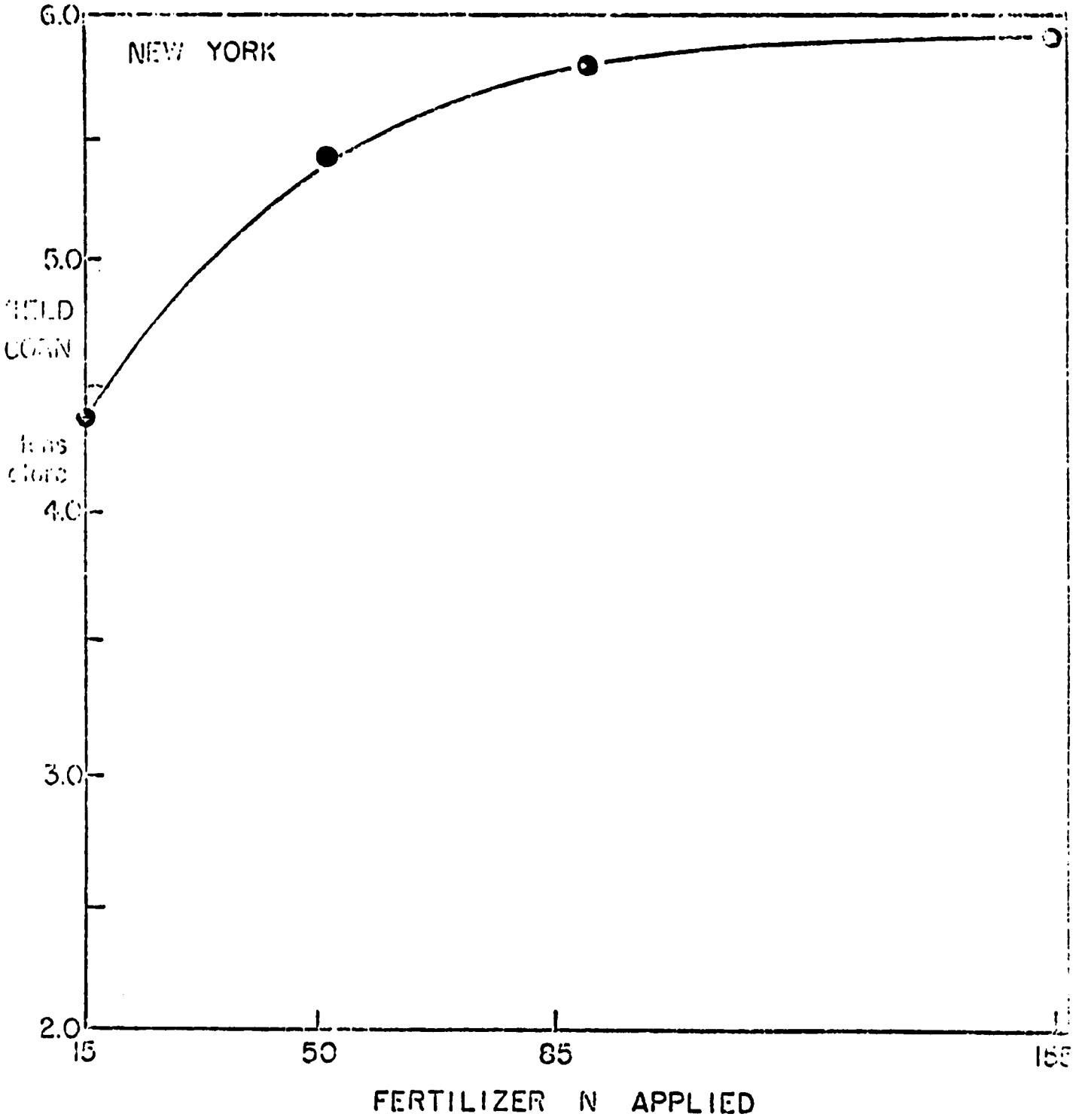


FIGURE 3. Grain Yield Response to Nitrogen: New York.

3. Fertility Response Measurement

NCSU has developed a Fertility Capability Classification System which is a technical system based primarily on topsoil criteria. It serves as a way of grouping soils having similar fertility limitations by simple techniques not requiring sophisticated laboratory analyses. Three countries (El Salvador, Colombia and Venezuela) are now using this system.

Experimental results demonstrate the high yield production potential of these soils. For example, on oxisols and ultisols in Puerto Rico, yields of corn grain with adequate fertilizer have averaged 4.5 m.t. grain/year (average of 14 locations/years of data): Planaltine, Brazil 6.2 m.5. grain/year (4 location years); Ghana, 4.5 m.t. grain/year; Central America 3.2 m.t. grain/year; and Yurimagaus, Peru 3.6 m.t. grain/year. Further, the native capacity of these soils to supply nitrogen is greater than is generally appreciated and good crop production can be obtained, as far as nitrogen is concerned, with moderate applications of properly applied fertilizer nitrogen during several years of cropping.

As indicated, these soils are so high in soluble aluminum and so low in phosphorus and calcium that long-term experiments were set up in 1972 to study these factors. Since the start of these experiments, it has become evident that there are genetic

differences in plant types with respect to tolerance to AL toxicity. Therefore, the long-term field experiment where lime was applied at four different rates, and two depths of incorporation, was modified during the 1974-1975 rainy season to accomplish an additional objective; to test varietal differences with respect to aluminum tolerance. The residual effects of lime applications and the related changes in soil properties and root development continuec to be measured.

Two grain sorghum hybrids, Taylor Evans Y-101 and RS-610, were supplied by plant breeders of the EMBRAPA Corn and Sorghum Research Center in Sete Lagoas because differential tolerance to aluminum was suspected. The original plots were split in half and sorghum was planted on November 7, 1974 in 60 cm rows at an approximate population of 250,000 plants/ha. The crop was harvested on March 11, 1975, after which a ratoon crop was allowed to grow. The main crop received broadcast applications of 150 kg K_2O/ha as KCL and 50 kg Mg/ha as $MgSO_4$ and a banded application of 150 kg P_2O_5/ha as triple superphosphate and 20 kg N/ha as ammonium sulfate. This was followed by two sidedressed applications totaling 200 kg N/ha as urea. The ratoon crop was not fertilized. No additional lime has been added to this experiment since the original applicatior of December 1972.

4. Varietal Differences in Sorghum

The grain yields of the fourth consecutive crop are shown in Figure 4. Deep lime incorporation was statistically superior to shallow incorporation only at the 1 ton/ha rate. There were no differences at the higher rates as it was observed in the first and second consecutive crops (1973 and 1974 Annual Reports). The large difference in this experiment, however, was the contrasting response between the two hybrids. Taylor-Evans produced dramatically higher yields than RS-610 at the 0, 1 and 2 tons/ha levels of lime. At higher rates, the differences tended to disappear. In general, Taylor Evans produced the same yields with half the rate of lime as RS-610. Figure 5A shows that the differential response of these hybrids is closely related to the percent aluminum saturation of the top 15 cms of soil. Taylor-Evans showed a slower rate of yield reduction with increasing aluminum saturation than RS-610. At 40% Al saturation, for example, Taylor-Evans produced only 27% of the maximum yield at the same level of aluminum saturation.

The ability of the sorghum plants' roots to proliferate under high levels of aluminum saturation was related to the yield differences. Figure 5B shows the relationship between root lengths and aluminum saturation in the top 15 cms. Deep liming applications increased root lengths in both varieties.

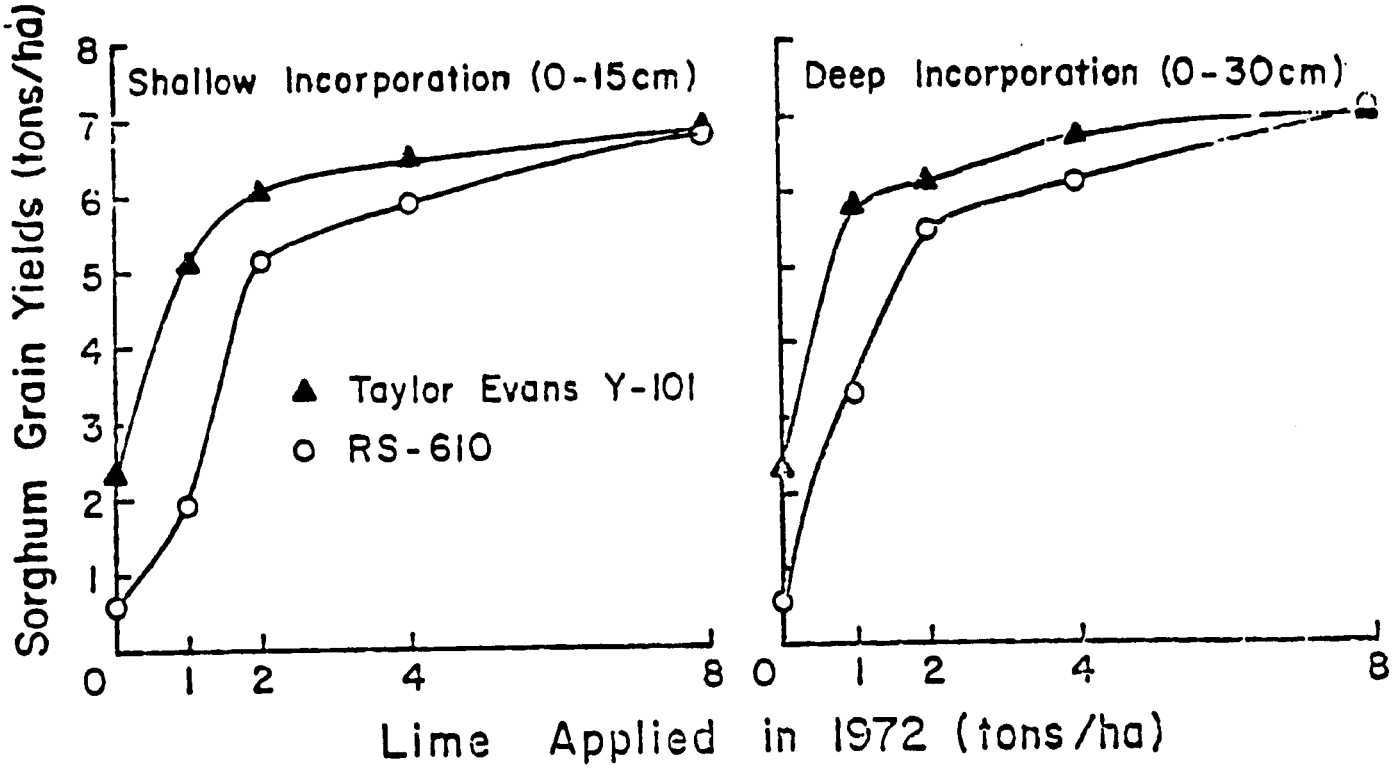


FIGURE 4. Differential response of two grain sorghum varieties to rates and depth of lime incoration. Brasilia, 1974-1975 rainy season.

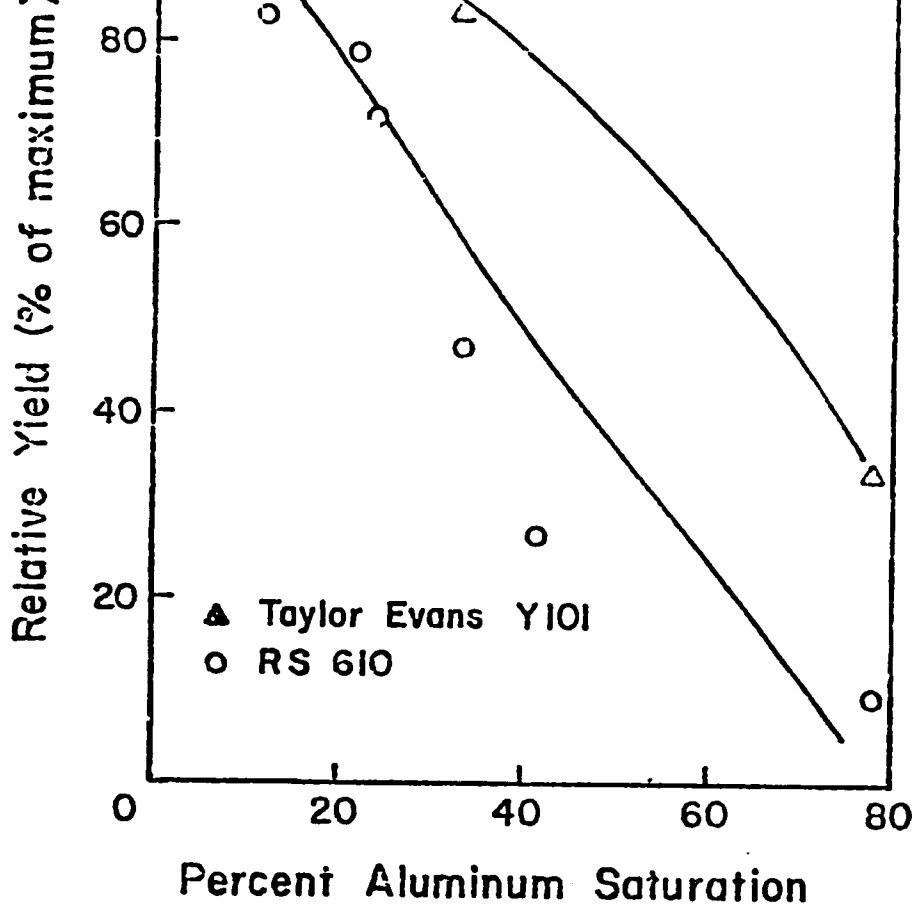


FIGURE 5A. Effect of aluminum saturation in the top 15 cm on the grain yield of two sorghum varieties. Brasilia 1974-1975 rainy season.

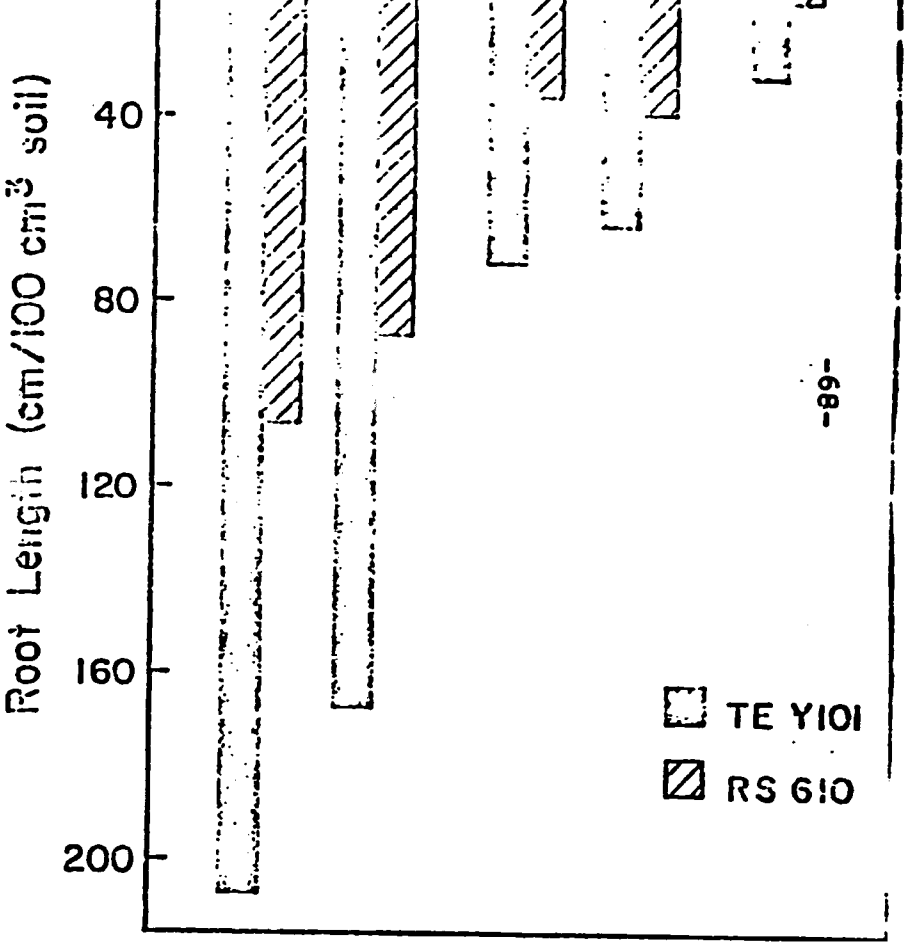


FIGURE 5B. Varietal differences of sorghum in relation to root length and percent aluminum saturation. Brasilia 1974-1975 rainy season.

These results show the potential for utilizing aluminum-tolerant cultivars as one of the management components for acid Oxisols. A combination of 1 ton/ha of lime incorporated deeply three years ago and an aluminum-tolerant hybrid produced a high grain yield of 6 tons/ha. In contrast, the conventional practice of shallow liming and an aluminum-sensitive sorghum hybrid required 4 tons/ha lime to arrive at the same yield of 6 tons/ha.

5. Cumulative Effects of Liming

The cumulative effect of four consecutive crops (3 of corn and 1 of sorghum) is shown in Figure 6. Although there was no response to depth of liming in the second and fourth crops, the overall trend shows a positive advantage of this practice. Incorporating lime to 30 cms in effect decreased the lime rate needed to attain a specific yield, by half. The advantages of deep lime applications are related to increasing root proliferation which, in turn, allows for better soil moisture and nutrient utilization. This favorable effect can be expected in other soils with high aluminum saturation in the sub-soil. No beneficial effects of deep liming can be expected in soils where the sub-soil is not aluminum-toxic, like the Red Yellow Latosol on the first erosion surface at CPAC.

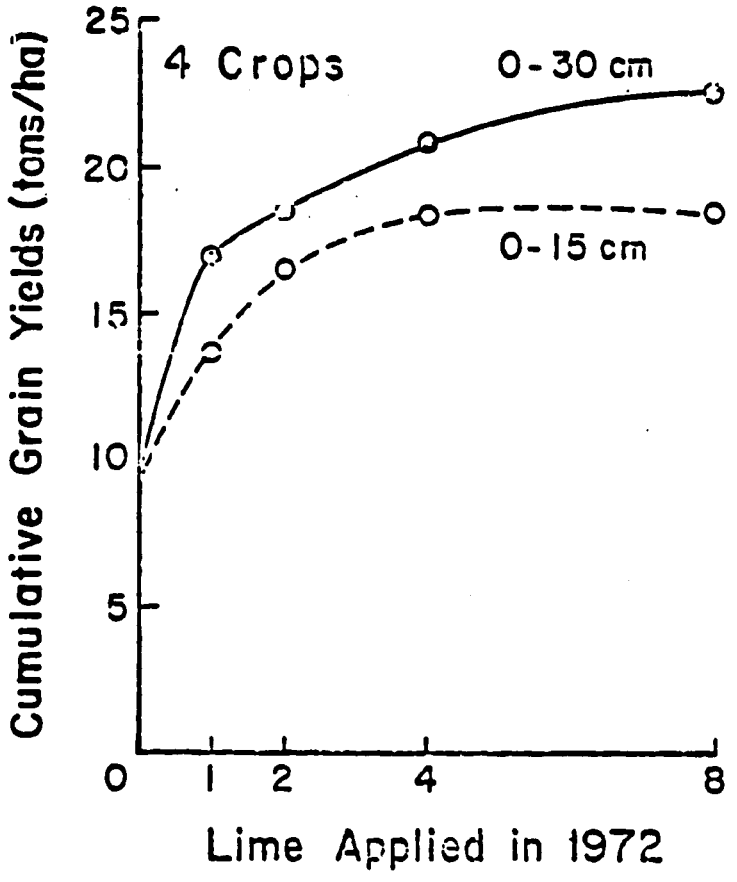


FIGURE 6. Cumulative grain yields of four consecutive crops harvested since the original lime applications. The fourth crop is the average of the two sorghum varieties. Brasilia, 1972-1975.

6. Residual Effects of Liming

An estimation of the residual effects of lime applied in 1972 to the first four grain crops is shown in Figure 7, expressed as percent maximum yield relative to treatment which always gave the highest absolute yield, which was 8 tons/ha of lime incorporated to 30 cms. Among the shallow depths of incorporation, the 1 ton/ha rate has lost most of its residual effect, producing only about 26% of the maximum yield during the fourth crop. In comparison, the 2 tons/ha rate produced 72% of the maximum yield, the 4 tons/ha rate 83%, and the 8 tons/ha rate 97%. Consequently, the residual effect of these heavier rates is still considerable.

The deeply placed treatments, however, showed a slower rate of decline in their residual effects. The 1 ton/ha produced about 47% of the maximum yield, while the 2 and 4 tons/ha rates produced 79% and 86%, respectively. In spite of the lower lime rate per unit of soil volume, the residual effect of deeply incorporated lime is superior to that of the shallow incorporations.

The zig-zag pattern observed in some treatments with time is typical of data where relative yields are plotted as a function of time. The low points are normally associated with low maximum absolute yields because other limiting factors prevented a

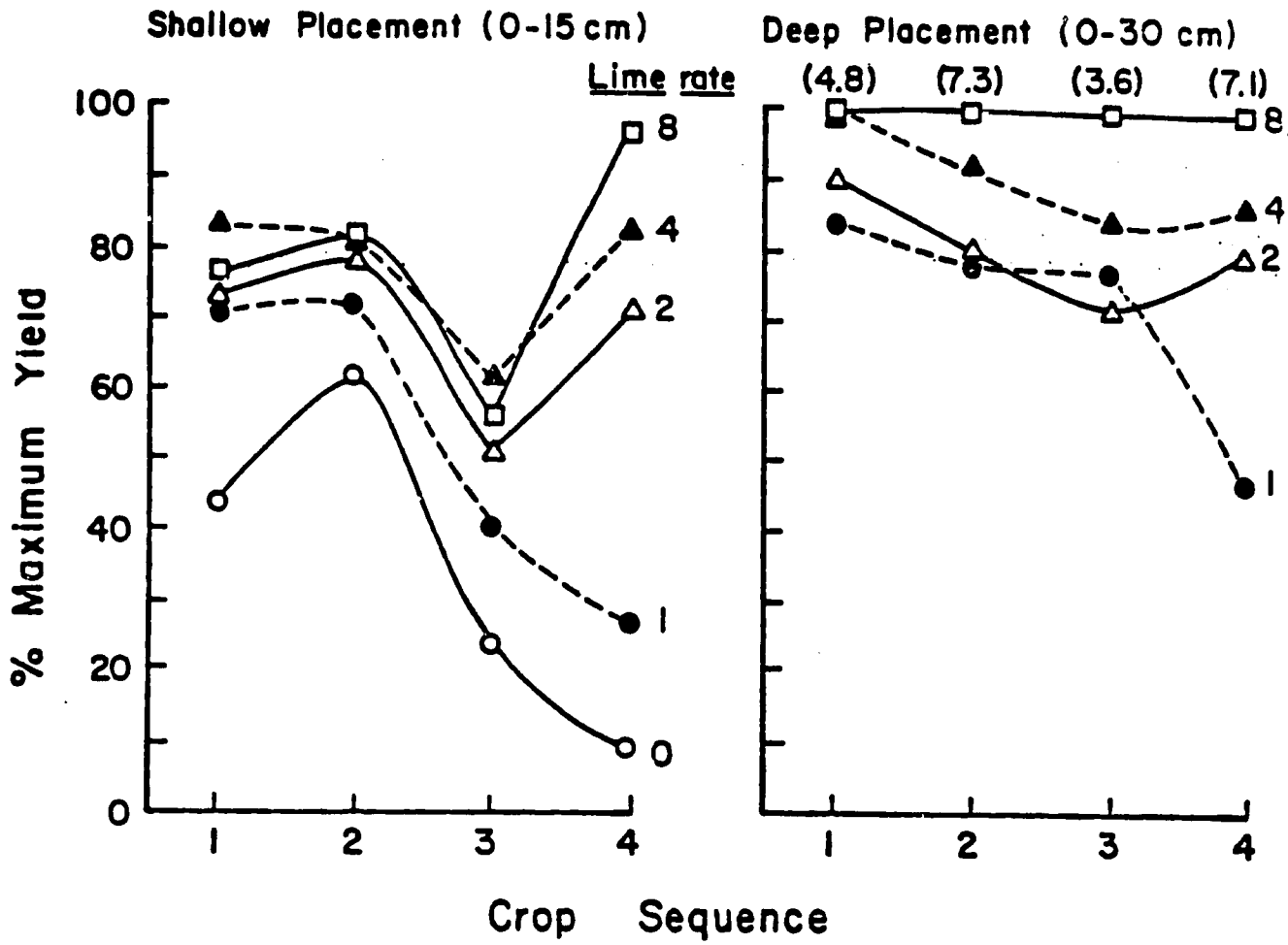


FIGURE 7. Residual effect of lime applications expressed as percent maximum grain yield relative to the yield of the 8 ton/ha deep treatment. Numbers in parentheses show the maximum yields in tons/ha. First three crops corn, fourth sorghum (RS-610 variety). Brasilia, 1974-1975.

full response to the materials added. This was the case in the third crop which was adversely affected by extremely wet weather and subsequent pest and disease attacks. The overall trend of the experiment suggests that a lime rate of 4 tons/ha deeply incorporated can provide a good residual effect with over 80% of the maximum yield. Deep incorporation of 8 tons/ha remains the best treatment.

While considerable information is now available on the short-term requirements for crop production on these soils, there is an urgent need for long-term studies. This especially true in relation to the more Al resistant varieties and species.

The trends for the residual effects of rates, placement, and timing of superphosphate applications are shown in Figure 8. There is a strong residual effect in all treatments. The total yield was highest for the 1280 kg/ha broadcast treatment. For all other treatments, the banded out-yielded the broadcast treatments. The residual effects of the original broadcast treatments continues to depend on the initial phosphate rate. The 160 kg P_2O_5/ha treatment is only producing about 20% of the maximum yield, the 320 kg P_2O_5/ha about 50% and the 540 kg P_2O_5/ha treatment about 80% of the yield obtained by the 1280 kg P_2O_5/ha broadcast rate. The residual

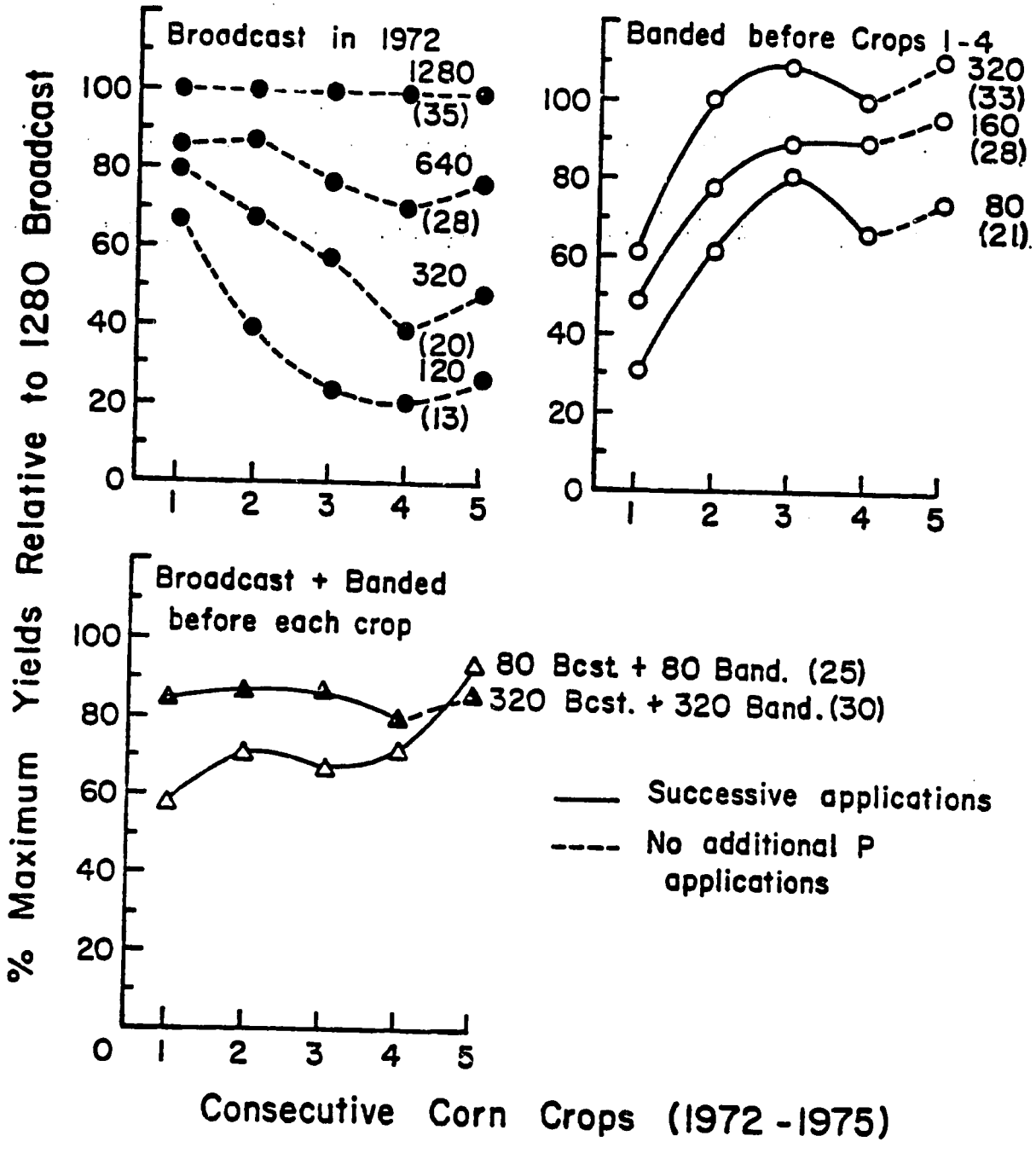


FIGURE 8. Effects of rate, placement and residual or ordinary superphosphate applications to five continuous corn crops. Grain yields expressed as percent of the 1280 broadcast treatments. Numbers in parentheses are the cumulative grain yields in tons/ha. Brasilia, 1972-1975.

effect of four banded applications was strong during the fifth crop. Because of the low initial yields during the first and second crops, the cumulative yields are similar between the banded and broadcast treatments at the same levels of total phosphorus applied.

The most practical approach appears to be the combination of an initial broadcast application followed by a banded application of 80 kg P_2O_5/ha before each crop. When 320 kg P_2O_5/ha was broadcast initially and was followed by four banded 80 kg P_2O_5ha applications, the yields were maintained at about 80% of the maximum with a total phosphorus application 640 kg P_2O_5/ha. When the initial broadcast application was only 80 kg P_2O_5/ha and was followed by five banded applications at the same rate the cumulative yield was 71% of the maximum. These latter two strategies appear to be most promising ways of managing superphosphate applications in this Oxisol with extremely high acidity and aluminum.

The excellent results of these and other phosphate studies show the high requirements for phosphate, and that excellent crops can be grown when phosphate is adequate. However, these data give very little information or insight into the long-term

phosphorus problems or how best to solve them. Such solutions will come from intensive long-term studies involving various cropping systems and crops having different feeding capabilities for mineral nutrients.

7. Available Soil Water

In the savanna areas, water is likely to be a limiting factor. This is due to the low water holding capacity of these soils, and where subsoil acidity or Al toxicity restricts root growth. One or two weeks without rain can nullify the benefits of all the other inputs required for good crop production. For extensive areas in Central Brazil, it is estimated that average yields of maize during the rainy season may only be about half of what is possible if supplementary irrigation were provided, or if lime is incorporated to 30 cm or more. Al tolerant varieties may go a long way toward correcting this. Experience in Ghana likewise has shown that uncertainties in rainfall may have serious consequences.

The following table indicates the general relationship between soil acidity and the ability of cotton plants to utilize available sub-soil moisture (U.S. data).

TABLE 1.

SOIL ACIDITY LEVELS	PERCENT OF "AVAILABLE" SOIL WATER EXTRACTED BY COTTON PLANT ROOTS
Very Acid (pH 4.2 to 4.3)	35%
Strongly Acid (pH 4.4 to 4.9)	60%
Mildly Acid (pH 5.0 to 6.0)	95%
Neutral or Above (pH above 6.0)	95%

NOTE: The higher acidity restricted root occupation of the soil profile and the absorption capacity of the roots (root branches and root hairs) that are present.

In addition to finding ways to use the sub-soil moisture, timing of planting and minimizing water run-off by good conservation practices, should help to insure good crop production.

In the Central Plateaus of Brazil, sufficient water is available at a reasonable cost to irrigate 5% to 10% of the land during the dry season and provide supplemental irrigation during the wet season. Thus, intensive, year around crop production on small acreages appears feasible. Thus, irrigation coupled with inputs of soil amendments and intensive management could provide very attractive investments.

8. Continuous Vs. Shifting Cultivation

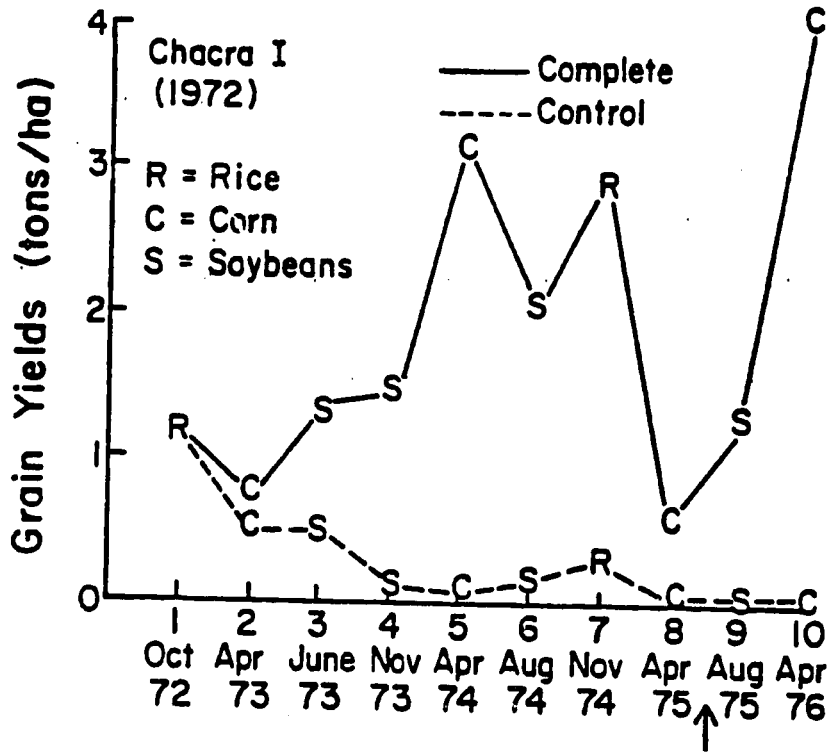
The ultisols of the jungle area of Peru have sufficient rainfall for year around crop production, and is a good example where shifting cultivation has been practiced, but is now feeling sufficient population pressures to dictate an alternative to shifting cultivation. Studies on different methods of clearing have shown that slash-and-burn land clearing methods are superior to bulldozer clearing. All experiments conducted here were on the Yrimagaus soil series, an ultisol classified as Typic Paleudult, fine loamy, siliceous, isohyperthermic, which is considered representative of the region. Soil analysis shows this soil to be deep, well-drained, very acid, low in organic matter and deficient in nitrogen, phosphorus, potassium, calcium, magnesium, and in some cases, sulfur, boron and molybdenum. The sandy topsoil texture makes this ultisol very susceptible to soil compaction but reduces serious phosphorus fixation problems.

Full use of the continuous cropping experiment was obtained in late 1974 with the opening of the third yearly chacra (or clearing). The same four cropping systems (continuous upland rice, rice-corn-soybeans, rice-cassava-plantains and rice-guinea grass) were grown in each clearing and subject to the same fertility

levels, as described in the 1974 Annual Report. In this fashion it was possible to compare the effects of time after clearing with the same crops growing on land cleared in 1972, 1973, 1974, and 1975 subject to the same weather conditions. Among the four cropping systems tested, the rice-corn-soybeans annual sequence appeared to be the most promising, permitting the harvest of three grain crops per year from the same field.

Up to 1974 the data indicated that good crop yields could be maintained with relatively modest fertilizer and lime inputs. A severe reversal of these trends was observed in 1975. The continuous upland-rice and the rice-corn-soybean cropping systems suffered a precipitous yield decline regardless of fertility treatments. It occurred in all three chacras indicating that the problem was not exclusively due to length of land use. (See Figures 9 and 10.) In April 1975, the nitrogen level for corn and rice was increased from 80 kg/ha to 180 kg/ha and for soybeans to 30 kg/ha. Other fertilization strategies continued as before. This had a tremendous effect in increasing corn yields. Soybean yields were up in chacra I and chacra III, but still low in chacra II.

FIGURE 9. RICE-CORN-SOYBEANS SEQUENCE



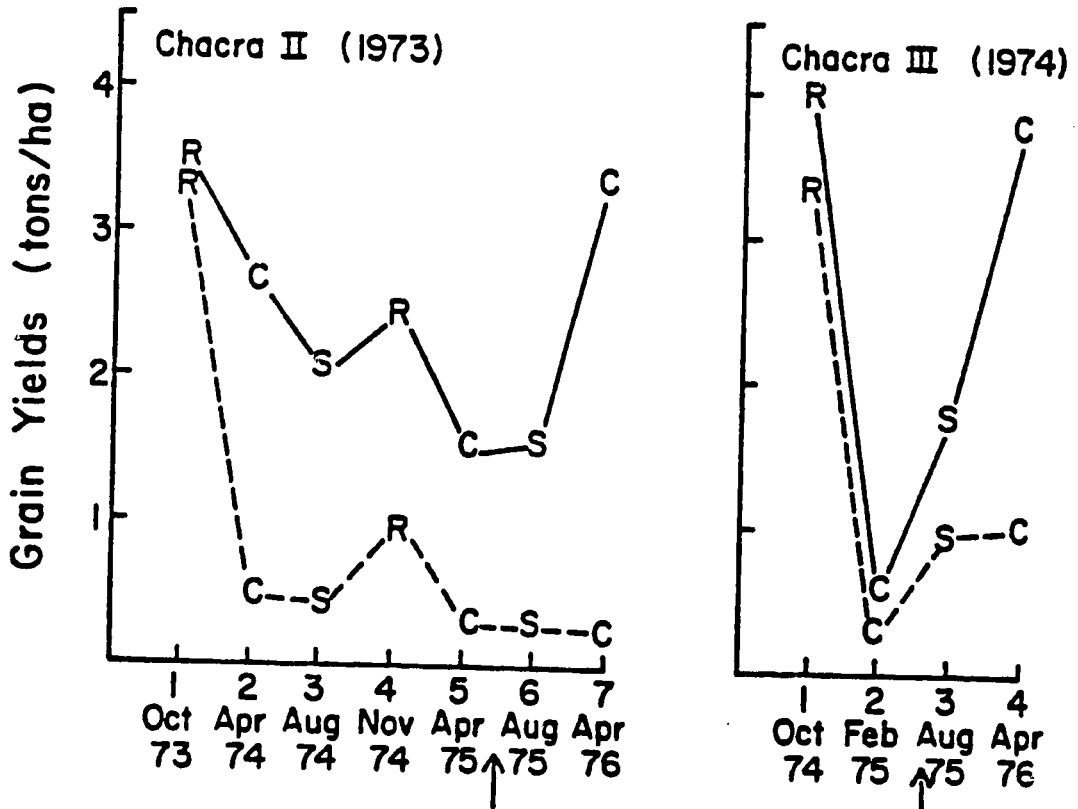


FIGURE 10. Crop Sequence and Planting Date

The yield decline pattern of the continuous upland rice system is shown in Figure 11 at three fertilization levels. In the oldest clearing, chacra I, the unfertilized (tilled) control approached zero yields during the fifth crop, while the maintenance and complete treatments showed a parallel decline with yields equilibrating at about 1 and 0.7 tons/ha, respectively, during the fifth and seventh consecutive crops. In chacra II, the yield declin pattern was much faster in the unfertilized treatments, but the fertilized treatments, which were able to produce good yields up to the fourth consecutive crop, declined drastically during the fifth crop. The decline for the third to fifth consecutive crop was almost identical in chacras I and II. The situation became even worse in chacra II which produced excellent initial yields because of better burning conditions. However, the fertilizer levels used were unable to prevent a precipitation yield decline. Although the lower upland-rice yields are generally expected in the February to April plantings because of a greater probability of drought stress, the declines observed in 1975 do not appear to be related to unfavorable weather.

Several factors were suspected to account for the yield declines: (1) insufficient rates of fertilization, (2) poor

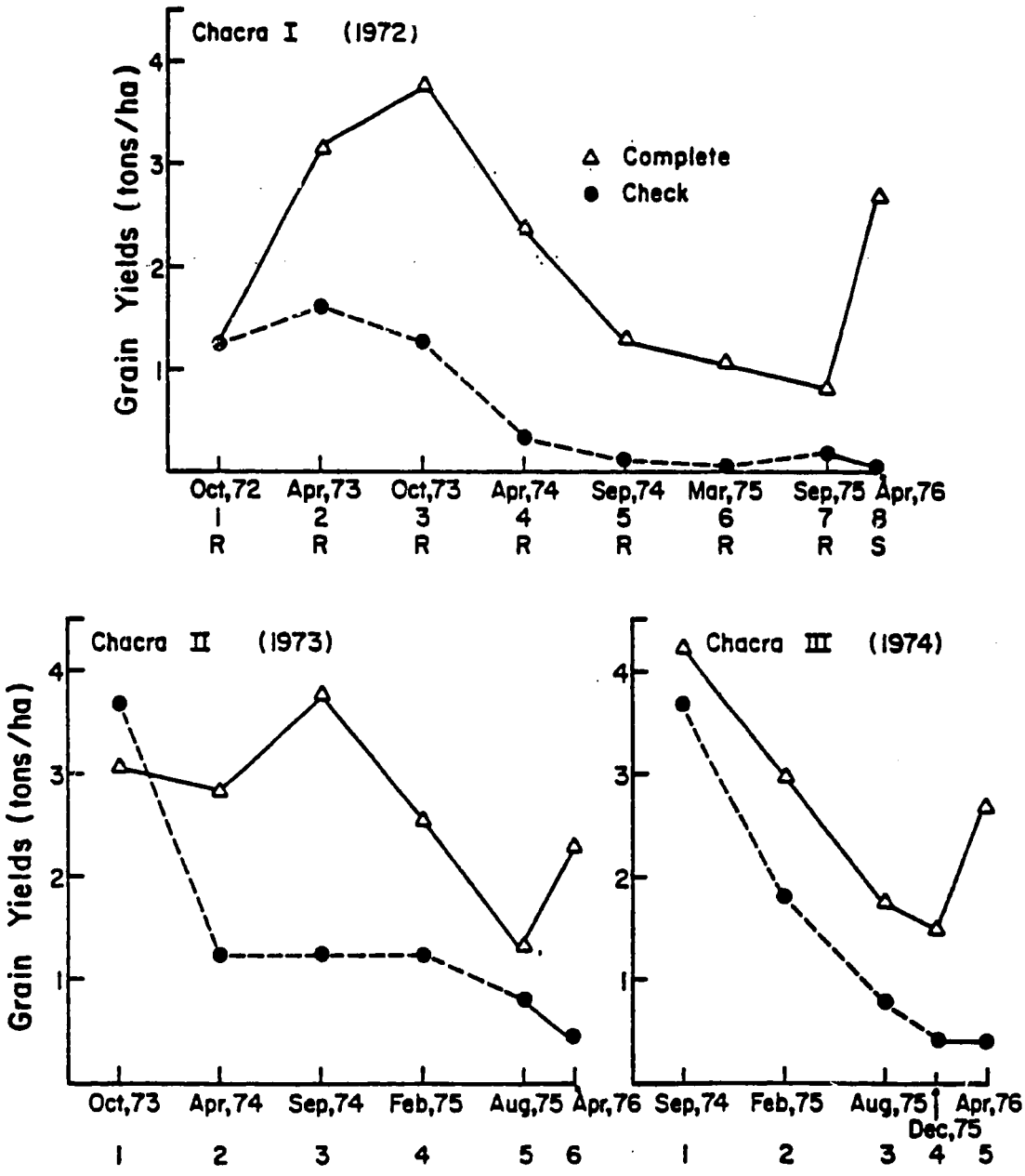


Figure 11. Planting Date and Crop Yields.

germination and initial stands, (3) increased insect attacks, and (4) soil compaction.

It is apparent that the higher level of nitrogen in 1976 reversed the trend. However, the yields are still somewhat lower than in previous years. Thus, for both the continuous rice and the rice-corn-soybean rotations, there appear to be other factors that must still be identified and corrected. These data do, however, give great confidence that these soils can be continuously farmed without shifting-cultivation. Long-term studies are needed to determine the best rotations, fertilizer, and cultural and biological practices for continued economic production.

9. Problems Involved in Utilization of Research

The problems to be solved pertain to actual utilization of lands occupied by oxisols and ultisols, to produce crops on a continuing economically sound basis, under the general climatic conditions and stages of agricultural development that prevail in developing countries. Consequently, actual field testing in the respective regions and countries is an essential part of the research The contractors have enlisted the cooperation of the host country

agriculturists, to conduct field trials on a realistic basis, within the capabilities of local farmers. The field tests have served to provide valid data on actual production, to identify and cope with unanticipated constraints, and they have also served as demonstrations to the local farmers. Field tests permit prompt translation of the most productive treatments into practical production by farmers, on a field scale. However, the host country has carried the responsibility of influencing the country farmers to implement the improved technology.

The researches to date have suggested important opportunities, including: (1) further problem identification and methods of coping with such problems; (2) the creation of host country institutions to provide continuing research on soil, water, and crop management; (3) the training of country professionals at M.S. and Ph.D. levels to man the research institutions; (4) the formulation of policies and procedures relating to regional agricultural development; (5) the operational aspects of a program to transfer new technical knowledge to the producers on the land; and (6) practices that will move the increased production to ultimate markets in a manner that produces economic incentives to the producing farmer.

The first 3 of the above items are within the scope of the research contract and have been well handled to date. Continuity of these efforts is essential if the ultimate broader goals are to be achieved. The outlook is quite favorable in those countries where field work has been underway. Those countries have been keenly interested in observing field results. They have expanded their institutions and designated personnel to aid in utilization of results. The marketing and economic evaluations may be expected to follow, as new production occurs. Items 4 thru 6, above, call for the development of a "utilization" program between the research capacity of Cornell and NCSU and the LDCs (see item 10, following, and section VI).

10. Evaluation of Problem Identification

a. Soil Characterization

The great soil groups termed the oxisols and ultisols, have been shown to have 3 major constraints in terms of crop production capability--limited water supplying power, high soil acidity, and very low phosphorus content. These constraints vary in intensity from location to location, but are universally present on the soils. The limited water supplying power is only partly due to the relatively long dry season with little rainfall, but is also caused even in the rainy season, by low water-holding capacity of these free-draining

soils and by the high content of soluble aluminum that largely prevents occupation of the moist soil profile by crop plant roots. Periods as short as one week without rain cause severe water stress in crops and greatly reduce yields. The high content of soluble aluminum throughout the profile of the oxisols (savanna lands) and ultisols (forested lands), are not only toxic to roots of crop plants, but also react strongly with phosphorus applied as fertilizer, converting it to very slowly available aluminum phosphate. The soils of both groups are very low in total content of calcium and magnesium, both of which are required for growth of most crop plants. There has been identification of deficiencies in the supply of micronutrients (zinc, copper, boron, molybdenum) on acid, high aluminum soils, although aluminum toxicity and deficiencies in calcium and/or magnesium are more important.

The critical matter is the identification of the physico-chemical properties responsible for low productivity, that are characteristic of soils as they are mapped in the field. It is now clear that the great bodies of oxisols and ultisols with similar constraints have been mapped in the tropics and subtropics throughout the world. The management of such soils for efficient crop

production will necessarily deal with their characteristic constraints. It is estimated that such soils occupy more than 800 million hectares or 40% of the potentially arable but virtually unused lands in the world. These soils are important in some 48 less developed countries which are predicted to have a total population of 1.6 billion people by the year 2000.

b. Classification of Soils According to Soil Fertility

In conjunction with the contract research of North Carolina State University, a technical soil classification system has been developed (FCC = Fertility Capability Classification) for grouping soils with similar characteristics from the point of view of native soil fertility and crop response to fertilizers. Progress has been made in the use of the system as a guide to land development and settlement programs. It is probable that the FCC system will not only greatly simplify the characterization of soil types within the great soil groups of oxisols and ultisols, but may be useful in lands where other soil groups occur, in temperate as well as tropical zones. This FCC classification identifies constraints in the soils, such as aluminum toxicity, low phosphorus content, low cation exchange capacity, as well as soil depth, water relations, drainage, and similar characteristics associated with agricultural productivity.

It is vastly simpler than the more precise classification of soils based on a broad array of inherent characteristics of soils; but adequate to make good estimates of the potential productivity of land areas.

c. Efforts to Convert Traditional Shifting Cultivation Systems of Land Management to Those That Permit Continuous Cropping

Research has continued on replacement of shifting cultivation by continuous cropping, where yields are maintained at economically profitable levels. The causes for rapidly declining yields when native vegetative cover is removed by clearing and burning, and on which cropping then is practiced for a few years, have been explored. Both chemical and physical changes occur in the soil, that include increases in aluminum toxicity, declines in supply of calcium and phosphorus, depletion of nitrogen, and serious reduction in water retention capability of the soil. Methods of using lime, phosphate and nitrogen fertilizers, in amounts and the timing of application to meet crop needs, have been charted for some important food crops. Mulching with grass or kudzu (legume forage plant(, in conjunction with use of lime and fertilizer, has

been beneficial, and this approach warrants expanded studies; as well as methods of introducing organic matter into the soil profile by roots of adapted plant species. There is reason to believe that continuous productivity is possible which will enormously increase total productivity of lands occupied by oxisols and ultisols by several-fold over the traditional slash and burn systems that require long periods (5-15 years) of "fallow" for native vegetation to restore soil productivity after a short period of cropping.

d. Low-Energy Technology for Farming Systems

Small farmers rely largely, or wholly, on crop production systems that rely largely on hand labor, with comparatively little use of machine power, commercial fertilizers, or pesticide chemicals. The application of technology to such systems, in which relay plantings of compatible crops, or inter-planting, and other methods are used for continuous occupation of the land by upland rice, maize, peanuts, cassava, beans or cowpeas, etc., has distinct possibilities. Some systems have been determined to be at least 30% more profitable than monocultures, and with much less risk of failure. A great array of variations are possible with hand labor, that are impossible with mechanized systems where one crop is grown

at a time, and the seasons and the land are more completely used. The technology as to most effective use of fertilizers, choice of suitable crops, improved farieties, continuous weed control, etc., are new dimensions to traditional farming.

e. Managing Soil Acidity

Soil acidity, and the associated aluminum toxicity and low phosphorus availability have been shown to be universally critical constraints to the productivity of oxisol and ultisol soils. The addition of lime is the major means of controlling soil acidity. Because the cost of liming is significant, the most effective methods of using lime have received attention. Deep incorporation (to 30 cm) is most effective, but surface application and hoeing to mix with the surface soil is a practical method for small farmers, and smaller amounts applied to successive crops have been effective.

A relatively new approach to the problem is the incorporation of organic matter (crop residues, composts, manures, etc.) as a means of mitigating the effects of soil acidity on crop plants. This offers the opportunity for increasing the benefits from liming with little additional cost and warrants expansion of research in this direction.

f. Phosphorus Management on Soils with High "Fixation" for This Nutrient

There are 2 alternatives available, in the light of modern technology: (1) better methods of using phosphate fertilizers, and (2) plant breeding to improve the crop plants use of phosphorus in increasing yields. Evaluations have been made on effective methods of applying phosphate fertilizers; specifically, broadcasting and mixing with the soil; vs. placement in bands below the crop row; vs. massive applications at infrequent intervals, in contrast to smaller amounts supplied to each crop, and other variations. The researches to date indicate that smaller amounts of phosphate fertilizer for each crop will suffice, and this is economically preferable. However, comparisons of newly reclaimed ultisols with those farmed for many decades in Puerto Rico, indicate that these soils can be made (or actually transformed) over time, into productive soils. The nature of the changes warrant studies in both depth and duration, since they may apply to oxisols and ultisols on a world-wide basis. Studies on the use of certain rock phosphates suggest these forms may replace superphosphate fertilizer at much lower cost, but with equal effectiveness on these acid soils.

g. Increasing Crop Productivity by Breeding for Tolerance to Adverse Soil Conditions

Some highly significant initial researches have been made on the inherent tolerance of certain crop species, to the soluble aluminum that is toxic to crop plants, and to the low phosphate content of the soils. Not only are some crop species capable of meeting growth requirements on such soils (rice is highly tolerant) but within sensitive species (such as corn and sorghum) there are genetic strains that have substantial tolerance to high aluminum and low phosphate. These genetic differences are now known to exist, but the exploitation of tolerance by appropriate plant breeding combined with a companion program of management and improvement should be pursued intensively to produce early benefits. Techniques for rapid screening of strains and varieties of crop plants have been developed for use in seedlings grown in greenhouses or growth chambers. Field trials give dramatic evidence of tolerant strains producing satisfactory yields, alongside virtual failures of unselected, or sensitive strains or varieties.

11. Agro-Economic Analysis Relative to Economically Viable Farming Systems

The ultimate goals of tropical soils research are increased productivity of land, lower costs per unit of the

commodity, and a net enhancement of farm profitability. These matters must not be taken for granted. The application of technology may fail even with increased yields without improved farm income. Also, the technology must be made feasible for application by the farmer.

The analysis bearing on utilization of soils technology appears to call for a focus on farming systems as the evaluative matrix and on data with respect to three "sets" of factor-product relationships. The first of these are production function or input-output data such as amounts of nitrogen relative of yields. The second data set are those related to the choices to be made among alternative practices or cropping systems. The third set is the management requirement of the farming operations and maintenance of the farming system. To evoke technical data, utilization conclusions regarding yield and income possibilities must be presented in sufficient prescriptive detail that the total cropping system can be fully understood and comprehended. Too high a level of generalization does not lead to information of a useable nature.

Further, generalization of utilization in an area or regional developmental sense must be preceeded by a more definitively

systematic land use classification system than is presently available. North Carolina has undertaken a pioneer effort to evolve such a soil and land use classification system for the tropics. Land use classification provides the dynamic framework for agro-economic extrapolation. A second essential consideration of dynamic extrapolation and technology utilization is what it takes to "transition" from one system to another and to hold the new system in equilibrium with respect to the natural and economic environments. System transition from one form of agricultural production to another, say from what is traditional to one of higher level or order, is not usually something that happens all at once. The reasons are the additional requirements and changes in risk factors or conditions. Among these are farmer skill and capital requirements, land use transition lags, adjustment for an added array of factor inputs, levels of effort, and reaction to uncertainty. Therefore, economic analysis must include, in addition to input-output point reference estimates, an accounting for the influence of yield variance, time to maturity of investments, total capital formation requirement, and information on other variables which affect farmer and/or planning decisions such as growth in per capita income and consumption, rates of development of

infra-structure, available inputs, services, and credit, and projections on changes in attitudes and appetites with respect to different commodities.

A reasonable format for the type of economic analysis outlined is suggested below. With respect to this outline, the North Carolina State University agro-economic linear programming analysis underway could provide useful "directional" insights regarding farming systems which might evolve. However, it is suggested that this analytical modelling effort be dis-aggregated to deal with marginal analysis, capital formation, and optimizing of data with respect to the functionals of alternatives. A further suggestion is made that the analytics include "plateauing" of transition to provide the necessary element of dynamic analysis and that a systems model be attempted relative to the condition variables involved in extrapolation and area development considerations. The analysis suggested perhaps includes all of the following "systems" approaches:

a. The traditional farming system must be described:
   (1) under prevailing conditions it is the optimum system,

(2) it is the system to be transformed,

(3) conclusions of an analytical technique do not constitute a system.

b. Development of input-output data:

(1) Each soil adjustment practice involves various ways, methods, time sequences, and rates, any one of which may be optimum.

(2) Practices may be complementary, competitve, or supplementary, which they are, and what the yield effect is, to determine choice.

(3) Yield variance and time variance data are essential to estimates of risk and uncertainty, maturity of investments, skill acquisitions, level of managerial effort, and these directly affect and condition the operational decisions.

c. Essentially, a farming system is decided on non-technical grounds:

(1) Technology provides means, alternatives, and alternative means only.

(2) The choice of farming system is made on cost-price relations of alternative means and alternative commodities, as circumscribed by condition variables (risk, effort, variance, availability of factors).

(3) The capital formation requirement, materials, things, and human, is an absolute condition of transition timing and staging.

d. Possible "down the road" considerations for the future: Area Development Modelling:

(1) Programming, considering both the linear and dynamic forms, appear to be adequate for farming system comparisons.

(2) Area development projections appear to pose for consideration of systems simulation involving system science modelling and operations analysis.

VII. LDC and AID Utilization of the Findings and Achievements of the Tropical Soils Research Program

Introduction

The research program products and results have been utilized by LDC and the international network on soils from the program's beginning. The research findings on correcting tropical soils fertility deficiencies, toxicity and other major problems of soils utilization and land use have been directly incorporated into farming operations in certain areas of South and Central America, in the Caribbean, and to a certain extent in Africa, at the moment. An even wider range of incorporation of substantiated findings exists as the inclusion of agronomic response data is combined with the soils information created to make up recommendations of effectively viable farming systems for the tropics. Another occurrence which has the promise of rapidly enhancing the utilization of the products of the soils research is the improved soils classification and mapping system under development at North Carolina State University.

Commensurate with these farm level utilization strategies employed by both Universities, has been the strategy of building research response capability into the research institutions of individual countries (e.g. Puerto Rico, Brazil, Peru),

and the training of LDC soil scientists to direct research and to extend through demonstration and adaptive research means, the results of the U.S. sponsored program to their country's farmers. At the same time, AID itself has benefited from the expertise it has helped to fund. Both the Regional Bureaus and the Technical Assistance Bureau have been able to tap some of the best soil and crop expertise within the United States at very short notice and at nominal cost to meet AID commitments on soils and on general agricultural considerations.

A. Problem Identification and Coverage

Research results adapted, or under adaptive procedures, by LDC host institutions or by farmers include the following:

1. Land Use Capability

   a. Projections based on historic experience modification

   b. Improved methods of problem identification and land use capability mapping

2. Fertility Status

   a. Major and minor soil nutrient elements

   b. Incorporation of organic materials

   c. Inclusion of leguminous plants in crop rotations

3. Soil Toxicity and Ph Factors

   a. Liming and tillage

   b. Plant tolerance screening

4. Soil Moisture-Plant Relations

   a. Root zone and root complex investigations

   b. Adaptation of plants to moisture stress

   c. Precipitation mapping and weather forecasting

5. Low Energy Farming Systems

   a. Legumes as an indirect source of nitrogen

   b. Nutritional multiplier effect of crop selection and crop rotation

   c. Special requirements of nodulation of legumes

   d. Disease and pest control

6. Agro-Economic Analysis

   a. Development of technically feasible farming systems

   b. Economic assessment for economic viability.

B. Utilization Response Capability

The research results achieved, and the research underway, will, by the process of being extended and tested for adoption, apply to Oxisols and Ultisols generally. At present these two tropical soils are mostly in their natural state, or are devoted to shifting cultivation and extensive type cattle grazing.

However, together they comprise the largest single block of potentially arable land remaining in the world.[1/] Regarding developing this potential Cornell and North Carolina State have a response capability composed of more than 30 senior scientists with special qualifications in tropical soils and crops. Together they have also trained, during the course of the soils research program, more than 60 graduate degree students, predominately PhD.s, divided roughly 50-50 between U.S. and foreign students. These personnel, now trained in soil science and agronomics of tropical agriculture, comprise an immeasurably valuable research, institution building, and utilization resource.

In specific terms, the response capability of the two Universities covers the following areas of competency:

1. <u>A Technical Assistance Response Capability on</u>:

   a. The technical aspects of tropical soils

   b. Land classification and soil survey

   c. Agricultural development planning and analysis

   d. Training courses for LDC soils and agronomy specialists

   e. Participation in technical workshops and seminars

1/ There are approximately 1600 million hectares of acid Oxisols and Ultisols, of which about half are believed to be potentially arable.

2. Research Institution Building by:

   a. Providing a scientific basis and staff assistance

   b. Providing research designs and project leadership

   c. Providing soils information and recommendations for adaptive research

   d. Working with host country personnel responsible for farming system recommendations and area development planning

3. Reports and Technical Documents:

   a. Annual reports

   b. Research publications

   c. Thesis documents

   d. Written and verbal reports to LDC researchers and planners

4. Workshops, Seminars, and Professional Meetings:

   a. Presentation of technical papers

   b. Discussion of methodologies of research and extension

5. International Coordination:

   a. FAO and other International Assistance agencies

   b. The International Research Centers (CIAT, IITA, CIP).

By the processes outlined, a scientific basis for continuous and multiple cropping of the acid Oxisols and Ultisols has been established. Sufficient basic data is on hand and

research and utilization methodologies are improved to the point where extrapolation through soil classification, problem identification, and testing is a reality. This does not mean, however, that the research is complete, but, at the same time, the research because of its magnitude, complexity, and long termness, is an international responsibility. The continuing need for research is summarized in the following five (5) points.

C. <u>The Argument in Favor of Sustained Agricultural Research for LDCs</u> (a rational philosophy)

1. LDCs do not now have the capacity for basic research needed to support adaptive, site-specific research for the individual countries. External assistance on basic agricultural problems is essential, and must be continued for an extended period. Such basic research should deal with problems of natural resources and their utilization, that are regional or international in nature.

   Lands and soils, climatologic influences, vegetation and crops, animal resources, these comprise the group of resources that are unique in the tropics, but have sufficient similarities

to warrant extrapolation of the known body of knowledge from the developed countries, to the LDCs.

2. The International Agricultural Research Institutes are important agencies to foster agricultural development of LDCs. However, their individual charters and their active programs of research are dedicated to selected commodities or practices. For example, CIAT has elected to concentrate its research on Cassava, beans and pastures and feed for cattle. It's program on soils is limited to that which is pertinent to these three (3) commodities. A similar selection of objectives has been made by each of the other international institutes. It is clear that these institutes were not created to cope with widespread basic problems on natural resources development; and that research on widely occurring problems (such as those on tropical soils) must be accomplished by other means.

3. Individual LDCs, because of their limited development and scanty resources available for agricultural

research, are not likely to pick up the ball of basic research, and carry it along to the stage where a body of principles and tested knowledge can serve as the base for adaptive research programs that will serve agricultural development for the individual country. There is clear evidence that premature termination of basic research by AID or other external assistance agencies, results in abandonment of the activities, and the loss of most or all of the promising advances that have been made previously. Continuity is the life-blood of effective research.

4. The basic research programs dealing with natural resources underlying agricultural development in the tropics, must be continued to evaluate practices and materials that will not only be profitable as individual enterprises, but suitable for inclusion in farming systems that are economically sound and feasible for adoption by small farmers of representative regions.

5. The necessary program of assistance to individual LDCs to organize and develop their own programs

of adaptive research to serve the country (with its unique economic and social needs), may be selected as a useful activity of USAID. Such country programs of adaptive research to serve local agricultural productivity and development, will be difficult to inaugurate and have less chance of proving useful, if they must also develop the broad principles of natural resource development and utilization. The chances of success in country-based adaptive agricultural research should be greatly enhanced by basic research on natural resources of ecological regions, if this is achieved by some international agencies.

D. Evaluative Comment on Future Research and Utilization Strategy

The comment and observations of Cornell and North Carolina State Universities on research utilization are stated under appropriate headings in the summaries each University furnished the review (Appendices I and II). Essentially, the statements made conform to the outline of utilization materials and processes set forth above. These statements are excellent

as far as they go. What mainly is lacking is a sense of organization and of concerted and concentrated focus on agricultural development. Two things were apparent to the review team. The soils research must derive from a desired farming system or systems being given. And, secondly, there must be a conscious effort to link the research to feasible and viable farming systems through the reinforcement, or assisting to establish, an LDC institutional response capability.

Under this concept, utilization is a special undertaking having its own uniquely defined and formalized processes and mechanisms. All of the above that has been outlined and which has been called utilization would be blended into this concept. The difference in the utilization concept of the review team and the foregoing is not merely one of slant, cast, or emphasis; the difference is fundamental in at least three respects: (1) the research requirement would be decided in a desired farming system context, starting with the traditional system, (2) the research would not, then, be single factor, e.g. toxicity, but would be multiple factor with respect to the elements of the biological-physical-chemical make up of the environment, and (3) utilization would be determined commensurate with the research determination and utilization, and would in such a framework play a leadership and decision role in determining how the entire research-utilization process would take place.

This argument subsumes a multi-disciplinary "team" approach, and it further subsumes that the team will accept joint research utilization and responsibilities An appropriately stated step in this direction is outlined in the North Carolina State proposal entitled, "Tropical Soils Management Network." This proposal pertains mainly to the research side of the question but there is no doubt in the review team's mind that the concept of an informational network is a timely consideration. The team doubts that utilization can be as well blended effectively into the entire development assistance effort in any other way. There is no reason that the North Carolina proposal cannot be rounded out and given the dimensional focus on the visualized research-utilization program.

Since the natural instruments of research are those outlined in the foregoing sections, and since the natural mode of operation of U.S. Universities is through existing institutions, the question of collaborating with institutions and with individuals of these institutions is a vital consideration. The following excerpt from the 1975 NCSU Annual Report indicates the success that can be achieved:

> "A highly significant aspect of these university contracts on tropical soils, is the success in involving the host country governments, institutions and individual scientists in the programs of research and

utilization. The governments have recognized the importance of soils research to national development, and are moving to institutionalize these activities and to staff the work with their own scientists. At present, these countries are still quite dependent on the superior capability of the U.S. university staff, and on the university laboratories and greenhouse facilities that permit indispensible support for field research. However, it is encouraging that the U.S. contracts are stimulating strong country activity that should eventually permit each country to become more nearly self-sufficient in research and development. This should always be the ultimate goal of the USAID effort.

The following report (1975 Annual Report - Tropical Soils Research Program) is indicative of the strong participation by the host countries:

"Collaborating Institutions and Individuals

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

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

In the Amazon Jungle of Peru, field research is conducted at the Yurimaguas Experiment Station which is part of the Centro Regional de Investigaciones Agropecuarias del Nor-oriente of the Ministerio de Alimentación. Supporting

laboratory work is conducted at La Molina. The Dirección General de Investigaciones of the Ministry has assigned Dr. Carlos Valverde as project leader, representing Peru. Dr. Valverde has been very effective in expediting administrative matters with the Peruvian Government. The International Potato Center plays a major role in providing administrative and logistical support. In turn, the program grows its potato trials at Yurimaguas as the lowland tropical station for adapting potatoes to the region.

In Central America joint projects are conducted with the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) at Turrialba, Costa Rica; the Ministries of Agriculture of Costa Rica and El Salvador and the Instituto de Ciencias y Tecnologia of Guatemala. Activities are also linked with the International Soil Fertility Evaluation and Improvement Program (ISFEIP). Logistical support is provided by CATIE. Program plans are coordinated with the ROCAP offices of AID in the region.

Several extrapolation studies are also collaborative in nature. Data for evaluating the Fertility-Capability Soil Classification System has been provided by EMBRAPA, the Instituto Colombiano Agropecuario, Instituto Geográfico Agustin Codazzi in Colombia. Soil characterization studies have been conducted with partial financial support in the form of scholarships for graduate students from the USAID Mission to Colombia, the Ministerio de Obras Públicas of Venezuela, the Fondo de Amparo a la Pesquisa do Estado de São Paulo, Brazil.

"Approximately 75 individuals from the different cooperating institutions provided substantial administrative support or are co-authors of some of the research projects."

Given the above cooperative and collaborative framework, by the network concept proposed the way becomes open to integrate cooperating countries and international research centers into the overall network. For example, the Director of EMBRAPA outlined in Brasilia to the review team how the Brazilian Government was prepared to support Brazilian assistance to other Latin American countries, and that they were prepared to utilize their soils research facilities and personnel in a research-training program as we might jointly work out. It should be added that a similar arrangement is being considered with EMBRAPA involving soybeans.