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# TropSoils Technical Report, 1986-1987

Compiled by the Management Entity, Soil Management Collaborative Research Support Program, Charles B. McCants, director. Neil Caudle, editor. Christine Levesque, editorial assistant.

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Copies of this report may be obtained by writing TropSoils Management Entity, Box 7113, North Carolina State University, Raleigh, NC 27695-7113.

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# Preface

TropSoils' goal is to develop and adopt improved soil-management technology that will reduce constraints to plant growth, and to ensure that this technology is agronomically, economically and ecologically sound for developing countries in the tropics. Because it is impractical to do this in every tropical nation or region at once, the program has situated and developed its research projects in a way that makes their results applicable over broad areas having similar soils and environments. These areas, or "agroecological zones," are the basic units of TropSoils' organization.

This document reports the progress of TropSoils research in three agroecological zones: the humid tropics, the acid savannas and the semiarid tropics. Each participating university has taken a lead role in one of these zones. For more information about any of the projects covered in this report, contact the Management Entity or one of the program coordinators listed below.

**Program Coordinators**


Pedro A. Sanchez
Soil Science Department
Box 7619, N.C. State University
Raleigh, NC 27650-7619

Goro Uehara
Department of Agronomy & Soil Science
University of Hawaii
Honolulu, HI 96822

Douglas Lathwell
Department of Agronomy
Cornell University
Ithaca, NY 14853

Tony Juo
Department of Soil & Crop Science
Texas A&M University
College Station, TX 77843

Neil Caudle (communications)
Department of Agricultural Communications
Box 7603, N.C. State University
Raleigh, NC 27695-7603

# Humid Tropics
# North Carolina State University

*Prepared by*
*The Tropical Soils Research Program*
*Department of Soil Science*
*Pedro A. Sanchez, Program Coordinator*

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# Introduction and Highlights

This is the fifteenth continuous year of operations of North Carolina State University's Tropical Soils Program and the fifth as part of TropSoils, the Soil Management Collaborative Research Support Program, financed mainly by the U.S. Agency for International Development and collaborating host institutions: INIPA in Peru, EMBRAPA in Brazil, and AARD in Indonesia. The year 1986 was simultaneously very difficult but also very rewarding. We received a 25% budget cut from our donor agency in February 1986, which resulted in the discontinuation of our field research in Indonesia in August 1986 and in major adjustments in research activities in Peru, in Brazil, and on campus. For the first time in the program's history, we were unable to offer new graduate assistantships.

But 1986 was also a very rewarding and productive year, partly due to the momentum of all our projects in full operation and partly by the implementation of two major initiatives: the soil management research network, and comparative soil dynamics with emphasis on tropical soil biology. INIPA's building program at Yurimaguas is almost complete and the station was officially inaugurated by the Minister of Agriculture. Although modest by world standards, the Yurimaguas Experiment Station now has sufficient office, laboratory, and computer facilities to support long-term experiments and a 30-person training and conference center for on-the-job training. Three major international workshops were held at Yurimaguas in 1986: a Latin American Agroforestry Workshop in cooperation with ICRAF; the Third Tropical Soil Biology and Fertility Workshop; and the Latin American Soil Management Workshop, which trained 31 professionals from the "planting stick to the computer" in three weeks and helped launch the network. Extrapolation activities were also facilitated in tropical Asia and Africa through IBSRAM's Acid Tropical Soils Network. These network activities have paved the way for meaningful technology validation and transfer for 37 countries throughout Latin America, Asia, and Africa.

Work reported herein is carried out in close collaboration with INIPA in Peru, EMBRAPA in Brazil, AARD in Indonesia, several international centers, USAID Missions, and our sister TropSoils universities.

# Personnel

## Faculty

| | |
|---|---|
| Robert H. Miller | Department Head |
| Pedro A. Sanchez | Program Coordinator |
| Dale E. Bandy | Chief, NCSU Mission to Peru |
| T. Jot Smyth | Assistant Professor of Tropical Soils |
| José R. Benites | Project Leader, Yurimaguas |
| Michael K. Wade* | Project Leader, Indonesia |
| Julio C. Alegre | Assistant Professor of Soil Physics, Yurimaguas |
| Dennis del Castillo | Project Leader, Pichis Palcazu |
| Stanley W. Buol | Professor of Soil Genesis and Classification |
| D. Keith Cassel | Professor of Soil Physics |
| Fred R. Cox | Professor of Soil Fertility |
| Charles B. Davey | Professor of Forestry and Soil Science |
| Eugene J. Kamprath | Professor of Soil Fertility |
| Robert E. McCollum | Associate Professor of Soil Fertility |
| Kenneth Reátegui | Research Associate, Pichis Palcazu |
| Robert J. Scholes | Post Doctoral Fellow in Plant Ecology (Yurimaguas) |
| Mary C. Scholes | Post Doctoral Fellow in Soil Microbiology (Yurimaguas) |
| George C. Naderman, Jr. | Extension Soil Management Specialist |

## Staff

| | |
|---|---|
| Bertha I. Monar | Program Administrator |
| Mariela Gonzalez | Administrative Assistant, Lima Office |
| Sue Florindez* | Administrative Assistant, Yurimaguas |
| Patricia Gowland | Research Technician |
| Tonya K. Forbes | Research Technician |
| Olinda Ayre | Soil Analysis Laboratory, Yurimaguas |
| Rafael Román | Plant Analysis Laboratory, Yurimaguas |
| Graciela del Aguila | Bilingual Secretary, Yurimaguas |
| Valeria Medeiros* | Bilingual Secretary |
| Elizabeth Phillips | Bilingual Secretary |
| Amparo Ayarza | Translator, Yurimaguas |

* Resigned during the year.

## Graduate Students (with degree candidacy and nationality)

| | |
|---|---|
| Miguel A. Ara | Soil-pastures, Pucallpa (PhD-Peru) |
| Miguel A. Ayarza | Soil-pastures, Yurimaguas (PhD-Colombia) |
| Dan W. Gill | Soil fertility, Indonesia (PhD-USA) |
| Ricardo J. Melgar | Soil fertility, Manaus (PhD-Argentina) |
| Iberé D. G. Lins | Soil fertility, Brasilia (PhD-Brazil) |
| Amílcar Ubiera | Soil mineralogy, Raleigh (PhD-Dominican Republic) |
| Helmut Elsenbeer | Soil physics, Pichis (PhD-Germany) |
| José R. Davelouis | Soil fertility, Yurimaguas (PhD-Peru) |
| Cheryl A. Palm | Soil–agroforestry, Yurimaguas (PhD-USA) |
| Lawrence T. Szott | Soil–agroforestry, Yurimaguas (PhD–USA) |
| Erick C. M. Fernandes | Soil–agroforestry, Raleigh (PhD-Kenya) |
| Carlos E. Castilla | Soil–pastures, Raleigh (PhD-Colombia) |
| Christopher W. Smith | Soil classification, Raleigh (PhD-USA) |
| Hardjosubroto Subagjo | Soil classification, Indonesia (PhD-Indonesia) |
| Victor Ngachie | Soil fertility, Raleigh (MS-Cameroon) |
| Eleazar Salazar | Soil classification, Raleigh (MS-Venezuela) |
| Eduardo Uribe | Soil fertility, Raleigh (PhD-Colombia) |
| Jane Mt. Pleasant | Weed control, Raleigh (PhD-USA) |
| Jonathan Hooper | Soil classification Raleigh (MS-USA) |
| Marisa R. Fontes | Soil chemistry, Raleigh (PhD-Brazil) |
| Abdul Karim Makarim** | Soil fertility, Indonesia (PhD-Indonesia) |
| Mwenja P. Gichuru** | Soil fertility, Yurimaguas (PhD-Kenya) |
| Laurie J. Newman** | Soil classification, Raleigh (MS-USA) |
| Robert H. Hoag** | Soil classification, Raleigh (PhD-USA) |

## Instituto Nacional de Investigación y Promoción Agropecuaria (INIPA), Peru

| | |
|---|---|
| Benjamín Quijandría* | Head of INIPA (and TropSoils Board Member) |
| Lander Pacora | Head of INIPA (and TropSoils Board Member) |
| Manuel Villavicencio | Director, Yurimaguas Station |
| Angel Salazar | Agroforestry, Yurimaguas |
| Jorge M. Pérez | Agrogorestry, Yurimaguas |
| Pedro O. Ruiz | Mycorrhiza specialist, Yurimaguas |
| Luis A. Arévalo* | Soil fertility specialist, Yurimaguas |
| Beto Pashanasi | Soil zoology, Yurimaguas |

* Resigned during the year.
** Completed degree in 1986.

| | |
|---|---|
| Miguel Bustamante | Training officer, Yurimaguas |
| Rolando Dextre* | Pastures specialist, Yurimaguas |
| Daysi Lara | Pastures specialist, Yurimaguas |
| Marcos Gálvez | Corn-weed control specialist, Yurimaguas |
| Andrés Aznarán | Tillage specialist, Yurimaguas |
| César Tepe | Paddy rice specialist, Yurimaguas |
| Alfredo Racchumí | Upland rice specialist, Yurimaguas |
| Jonathan López | Corn and sorghum specialist, Yurimaguas |
| Mercedes Escobar | Economist, Yurimaguas |
| Wilfredo Guillén | Grain legumes specialist, Yurimaguas |
| Jorge W. Vela | Pastures specialist, Pucallpa |
| Luis Zúñiga | Soil physicist, Pichis |
| José Merino | Head, La Esperanza Station, Pichis Valley |
| Hemilce Ivazeta | Pastures specialist, Tulumayo, Tingo María |
| Maria Gallo | Soil specialist, Tulumayo, Tingo María |
| Rodolfo Schaus | Pastures specialist, Pucallpa |
| Miguel Flores | Farming systems specialist, Tulumayo, Tingo María |
| Jorge Figueroa | Farming systems specialist, Tulumayo, Tingo María |
| Juan Lermo | Agronomist, Proyecto Especial Pichis Palcazu, Puerto Bermúdez |
| R. Ruíz | Pastures specialist, Proyecto Especial Pichis Palcazu, Puerto Bermúdez |
| G. Cantera | Pastures specialist, Proyecto Especial Pichis Palcazu, Puerto Bermúdez |
| E. Acuña | Pastures specialist, Proyecto Especial Pichis Palcazu, Puerto Bermúdez |

## Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Brazil

| | |
|---|---|
| Erci de Moraes | Chief, UEPAE de Manaus Station |
| Manoel S. Cravo | Soil fertility specialist, Manaus |

## Centre for Soils Research, AARD, Indonesia

| | |
|---|---|
| Mohammed Sudjadi | Director, CSR, Bogor |
| I. P. G. Widjaya Adhi | Soil fertility, country coordinator, Bogor |
| Sri Adiningsih | Head, soil fertility division, Bogor |
| Fahmuddin Agus | Soil physicist, Sitiung |
| M. Heryadi | Soil fertility, Sitiung |
| Al-Jabri | Soil fertility, Bogor |
| Putu Wegena | Soil fertility, Jambi |

* Resigned during the year.

# Research Network

Tropical soils research has progressed to the point that several management options for sustainable productivity in agronomic and ecological terms are ready to be widely tested by national research institutions. The different options for the humid tropics constitute the model for networking (see first report). A training workshop, conducted in Spanish at Yurimaguas during September 1986, provided on-the-job training for 31 front-line professionals from the planting stick to the computer.

The workshop participants created RISTROP (*Red de Investigatión de Suelos Tropicales*), with core experiments on low-input systems, agroforestry, continuous cropping, legume-based pastures and paddy rice. This network is now operating in 11 Latin American countries. Continuing technical backstopping is being provided to IBSRAM (International Board for Soil Research and Management) in the establishment of two Acid Tropical Soils Networks in Asia and Africa. Given the striking similarities in soil constraints between tropical America and tropical Africa, a similar workshop is being planned in coordination with IBSRAM to train African soil specialists at Yurimaguas and to establish a viable link between soil-management technologies generated in Latin America and their potential users in Africa.

## Yurimaguas Workshop

*T. Jot Smyth, N. C. State University*
*José R. Benites, N. C. State University*
*Dale E. Bandy, N. C. State University*
*Pedro A. Sanchez, N. C. State University*

Tropical soils research has progressed to the point of grouping promising alternatives into soil-management options that account for differences in physical and socioeconomic conditions within this ecosystem (Figure 1). Many of the key components for these technologies can now be transferred to national research institutions, allowing local investigators to adapt soil-management options to their specific conditions. A concerted validation and extrapolation effort across tropical soil ecosystems in Latin America would not only encourage interaction among participating institutions but also identify refinements and modifications that should be pursued to improve existing management options. Such an effort requires the identification and training of capable on-site personnel at collaborating national institutions.

In September 1986, North Carolina State University's TropSoils program conducted a 21-day workshop on tropical-soils management at its primary research site in Yurimaguas, Peru, in cooperation with INIPA, USAID/Lima, and the Interamerican Institute for Cooperation in Agriculture (IICA). Purposes of the workshop were to acquaint key Latin American scientists with the most recent techniques in tropical soil characterization and management, to identify common interests, and to establish a soil research network. Criteria for selection of participants were based on the national research institutes' (a) interest and capabilities in pursuing soil-management research in tropical ecosystems and (b) designation of workshop candidates, with at least a B.S. in agronomy or equivalent training, as the personnel responsible for conducting network investigations resulting from this workshop. The 31 participants who attended the workshop represented 23 potential research sites distributed among 15 national institutions in ten different countries (Table 1). A detailed description of the workshop and the experiments developed for the research network can be found in a report to the U.S. Agency for International Development available in English and Spanish.

Activities were organized around the two workshop objectives and occurred simultaneously during the three-week schedule. The sequence of topics covered during the instructional component included: characterization of tropical ecosystems; diversity, classification and taxonomy of tropical soils; soil physics in relation to land-clearing and tillage systems; and fundamental aspects of soil chemistry, soil fertility, soil testing and plant analysis. Emphasis was placed on field activities that gave participants hands-on experience with the most recent field and laboratory techniques and computer software used in soil science research. Technology developed for humid tropical soil management was discussed as five distinct packages: mechanized high-input continuous crop production, low-input crop production with acid-tolerant species, agroforestry systems, paddy rice production on alluvial soils and legume-based pastures. One day was devoted to field tours of

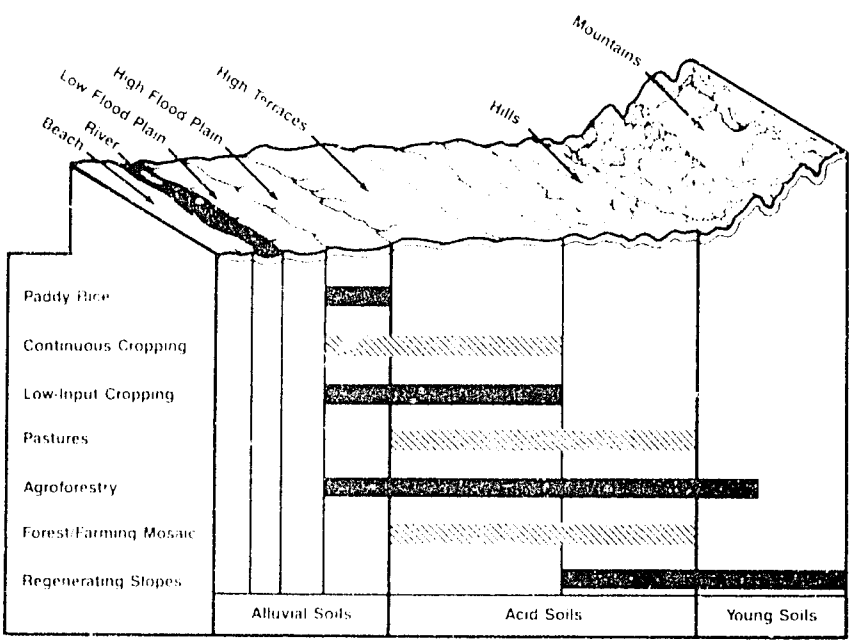


**Figure 1. Soil-management options for sustainable production in the humid tropics, used in the research network.**

experiments for each management option

During their three weeks in Yurimaguas, participants installed a low-input experiment on a secondary forest site. This activity acquainted the group with the procedures, measurements and decisions to be made during the processes of site selection, forest clearing, soil and vegetation characterization, plot establishment and planting the initial crop. The group performed nondestructive forest biomass measurements, burned the slashed vegetation, collected ash and post-burn soil samples, and analyzed the ash and soil for nutrient content in the laboratories. Before departing, participants were able to observe their experiment with an initial stand of upland rice.

Table 1. Distribution of participants by country, national institutions and experiment stations at the Tropical Soil Management Workshop, Yurimaguas, Aug. 31-Sept. 21, 1986.

| Country | National institution | Research site | Number of participants |
|---|---|---|---|
| Bolivia | IBTA | Chapare | 3 |
| Brazil | CEPLAC | Itabuna | 1 |
| | EMBRAPA: | Belém | 2 |
| | | Manaus | 1 |
| | | Porto Velho | 1 |
| | | Rio Branco | 1 |
| Colombia | UNIBAN | Urabá | 2 |
| Costa Rica | CATIE | Turrialba | 1 |
| | U. Costa Rica | Rio Frío | 1 |
| Dom. Repub. | ISA | Santiago | 1 |
| Ecuador | INIAP | Pichilingue | 1 |
| | PRONAREG | Quito | 1 |
| Guatemala | ICTA | Izabal | 2 |
| Honduras | Min. Rec. Naturales | Danlí | 1 |
| Panama | IDIAP | Calabacito | 2 |
| Peru | IIAP | Iquitos | 1 |
| | INIPA: | Moyobamba | 1 |
| | | Iquitos | 1 |
| | | Pichis | 1 |
| | | Puerto Maldonado | 1 |
| | | Tarapoto | 1 |
| | | Tingo María | 2 |
| | U. La Molina | Satipo | 1 |
| | U. Amaz. Peruana | Iquitos | 1 |

Considerations for network development were initiated by participant presentations geared to provide opportunities for interaction and identification of common interests. Each member described the ecosystem, facilities, research program and limitations of the experimental site where they performed studies for their national institutes. Comparative data among the participants' research sites (Table 2) indicate a broad spectrum of research thrusts and ecosystems.

Toward the end of the workshop, participants voluntarily chose to participate in individual working groups on each of the five soil-management options. Each working group was requested to (a) identify soil-management factors that should be investigated in an extrapolation and validation network, (b) design experiments with clearly defined objectives, and (c) define experimental methodologies and basic requirements of equipment and facilities. A brief description of the network studies developed by each working group follows.

## Low-Input Option

*Objectives*

1. Compare the sequence in which nutrient constraints appear in acid soils, under different ecosystems, under upland rice-cowpea production.

2. Compare the effect of nutrient additions by ash from burning different types of standing vegetation in different climatic regimes.

3. Establish soil nutrient levels to aid in formulating minimum fertilizer recommendations for sustained upland rice-cowpea production in acid soils.

*Experimental approach*

Thirteen fertilization treatments, in a randomized complete block design with four replications, were developed as common to all network sites. Both udic and ustic moisture regimes exist among sites; vegetation varies from primary rainforest to savanna. Post-clearing management will be constant among all sites.

## High-Input Option

*Objectives*

1. Evaluate, under continuous cultivation, crop responses to increasing rates of K fertilization.

2. Evaluate the effects of crop residues on soil K dynamics.

**Table 2. Comparative data among potential network research sites.**

| Country | Institution | Location | Annual rainfall | Dominant soils | System under investigation: Pastures | Tree crops | Food crops | Labs avail. | Soil scientists avail. |
|---|---|---|---|---|---|---|---|---|---|
| | | | mm | | | | | | |
| Bolivia | IBTA | Chapare | 2500 4500 | Entisols-Inceptisols | yes | commercia | yes | none | 1 |
| Brazil | CEPLAC | Itabuna | 1300 | Oxisols-Ultisols | yes | commercial | yes | soil-plant | |
| | EMBRAPA | Belém | 2200 | Oxisols-Ultisols | yes | commercial | yes | soil-plant | 6+ |
| | | Manaus | 2300 | Oxisols-Ultisols | yes | native fruits | yes | soil-plant | 2 |
| | | Porto Velho | 2400 | Oxisols-Ultisols | yes | commercial & native fruits | yes | soil[1] | 1 |
| | | Rio Branco | 1800 | Ultisols | yes | commercial | yes | soil[1] | 1 |
| Colombia | UNIBAN | Urabá | 2000-4000 | Entisols-Inceptisols | no | banana plantations | no | soil-plant | 0 |
| Costa Rica | CATIE | Turrialba | 2500 | Inceptisols | yes | commercial | yes | soil-plant | 2 |
| | Univ. Costa Rica | Rio Frío | 4000 | Ultisols-Inceptisols | yes | no | yes | soil-plant | 1 |
| Dom. Repub. | ISA | Santiago | 2800 | Entisols-Inceptisols | no | fuelwood | yes | soil | 1 |
| Ecuador | INIAP | Pichilingue | 2160 | Inceptisols | yes | commercial | yes | no[2] | 1 |
| Guatemala | ICTA | Izabel | | Entisols-Inceptisols | yes | no | yes | soil-plant | 3 |
| Honduras | Min. Rec. Naturales | Danlí | 1000 | | yes | commercial | yes | no[3] | |
| Panama | IDIAP | Calabacito | 2500-3300 | Ultisols-Alfisols-Inceptisols | yes | commercial | yes | soil-plant | 3 |
| Peru | IIAP | Iquitos | 2700 | Ultisols-Inceptisols | yes | native fruits | yes | no[4] | 0 |
| | INIPA | Pichis | 2800 | Ultisols | yes | commercial & native fruits | yes | no[4] | 3 |
| | | Puerto Maldonado | 2200 | Ultisols | yes | commercial | yes | no[4] | 1 |
| | | Moyobamba | 1230 | Ultisols-Alfisols | no | commercial | yes | no[4] | 1 |
| | | Tingo María | 2900 | Ultisols | yes | commercial | yes | no[4] | 2 |

Note on other institutions:
PRONAREG/ECUADOR conducts soil surveys and land resource evaluations through the entire country.
UNIV. LA MOLINA/PERU conducts potato fertilization trials and M. Sc. thesis research in agronomy in the Peruvian Amazon. University campus is located in Lima.

[1]Plant analyses are performed at the EMBRAPA stations in Manaus and/or Belém.
[2]Soil and plant analyses are performed at another INIAP station within 200 km distance.
[3]Soil and plant analyses are performed at laboratories in Tegucigalpa.
[4]Soil and plant analyses are performed at central laboratories in Lima.

3. Evaluate crop response to residual fertilizer K.

4. Determine the influence of K rates on K interactions with Ca and Mg in soils and plants.

*Experimental approach*

Crop rotations will be corn-soybean or corn-cowpea. Yield response to K will be evaluated over six K rates, ranging from 0 to 250 kg K/ha. Crop residue effects and interactions with Mg will be evaluated in four additional treatments. Potassium will be monitored in soil profile and plant tissue.

**Improved Pastures Option**

*Objectives*

1. Determine the appropriate method for renewing pasture productivity through legume incorporation.

2. Determine the effects of P fertilization on legume establishment in pastures.

3. Evaluate the persistence of legume-grass associations as a function of establishment.

*Experimental approach*

The experiment will be conducted in degraded pastures and will be composed of two distinct phases: (a) legume establishment as a function of tillage and P fertilization and (b) P dynamics and legume persistence as a function of animal grazing. The initial phase will be conducted in a network experiment with three P rates, two tillage methods and four legume species in a split-split plot design with three replications.

**Agroforestry Option**

*Objective*

Improve soil fertility and control soil erosion and weed incidence by improved fallows and tree crops in agroforestry systems.

*Experimental approach*

The group chose to develop one experiment for improved fallows and two experiments for tree crops, with a distinction in the latter for steep and flat topography. The improved fallow study will compare the effects of a selected tree + groundcover legume short-term (three-to-five years) fallow to a traditional secondary forest fallow (five-to-ten years) on the control of weeds, soil erosion and soil fertility replenishment for subsequent crop production. The tree crop experiments will evaluate the productivity, nutrient distribution and use of selected perennial crops in multistrata systems. Annual crops will be excluded from the experiment for steep topography.

**Paddy Rice Option**

*Objectives*

1. Investigate alluvial soil-management systems for paddy rice production.

2. Evaluate, over time, changes in soil nutrient availability in alluvial soils under paddy rice.

*Experimental approach*

Paddy rice production has not been practiced in large areas of the Amazon. Local expertise, therefore, is almost nonexistent. Farmer acceptance of the system in the lower Amazon Basin is believed to depend on the demonstration that (a) labor-intensive dike formation persists after seasonal river flooding, (b) constant flooding of rice paddies reduces weeding, and (c) broadcast seeding is a viable alternative to labor-intensive transplanting.

After reviewing the proposals, participants were asked to identify, on a priority basis, the top three (if any) experiments they considered most applicable to their research-station activities. Responses suggested primary interest in the low-input and agroforestry soil-management options. (This workshop activity provided valuable feedback information to the TropSoils program in Latin America, especially because these opinions were provided by professional field scientists after an intensive review of the program at the primary research site.)

Participants agreed that a common goal of the network would be the transferral and validation of improved soil-management technologies on acid humid tropical soils in Latin America. The group requested that North Carolina State University coordinate information exchange and technical backstopping among network participants.

The quality of the projects developed by the group suggests that the workshop was successful in enhancing the soil-management research capabilities of collaborating country personnel. Workshop program evaluations by the participants highlighted the feasibility of using the Yurimaguas Experiment Station research program to provide scientists in the humid tropics with on-site exposure to knowledge of how to manage soils.

## Network Development In Latin America: RISTROP

*T. Jot Smyth, N. C. State University*

Participants in the Yurimaguas workshop requested that NCSU provide the central coordination for the network, which they chose to name RISTROP (*Red de Investigación de Suelos Tropicales*). Assistance was requested for research-site selection and characterization, support services for analyses and interpretation of resulting data, and information exchange among participating national institutions. Funding was not available to sponsor each participant's research activities in the network. Participants were therefore individually responsible for obtaining approval and funding from their national institutes for their network activities. The limited budget available for network coordination also led to the stipulation that support services from NCSU's Tropical Soils Program would only be initiated for a network participant upon confirmation of the national institute's approval of network activities.

The network coordination has received positive responses from participants in eight of 11 countries, for a total of 27 initiated or planned experiments, encompassing all management options presented during the Yurimaguas workshop (Table 1). With the exception of collaborators in Bolivia, participants have limited their commitments in 1987 to initiating network experiments, which they identified as first priority during the Yurimaguas workshop. Participants from IBTA/Bolivia intend to initiate experiments identified as both first and second priority for their institutional programs. INIPA stations in Puerto Maldonado, Moyobamba and Iquitos plan to incorporate the low-input and agroforestry studies into experiments on native fruit-tree production systems for peach palm, Brazil nut and camu-camu. A similar approach is planned for the same network experiments at EMBRAPA/Manaus in guaraná production systems. The Peruvian government recently established lime management as top research priority for the Selva region. High-input annual crop experiments at Tingo María and Moyobamba, therefore, will be directed toward comparisons of yield responses to locally available lime sources.

RISTROP collaborators in Ecuador recommended delaying network initiatives in their country until funding is available through the recently established agricultural research foundation. Despite several inquiries, no response has been received on the network status in the Dominican Republic. A similar situation in Honduras was transformed into a positive commitment, after discussions with the participant's superiors during recent travel to Central America. Additional correspondence with Colombian scientists, who were unable to attend the workshop, may result in implementation of two studies in that country. Venezuela also was not represented at the Yurimaguas workshop; however, after reviewing the workshop report, collaborators from the Universidad Central de Venezuela notified RISTROP coordination of their intention to participate in three network experiments.

Since the completion of the Yurimaguas workshop, NCSU support activities for the network have centered on technical visits to participating institutions during implementation of field experiments. In addition to assisting participants in adjusting methodologies and field plans to local conditions, this action has also provided an opportunity to obtain on-site familiarity with the research programs of the national institutions. Extensive discussions with participating network scientists and travel conducted to date have provided the following observations.

### Observations

1. The specific needs for technical backstopping by national institutions and the capacity for NCSU's Tropical Soils Program to provide this expertise extends beyond the existing scope of the budget and/or conceptual development of the research network. The type of required technical support varies among institutions, from assistance in establishing functional soil testing laboratories to the identification of research priorities through interpretation of existing soils information. Such limitations often impede participants' abilities to implement knowledge gained during the Yurimaguas workshop on a broader institutional scale.

2. Ongoing national institute research programs, in some of the visited countries, are often unrelated and nonsupportive to the USAID Mission agricultural-development programs. Quite often network participants and their superiors have indicated

unfamiliarity with ongoing USAID Mission programs. Synchronization of national institute and USAID Mission programs would capitalize on the investment made, thus far, to transfer soil-management technology to the network participants.

Although it is not anticipated that soil science expertise in national institutions will be fully implemented through participation in RISTROP, it is fitting to consider supportive measures which will ensure that experiences gained in the network will be maintained and used in future national research endeavors.

**Table 1. Current stage of developments for RISTROP experiments in each participating country.**

| Country | Institution | Annual crops: Low input | Annual crops: High input | Agro-forestry | Improved pastures | Paddy rice |
|---|---|---|---|---|---|---|
| Guatemala | ICTA | I | | | | |
| Honduras | Min. Recursos Naturales | | | | I | |
| Costa Rica | Univ. C. Rica/CATIE | I | | | | |
| Panama | IDIAP | A | I | | | |
| Dom. Repub. | ISA | | | P | | |
| Ecuador | INIAP/PRONAREG | P | | P | | |
| Peru | INIPA/Puerto Maldonado | A | | A | | |
| | INIPA/Tingo Maria | | A | | | |
| | INIPA/Iquitos | A | | A | | |
| | INIPA/Moyobamba | A | A | A | | |
| | INIPA/Yurimaguas | I | | | | |
| Bolivia | IBTA/Chapare | I | | I | I | |
| Brazil | CEPLAC | A | | | | |
| | EMBRAPA/Manaus | A | | A | | I |
| | EMBRAPA/Porto Velho | I | | | | |
| Colombia | ICA | P | | | | |
| | Com. Esp. Guaviare | P | | | | |
| Venezuela | Univ. Central Venezuela | I | I | | | I |
| | Total: | | | | | |
| | Initiated (I) | 6 | 2 | 1 | 2 | 2 |
| | Approved Plan (A) | 6 | 2 | 4 | | |
| | Potential (P) | 3 | | 2 | | |

## Network Development In Africa and Asia

*Pedro A. Sanchez, N. C. State University*
*T. Jot Smyth, N. C. State University*
*Stanley W. Buol, N. C. State University*

TropSoils and IBSRAM signed a memorandum of understanding in which both institutions formally agreed to work together toward the development of an Acid Tropical Soils Network on a worldwide basis. TropSoils input has concentrated on providing technical leadership through the Network Coordinating Committees.

The Inaugural Workshop of the Acid Tropical Soils Network was held in Yurimaguas, Peru, and in Manaus and Brasilia, Brazil, from April 24 to May 3, 1985. It was organized by TropSoils/NCSU and co-sponsored by INIPA and EMBRAPA, with support from various international organizations and donor agencies. After several days of observing ongoing long-term research in the humid tropics and acid savannas of South America, representatives from 13 developing countries (Brazil, Cameroon, China, Congo, Ivory Coast, Madagascar, Malaysia, Mexico, Panama, Peru, Thailand, Venezuela and Zambia) decided to form the Acid Tropical Soils Network. The participants identified a defined target area, six principal research-validation topics and several support services.

The Inaugural Workshop Proceedings provide a state-of-the-art review on management of acid tropical soils and its publication, edited by TropSoils/NCSU, is expected in early 1987. The proceedings may serve as the conceptual base of the network.

The first IBSRAM African regional workshop was held in Douala, Cameroon, January 21-27, 1986. The five original African countries represented in the Inaugural Workshop were joined by Rwanda, Burundi and Nigeria. Fifty-five individuals from 15 countries participated, under the sponsorship of the Cameroonian Ministry of Higher Education and Research, with several donor inputs. The five original countries have all initiated activities without waiting for additional funds. Sites have been selected for new experiment stations in Cameroon and Congo, and plans call for scientists at these sites to implement several of the humid-tropical soil-management options seen at Yurimaguas. Zambia began applying many of the ideas gathered after visiting Yurimaguas, Manaus and Brasilia. Proposals for new sites were identified by representatives for Madagascar, Ivory Coast, Nigeria, Rwanda and Burundi.

Common methodologies for evaluating edaphic parameters were agreed upon at the Cameroon workshop and are shown in Table 1. To assist in project development, a list of equipment, supplies and reagents for a fully operational laboratory to

**Table 1. Edaphic paramenters to be measured in IBSRAM Acid Tropical Soils Network Experiments, as agreed in the Cameroon workshop, Jan. 1986.**

| Parameter | Depth 0-10 | 10-20 | 20-50 | Method |
|---|---|---|---|---|
| | cm | | | |
| pH ($H_2O$) | Yes | Yes | Yes | 1:2.5 $H_2O$ |
| pH (KCl) | Yes | Yes | Yes | |
| Exch. Al | Yes | Yes | Yes | |
| Exch. Ca | Yes | Yes | Yes | 1N KCl |
| Exch. Mg | Yes | Yes | Yes | |
| Exch. K | Yes | Yes | Yes | Modified Olsen |
| Avail. P | Yes | Yes | No | " " |
| Avail. Zn | Opt.* | Opt.* | No | " " |
| Avail. Fe | Opt.* | Opt.* | No | " " |
| Avail. Cu | Opt.* | Opt.* | No | " " |
| Avail. Mn | Opt.* | Opt.* | No | " " |
| ECEC | Yes | Yes | Yes | Exch. Al + Exch. Ca + Exch. Mg + Exch. K |
| Al sat. | Yes | Yes | Yes | Exch. Al = ECEC x 100 |
| P sorption | Yes | Yes | No | Fox and Kamprath, Juo and Fox |
| Org. C | Yes | Yes | Yes | Walkley Black |
| pH (NaF) | Yes | Yes | Yes | If allophane suspected |
| ZPC (Zero point of charge) | Yes | Yes | Yes | If subhoriz. approaches acric properties |
| Slope | | | | % |
| Bulk density | Yes | Yes | Yes | At planting time |
| 1/3 bar $H_2O$ | Yes | Yes | Yes | |

*Optional. Mn not optional where deficiencies or toxicities are suspected.

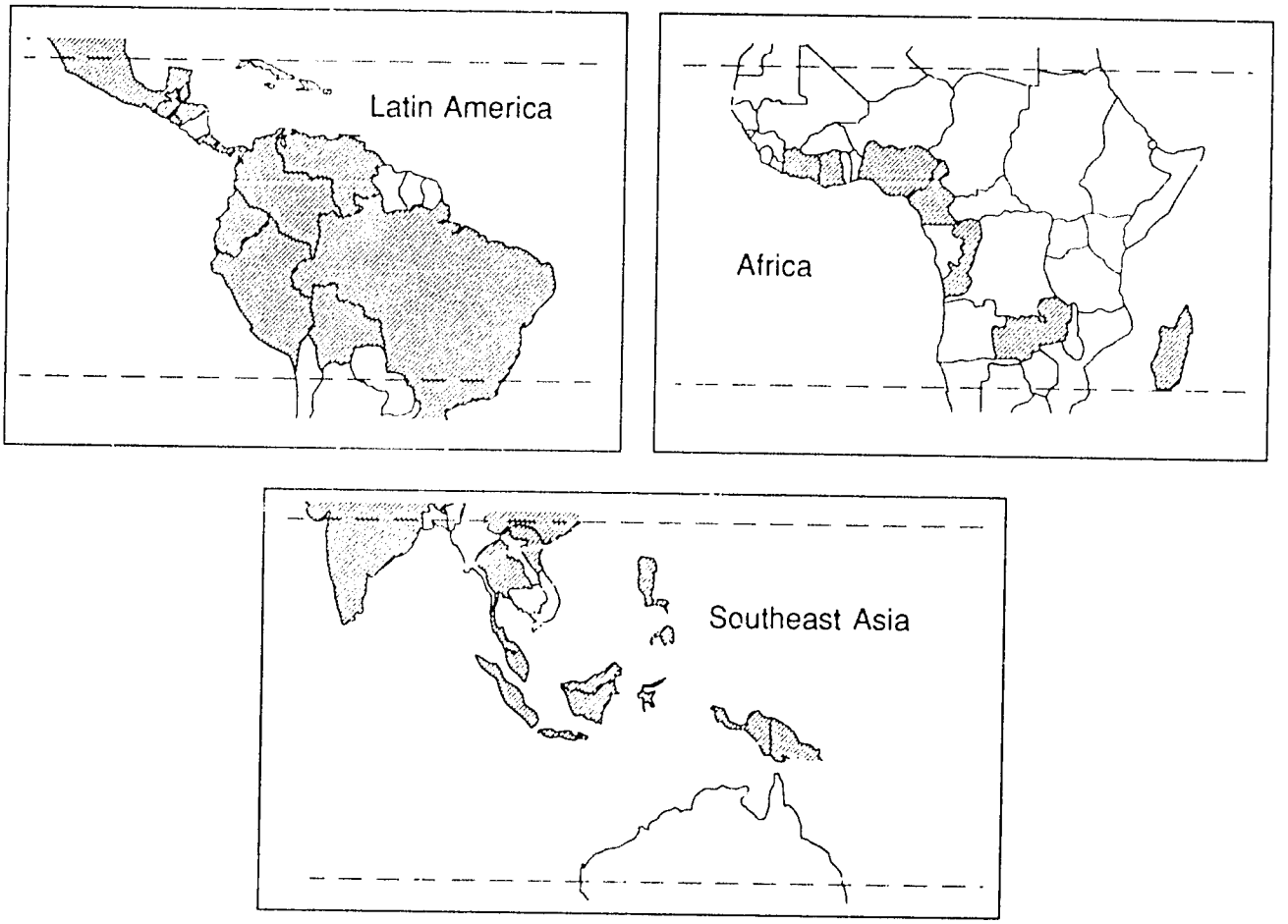


**Figure 1. Countries in tropical soils research networks supported by IBSRAM and TropSoils (shaded areas).**

analyze the agreed-upon edaphic parameters was prepared by TropSoils/NCSU and submitted to IBSRAM headquarters. A second African meeting, scheduled for April 1987 in Lusaka, Zambia, is expected to produce concrete experimental designs.

The first IBSRAM Regional Workshop on Soil Management under Humid Conditions in Asia was held at Khon Kaen and Phitsanulok, Thailand, October 13-20, 1986, with 82 participants from 17 countries. Thailand's Ministry of Agriculture and Cooperatives and IBSRAM were the co-hosts of the workshop, which was funded primarily by the Asian Development Bank (ADB) and the Australian Council for International Agricultural Research (ACIAR). Eight countries expressed interest in joining the Acid Soils Network. Included in the list are the three Asian participants at the Inaugural Workshop—China, Malaysia and Thailand—and five additional countries—India, Indonesia, Philippines, Vietnam and Western Samoa. The common theme was the limited base of knowledge about how to produce food crops on acid upland soils of tropical Asia.

The participants agreed on two types of research activities—a "core" experiment and component research—in addition to site characterization, a common activity of all networks. The core experiment is designed to compare current acid upland soil-management practices with (a) low-input systems based on acid-tolerant cultivars, low levels of added P and no change in the soil's acidity and (b) an intensive system with liming to neutralize exchangeable Al and appropriate fertilizer practices for cropping systems based on corn, soybean or cotton. Although the specific cropping system will vary with the site, the common thread will be the monitoring of soil dynamics as proposed at the Inaugural Workshop.

Component research projects focus (a) liming, (b) screening of acid-tolerant species and varieties,

(c) residual effects of P fertilization, (d) organic inputs, initially focusing on determining the nutrient contents of composts, green manures, or animal manures, and (e) Fertility Capability Classification.

**Outlook**

Participants in the African network have expressed to IBSRAM particular concern about the need to increase their expertise in acid tropical soil-management techniques among their front-line scientists. Based on the recent success of a similar activity for RISTROP participants, and on the African network emphasis on technologies developed in the TropSoils program, IBSRAM has requested NCSU's assistance with on-the-job training of soil scientists who will be doing the work in the Acid Soil Management Network. The experience accumulated in Latin America by the TropSoils program and the commonality of interests with IBSRAM in transferring such knowledge to African scientists makes it fitting that assistance be provided toward network implementation through a workshop/training course at the primary research site in Yurimaguas, Peru.

**Implications**

Acid tropical soils comprise approximately 1.7 billion ha of land area in 72 developing countries. Their geographical concentration is primarily in least-developed Third World regions, many of which are currently undergoing social unrest and face several food shortages by the next decade. Thirty-seven of these countries are now involved in RISTROP and IBSRAM and tropical soils networks (Figure 1). The network support activities offer the opportunity for concerted worldwide efforts in disseminating existing information and developing local expertise on management of this fragile ecosystem in needy countries. Feedback from validation and extrapolation of existing information would enhance TropSoils' role in the discrimination of agronomically and economically sound acid soil-management technologies through the identification of refinements and modifications for ongoing research.

# Legume-Based Pastures

Cattle grazing for beef and milk production is one of the major land-use activities of cleared rainforest areas in Latin America. We continue to find that when they are well managed, legume-based pastures protect the soil, require relatively few cash inputs, make good use of soils unsuitable for food crops, and produce milk and meat with grazing animals, which recycle most of the nutrients they consume. But poorly managed pastures are an economic and ecological liability. The use of pasture species badly adapted to tropical soils and environments leads to poor animal nutrition and therefore low productivity. Several million hectares of rainforest have been cleared for pastures, only to be abandoned as the pastures became degraded by overgrazing, soil compaction and erosion.

Pastures research at Yurimaguas and Pucallpa, Peru, has been closely integrated with the Tropical Pastures Program of the Centro Internacional de Agricultura Tropical (CIAT), and with INIPA's National Selva Program, which is now conducting most of the agronomic studies. Research reported here is based on an overall long-term strategy shown in Figure 1. All stages but the last are fully implemented.

Long-term grazing studies show that high animal production levels can be sustained with three widely differing pastures in acid Ultisols with low inputs: a mixture of two stoloniferous grass and legume species (*Brachiaria humidicola/Desmodium ovalifolium*), a mixture of two erect grass and legume species (*Andropogon gayanus/Stylosanthes guianensis*), and one pure legume pasture of *Centrosema pubescens*. Other mixtures are failing because of low quality problems. After four to six years of continuous grazing, soil physical properties remain good and chemical properties have improved, because more than 80% of the P, K and Ca applied as fertilizer is recycled to the soil. This year we obtained the first estimate of the N contribution of legumes to the associated grass under grazing in highly acid soil: the legume contributed an equivalent of 150 kg N/ha of urea nitrogen. Potassium dynamics, a key issue for pasture persistence, continues to be quantified, and S accumulation in Ultisol subsoils was confirmed.

Perhaps the most exciting accomplishment of this year was the successful transformation of degraded steepland pastures into highly productive ones by establishing grass and legume species with minimum tillage and phosphate rock in slopes ranging from 20 to 80%. In areas where herbicides are available, the proper combination of tillage and herbicide was determined to eliminate undesirable species and plant improved ones.

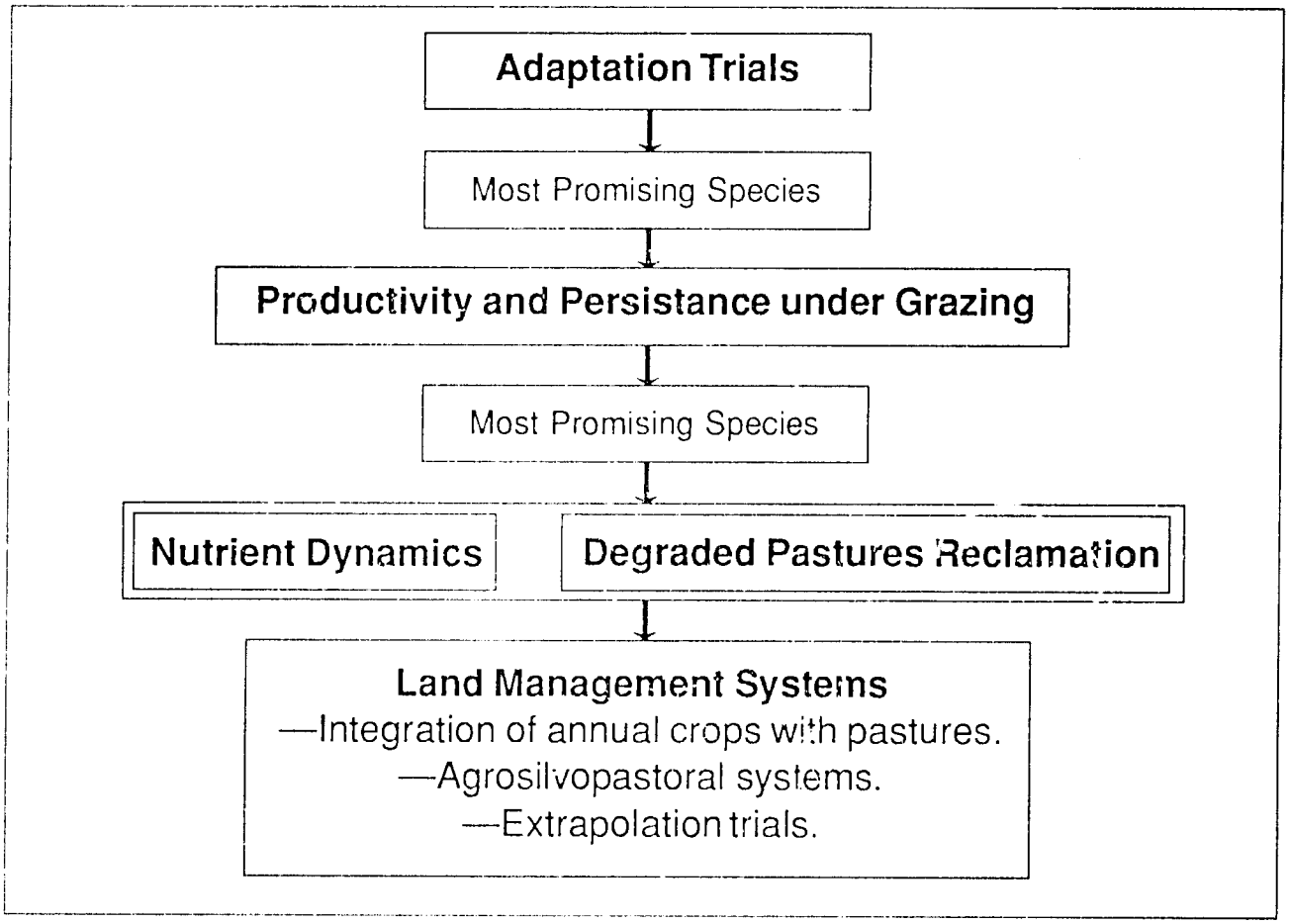


Figure 1. Strategy for developing the pasture soil-management option for the humid tropics.

# Persistence of Grass-Legume Mixtures under Grazing

*Miguel A. Ayarza, N. C. State University*
*Rolando Dextre, INIPA*
*Pedro A. Sanchez, N. C. State University*

The central experiment for the legume-based pasture soil-management option is now in its sixth year of grazing. Its objectives are 1) to measure pasture and animal productivity in different associations, in terms of daily weight gain and annual liveweight production; 2) to evaluate the compatibility and the persistence of the different grass-legume mixtures under grazing; and 3) to evaluate changes in soil properties as a consequence of long-term pasture production.

Four associations remain unchanged, but during the four years the project has been in progress, *Panicum maximum* + *Pueraria phaseoloides* was replaced by *Andropogon gayanus* + *Centrosema macrocarpum* 5056 in October 1984. A sixth association, *Brachiaria dyctioneura* + *Desmodium ovalifolium*, was established at a separate location with grazing initiated in March 1986. The species previously reported as *Centrosema* hybrid 438 was reclassified by plant taxonomists as *Centrosema pubescens* 438. The main features of the experiment are shown in Table 1.

**Table 1. Main features of the central, legume-based pastures experiment.**

Design: Randomized complete block, two replications
Plot size: 0.45 ha
Pasture established: Sept. 1979
Stocking rate: 3.3-5.5 an/ha (150-kg Cebu steers)
Grazing management: Continuous Nov. 1980-July 1981
Alternate 28-35 day cycles since July 1981

Fertilization:
- 22 kg P/ha as SSP (yearly)
- 42 kg K/ha as KCl (yearly)
- 10 kg Mg/ha as $MgSO_4$ (yearly)
- 500 kg lime/ha (once)

Soil: Typic Paleudult, fine loamy, siliceous, isohyperthermic.
Initial topsoil (0-20 cm) properties. Sept. 1979:

| | |
|---|---|
| Clay: 13% | Al sat.: 78% |
| O.M.: 1.85% | ECEC: 3.87 cmol/L |
| pH : 4.3 | Avail P: 2.2 µg/g |

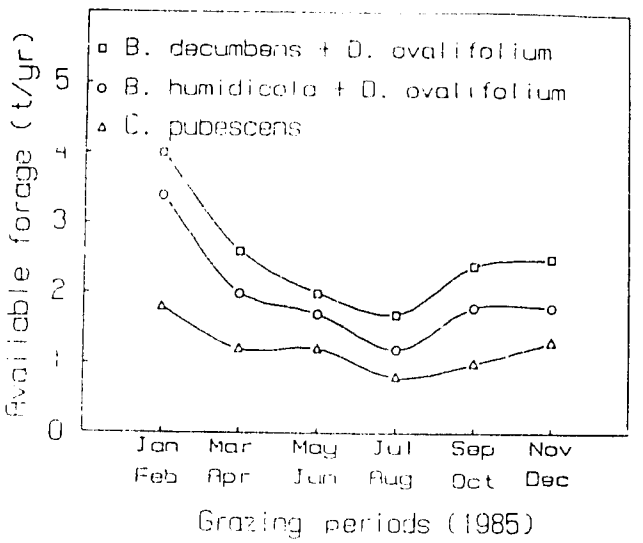


**Figure 1. Seasonal changes in available forage on offer of three pastures in 1985.**

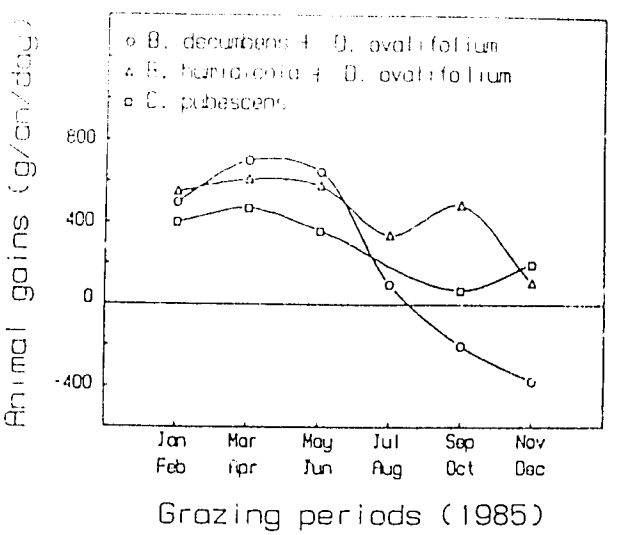


**Figure 2. Seasonal changes in individual liveweight gains in 1985.**

## Annual Production and Botanical Composition, 1985-1986

Annual liveweight gains per hectare (the measure of overall pasture productivity), individual animal daily gains (an estimate of pasture quality), legume content, actual grazing periods and stocking rates used are shown in Table 2 for 1985 and Table 3 for 1986.

Annual liveweight gains were generally better in 1985 than in 1986 due to a more favorable rainfall pattern in 1985 and a three-month delay in grazing initiation in 1986. Stocking rates were adjusted

**Table 2. Animal production, grazing periods and percentage of legume in five pastures under alternate grazing in 1985.**

| Pasture | Grazing years | Grazing period | Stocking rates Rainy period | Stocking rates Dry period | Liveweight gains Total prod. | Liveweight gains Indiv. prod. | Legume content |
|---|---|---|---|---|---|---|---|
| | | | ——an/ha—— | | kg/ha/yr | g/an/day | % |
| *C. pubescens* 438 | 4 | Jan. 14-Dec. 19 | 4.4 | 4.4 | 510 | 342 | 100 |
| *B. humidicola* + *D.ovalifolium* 350 | 3 | Jan. 14-Dec. 19 | 5.5 | 4.4 | 843 | 482 | 30 |
| *B. decumbens* + *D. ovalifolium* 350 | 5 | Jan. 14-Dec. 19 | 5.5 | 4.4 | 469 | 259 | 26 |
| *A. gayanus* + *S. guianensis* 134-186 | 5 | April 1-Dec. 3 | 3.3 | 3.3 | 363 | 594 | 49 |
| *A. gayanus* + *C. macrocarpum* 5016 | 2 | April 23-Nov. 20 | 3.3 | 3.3 | 502 | 775 | 13 |

**Table 3. Animal production, grazing periods and percentage of legume in five pastures under alternate grazing in 1986.**

| Pasture | Grazing years | Grazing period | Stocking rates Rainy period | Stocking rates Dry period | Liveweight gains Total prod. | Liveweight gains Indiv. prod. | Legume content |
|---|---|---|---|---|---|---|---|
| | | | ——an/ha—— | | kg/ha/yr | g/an/day | % |
| *C. pubescens* 438 | 5 | Mar. 18-Dec. 4 | 3.3 | 3.3 | 498 | 636 | 100 |
| *B. humidicola* + *D. ovalifolium* 350 | 4 | Mar. 18-Dec. 22 | 5.5 | 4.4 | 450 | 336 | 34 |
| *B. decumbens* + *D. ovalifolium* 350 | 6 | Mar. 18-Dec. 10 | 5.5 | 4.4 | 223 | 170 | 22 |
| *A. gayanus* + *S. guianensis* 136-184 | 6 | Mar. 18-Dec. 10 | 3.3 | 3.3 | 436 | 544 | 34 |
| *A. gayanus* + *C. macrocarpum* 5056 | 3 | Mar. 18-Dec. 22 | 3.3 | 3.3 | 632 | 755 | 33 |
| *B. dyctioneura* + *D. ovalifolium* 350 | 1 | Mar. 18-Oct. 10 | 4.4 | 4.4 | 131 | 149 | 52 |

according to forage availability and divided into two semesters (January to June as the wetter period, and July to December as the less wet period). *Brachiaria humidicola/D. ovalifolium* mixtures produced very high annual liveweight gains (843 kg/ha), way above the other mixtures. This mixture produced high available forage throughout the year (Figure 1), which permitted a higher stocking rate. Liveweight gains decreased in 1986, in spite of legume content similar to that in 1985.

The *B. decumbens/D. ovalifolium* mixture's performance was quite inferior, producing about half the daily animal gains of the previous mixture, in spite of the use of identical stocking rates (Tables 2 and 3). Although forage availability was higher with *B. decumbens* than with *B. humidicola* (Figure 1), sharp animal weight losses were observed with the *B. decumbens/D. ovalifolium* mixture during the second half of the year. Individual animal gains dropped drastically from June 1985 and continued dropping until December, when the animals lost more than 300 g/day (Figure 2). The same situation occurred at the same time in 1986, as was reflected in low individual animal gains. This problem may be due to photosensitivity, which sometimes occurs with *B. decumbens*, or to an unknown nutritional problem during the drier part of the year. Its solution is likely to require the collaboration of animal nutrition specialists.

The pure legume pasture *C. pubescens* 438 maintained good levels of animal production in both years, in spite of the lower amount of forage on offer than the mixed pastures (Figure 2), which resulted in no weight losses during the drier period. Since forage quantity is lower than in the previous mixtures, the higher quality of *C. pubescens* 438 over *D. ovalifolium* (Table 4) is considered responsible for its good performance.

The mixture of erect species *A. gayanus* with *Stylosanthes guianensis* performed remarkably well in 1985 and 1986, particularly in terms of daily gains, suggesting a higher quality of the legume component (Table 4). Promising results were obtained in *A. gayanus* + *C. macrocarpum* 5065. Excellent individual animal gains were recorded during 1985 and 1986. Since this pasture has only been grazed since May 1985, it is not possible to compare it with the older mixtures, but it certainly shows good promise.

In sharp contrast, the new mixture established in 1985, on which grazing was begun in March 1986 (*B. dyctioneura/D. ovalifolium*), performed very poorly, even during the first year (Table 3). This mixture showed an excessively high content of legume in the forage on offer. This may significantly reduce animal performance due to the low quality of the legume, in comparison with the *Centrosema* species (Table 4). This mixture was eliminated from the trial in 1986. This is disappointing because this

**Table 4. Nutrient quality of leaf blades (Dec. 1985).**

| Species | Crude protein | P | Tannins* |
|---|---|---|---|
| | % | | |
| **Legumes** | | | |
| *D. ovalifolium* | 12.4 | 0.22 | 21.0 |
| *C. pubescens* | 24.8 | 0.27 | 2.5 |
| *S. guianensis* | 21.4 | 0.35 | 4.0 |
| **Grasses** | | | |
| *B. decumbens* | 11.3 | 0.22 | — |
| *B. humidicola* | 10.6 | 0.22 | — |
| *A. gayanus* | 10.6 | 0.27 | — |

*Analyzed in 1983. Vanillin-HCL method.

**Table 5. Average annual productivity of legume-based pastures in the central grazing experiment at Yurimaguas (1980-86).**

| Pasture | Years grazing | Stocking rate | Liveweight gains: Total prod. | Liveweight gains: Indiv. prod. | Leg. content |
|---|---|---|---|---|---|
| | | an/ha | kg/ha/yr | g/an/day | % |
| *B. humidicola/D.ovalifolium* | 4 | 4.6 | 671 | 419 | 38 |
| *B. decumbens/D. ovalifolium* | 6 | 4.7 | 532 | 324 | 35 |
| *C. pubescens* 438 | 5 | 3.8 | 573 | 471 | 96 |
| *A. gayanus/S. guianensis* | 6 | 3.2 | 477 | 427 | 31 |

species is being considered an alternative to the other *Brachiarias* in the ustic tropics. Apparently this is not the case in Yurimaguas, with its udic soil moisture regime.

### Long-Term Trends in Persistence and Productivity

A summary of the six years of grazing was presented at the American Society of Agronomy meetings in November 1986. This summary gives for the first time a vision of pasture persistence. Only the four most promising mixtures are included in this analysis. The overall summary (Table 5) indicates

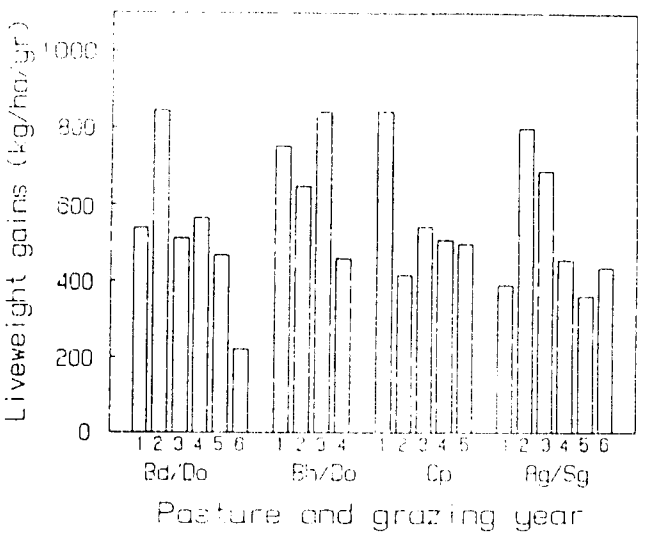


Figure 3. Yearly fluctuations in liveweight gains in four rotationally grazed pastures at Yurimaguas. Bd = *B. decumbens*; Do = *D. ovalifolium*; Bh = *B. humidicola*; Cp = *C. pubescens*; Ag = *A. gayanus*; Sg = *S. guianensis*.

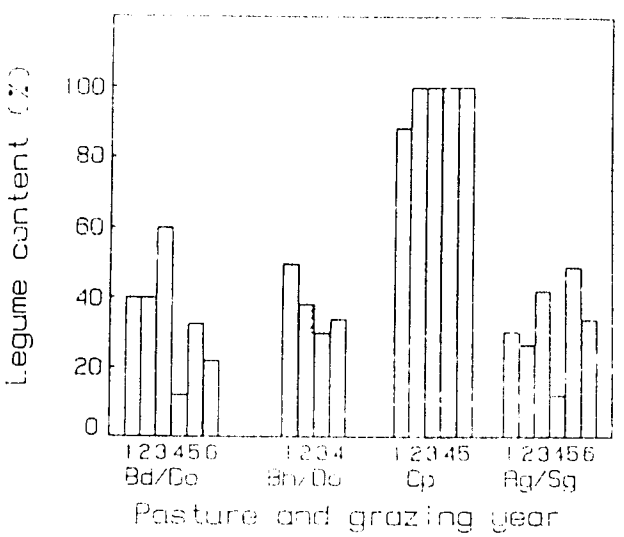


Figure 4. Yearly fluctuation in average legume composition of the mixture. Bd = *B. decumbens*; Do = *D. ovalifolium*; Bh = *B. humidicola*; Cp = *C. pubescens*; Ag = *A. gayanus*; Sg = *S. guianensis*.

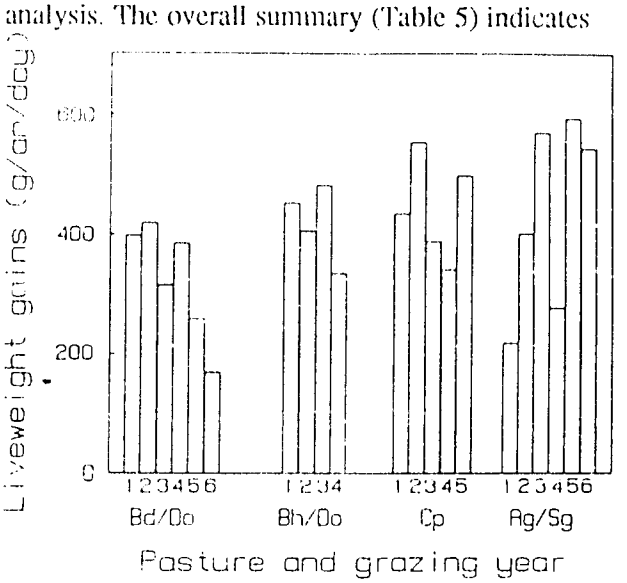


Figure 5. Yearly fluctuations in daily liveweight gains. Bd = *B. decumbens*; Do = *D. ovalifolium*; Bh = *B. humidicola*; Cp = *C. pubescens*; Ag = *A. gayanus*; Sg = *S. guianensis*.

Table 6. Infiltration values in five pastures under grazing in Yurimaguas for several years (mean of two replications and four observations per replication of each pasture).

| Pasture | Years of grazing | Infiltration* | S.E. $\bar{x}$ |
|---|---|---|---|
| | | cm/hr | |
| *B. decumbens* + *D. ovalifolium* | 5 | 4.71 a | 1.20 |
| *B. humidicola* + *D. ovalifolium* | 3 | 2.00 a | 0.58 |
| *C. pubescens* | 4 | 10.44 a | 2.60 |
| *A. gayanus* + *C. macrocarpum* | 1 | 1.96 a | 2.82 |
| *A. gayanus* + *S. guianensis* | 5 | 1.00 a | 0.19 |

$LSD_{0.05}$ = 10.4

*Numbers followed by the same letter are not statistically significant at P = 0.05.

that there are several widely different options, all with very high animal productivity potential (annual liveweight gains on the order of 500 to 600 kg/ha/yr). Considering that cattle production from unimproved pastures is of the order of 50-100 kg/ha/yr, each mixture is very attractive. The quality problem of *B. decumbens/D. ovalifolium* definitely puts it at a disadvantage in relation to the other three.

Each of the remaining three represents a different approach: a mixture of creeper species (*B. humidicola/D. ovalifolium*), a mixture of erect species (*A. gayanus/S. guianensis*), and a pure, high-quality legume pasture (*C. pubescens* 438).

The yearly fluctuation in the above parameters gives a feel for pasture stability. Annual liveweight gains fluctuated considerably, but the greatest fluctuations were observed in the erect mixture (Figure 3). The legume content tended to fluctuate less than liveweight gains (Figure 4) and showed little relationship with annual liveweight gains. Legume content seldom dropped below 20% of the forage on offer, a level below which is considered undesirable. Daily liveweight gains (Figure 5) showed less yearly fluctuations than the previous two parameters. Nevertheless, these yearly averages include sharp weight losses in the *B. decumbens/D. ovalifolium* mixture during the last two years. Overall, Figures 3, 4 and 5 suggest a reasonable degree of stability in the other three mixtures.

## Long-Term Changes In Soil Properties

### *Infiltration*

Measurements taken in December 1985 indicated a marked decrease in water infiltration rates in most of the pastures as a result of soil compaction produced by animals after five years of grazing (Table 6). Lowest values were found in *A. gayanus/S. guianensis* and *A. gayanus/C. macrocarpum*. This may be associated with the erect growth of these species so that they do not cover the soil as do the other pastures. Statistical analysis, however, showed that infiltration differences among pastures were not significant, due to the high variability of the double ring infiltrometer measurement.

The infiltration rate prior to the start of grazing in November 1980 was 12.7 cm/hr, with a range of 6.3 to 19.8. Five years later the average infiltration was 4.1 cm/hr with a range of 1.0 to 10.4 (Table 6). There is no question, therefore, that five years of trampling have decreased infiltration rates in this sandy loam Ultisol. The magnitude of the decrease has not produced visible runoff or erosion. This is because rainfall intensity values average much less than 41 mm/hr (see Continuous Cropping section) and also because these pastures provide a full plant canopy year-round, protecting the soil from raindrop impact.

### *Soil organic matter*

Topsoil (0-20 cm) organic matter and total N for each pasture were determined in December 1985, and values were compared to those obtained five years before the initiation of grazing (Table 7). These

**Table 7. Changes in organic matter total nitrogen in the topsoil (0-20 cm) of five pastures under grazing after five years (1980-1985).**

| Pasture | Organic matter | Total N $\bar{x}\pm$SD* | Total N Amount** |
|---|---|---|---|
| | % | % | kg/ha |
| Before grazing (Nov 1980) | 1.93±0.4 | 0.0707±0.016 | 1837 |
| *B. decumbens* + *D. ovalifolium* | 3.35±0.4 | 0.0895±0.015 | 2327 |
| *B. humidicola* + *D. ovalifolium* | 1.35±0.6 | 0.0705±0.412 | 1085 |
| *C. pubescens* | 1.95±0.2 | 0.0856±0.0025 | 2225 |
| *A. gayanus* + *S. guianensis* | 2.02±0.2 | 0.0770±0.005 | 2002 |
| *A. gayanus* + *C. macrocarpum* | 2.14±0.2 | 0.0757±0.009 | 1969 |

* Mean of two composite samples (ten subsamples each). Rest of pasture is the mean of two replications (ten subsamples each).
** Value calculated assuming 1.4 g/cc in the 0-20 cm depth. Mean of three composite samples (ten subsamples each). Mean±standard deviation.

**Table 8. Status of soil fertility of the topsoil (0-20 cm) of five pastures after five years of grazing in Yurimaguas.**

| Pasture | Year | pH | O.M. | Olsen P | Exchangeable Ca+Mg | Exchangeable K | Exchangeable Al | Al sat. |
|---|---|---|---|---|---|---|---|---|
| | | | % | ppm | cmol/L | cmol/L | cmol/L | % |
| *B. decumbens* + | 1980 | 4.2 | 1.9 | 3.9 | 1.7 | - | 2.7 | 55 |
| *D. ovalifolium* | 1985 | 4.6 | 3.3 | 8.3 | 1.0 | 0.10 | 0.9 | 53 |
| *B. humidicola* + | 1980 | 5.2 | 1.7 | 2.2 | 2.4 | - | 1.7 | 42 |
| *D. ovalifolium* | 1985 | 5.0 | 1.3 | 6.4 | 1.2 | 0.12 | 1.3 | 49 |
| *C. pubescens* | 1980 | 4.9 | 2.2 | 8.6 | 2.1 | - | 2.5 | 54 |
| | 1985 | 5.0 | 1.9 | 6.5 | 1.8 | 0.18 | 2.4 | 54 |
| *A. gayanus* + | 1980 | 4.6 | 2.1 | 5.8 | 1.7 | - | 2.4 | 56 |
| *S. guianensis* | 1985 | 5.3 | 2.0 | 7.9 | 1.6 | 0.11 | 1.8 | 51 |
| *A. gayanus* + | 1980 | 4.3 | 1.8 | 4.3 | 1.5 | - | 2.4 | 60 |
| *C. macrocarpum** | 1985 | 5.1 | 2.1 | 1.0 | 1.1 | 0.07 | 2.2 | 65 |

* *A. gayanus* + *Pueraria phaseoloides* for the first three years.

data compare the overall levels of the experiment prior to grazing with the effects of individual pastures, and not on a plot-per-plot basis. In spite of this limitation, it appears that organic matter and total N contents either increased or remained the same during five years of grazing. The differences between pastures cannot be explained in terms of legume content, since both the highest and lowest levels were observed in mixtures with *D. ovalifolium*. The lowest levels were observed with *B. humidicola/ D. ovalifolium*, the most productive pasture. Topsoil organic matter contents were maintained under this management option (Table 7).

*Soil fertility parameters*

Status of soil chemical properties in the 0-20 cm depth is reported in Table 8. Topsoil pH and P values were higher in 1985 than in 1980 in most of the pastures. Acidity decreased greatly in topsoils under *B. decumbens/D. ovalifolium*. Additional soil characterization at the 0-5 and 5-20 cm depths on *B. humidicola/D. ovalifolium* showed that most changes observed in topsoils were restricted to the 0-5 cm soil surface layer (Figures 6, 7, 8, 9). This may indicate that nutrient accumulation and cycling occurs mainly at the soil 0-5 m layer.

*Nutrient cycling*

The improvements in soil properties in the top 20 cm can probably be attributed to the original and annual maintenance fertilization schedule shown in Table 1. It is noteworthy to observe that the annual maintenance fertilization was not applied in November 1983. The total amounts of P, K and Ca added as fertilizers and lime during the five-year period were compared by the amount calculated to be removed by animals in terms of annual liveweight gains. The results, shown in Table 9, indicate that 80% of the P, 98% of the K, and 92% of the Ca added as fertilizer were recycled to the soil in the *B. decumbens/ D. ovalifolium* mixture. This high level of recycling is one real advantage of grazed grass-legume pastures, where nutrients exported on the hoof are very low.

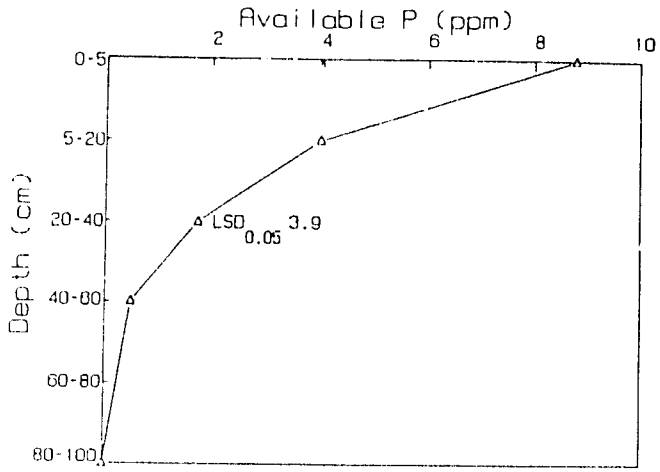


Figure 6. Available P profile five years after grazing a *B. humidicola/D. ovalifolium* mixture. Initial level (1980): 2.2 ppm at 0–20 cm.

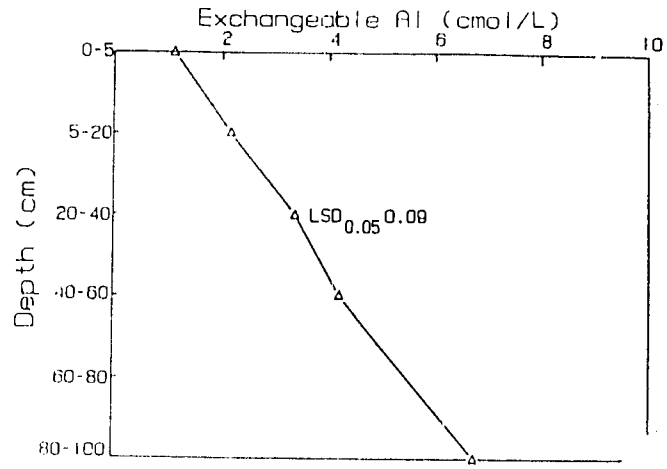


Figure 7. Exchangeable Al profile five years after grazing a *B. humidicola/D. ovalifolium* mixture. Initial level (1980): 1.5 cmol/L at 0–20 cm.

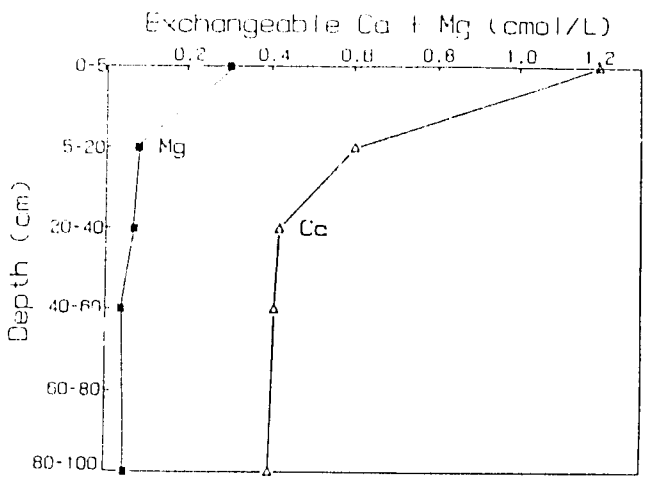


Figure 8. Exchangeable Ca and Mg profiles five years after grazing a *B. humidicola/D. ovalifolium* pasture. Initial level (1980): 2.2 cmol/L Ca + Mg.

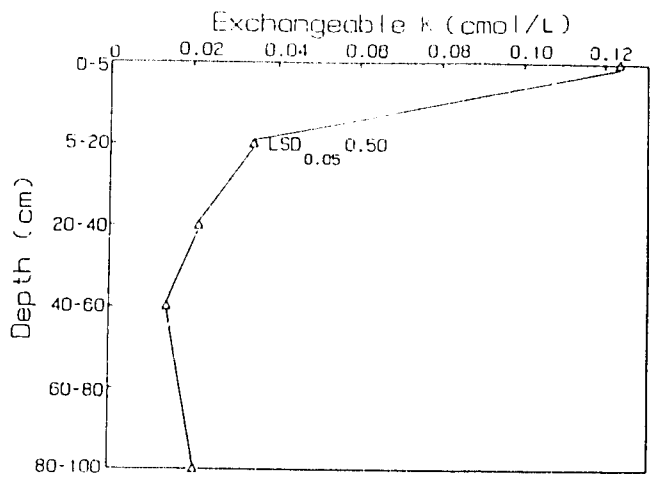


Figure 9. Exchangeable K profile five years after grazing a *B. humidicola/D. ovalifolium* pasture. Initial level (1980): 0.10 cmol/L.

Table 9. Nutrient balance in *B. decumbens/D. ovalifolium* during five years of grazing.

| Balance (1980-1985) | P | K | Ca |
|---|---|---|---|
| | kg/ha | | |
| Added as fertilizers and lime | 112 | 160 | 505 |
| Removed by animals | 22 | 6 | 39 |
| Balance | 90 | 154 | 466 |
| % "recycled" | 80 | 98 | 92 |

# Evaluation of Animal Preference In Small Grazing Plots

*Miguel A. Ayarza, N.C. State University*
*Rolando Dextre, INIPA*

Observation of animal preference at early stages of evaluating new forage accessions is considered an important tool in selecting desirable species from both the agronomic and the animal standpoints. Palatability is crucial in the acid-tolerant tropical legumes we are working with. Factors dealing with quality and preference can hardly be assessed without animals.

## Objective

The objective of this study is to test whether differences exist in animal preference for 13 legume accessions at Yurimaguas.

## Procedures

An old regional Trial B, for which agronomic evaluation concluded in 1985, was used in this work. The experiment was fenced in March and animals were introduced in May 1986. Accessions were arranged in randomized complete blocks with 3 x 4 m plot size per species. Three animals (180 kg liveweight) were observed 6 hr/day for three days in each replication. Position of the animals and time spent grazing a particular accession were recorded every 15 minutes.

Before entering the next replication, animals were kept out of the experiment on a pure stand of *B. humidicola* for three days in an attempt to diminish preference effects between replications.

## Results

The first evaluation showed average grazing time per species differed even within a genus. *Centrosema macrocarpum* 5065 was preferred over the other *Centrosema* accessions (Figure 1), and *Centrosema macrocarpum* 5052 was hardly consumed at all. *Desmodium ovalifolium* 366 was preferred over *D. ovalifolium* 350.

## Implications

These results indicate that differences in animal preference for legumes exist, even within the same genus and species. Although *Centrosema* species are known to be palatable, there are important differences in palatability. The preference for *D. ovalifolium* 366 is probably associated with its lower tannin content than *D. ovalifolium* 350, as has been reported by CIAT. A simple animal-preference test can be included at the earliest stages of germ plasm evaluation to obtain a comparative idea of animal preference with known species. This procedure could save significant time and effort by eliminating undesirable accessions before starting a grazing trial.

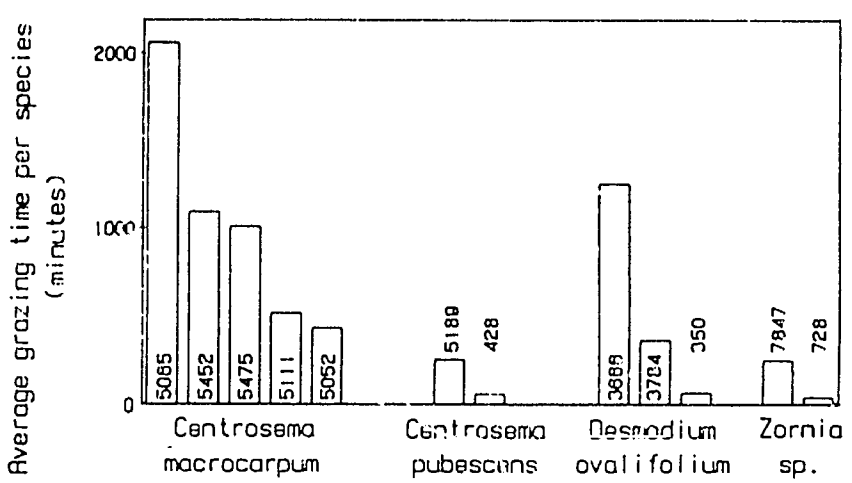


**Figure 1. Animal preference for 12 legumes at Yurimaguas.**

# Nitrogen Contribution Of Legumes in Mixed Pastures

*Miguel A. Ara, N. C. State University*
*Jorge W. Vela, INIPA*
*Pedro A. Sanchez, N. C. State University*

Mixed grass-legume pastures are rare in the humid tropics. Most of the successful mixtures occur in the ustic soil moisture regimes. The success of some mixed pastures in such areas is often related to the ability of the legume to provide protein during the strong dry season, when grasses cannot. In the humid tropics, where grasses remain green throughout the year, the role of the legume is different. The purpose of this work is to ascertain the role of legumes under humid tropical conditions. A long-term grazing experiment was established at the IVITA Principal Tropical Station west of Pucallpa, Peru, in collaboration with INIPA and IVITA.

## Objectives

The objectives of this study are 1) to estimate the N contribution of two adapted pasture legumes (*Centrosema pubescens* and *Desmodium ovalifolium*) to their respective mixtures with *Brachiaria decumbens* in terms of N yield, N availability to the grazing animals, legume litter accumulation and N release, and 2) to evaluate the effect of different grazing pressures on the mixture *B. decumbens/D. ovalifolium* in terms of N availability to grazing animals, legume litter accumulation and N release.

## Procedures

A six-hectare degraded pasture was planted to improved pastures to compare the N-supplying capability of two alternative N sources (legumes vs. different levels of N-fertilizer) on a grazed *B. decumbens* pasture, in terms of N yield of the standing biomass, N availability to the grazing animals, legume leaf litter accumulation and N release. An additional variable, high grazing pressure, was included in the legume mixture (normal = 4.5 kg available forage dry matter per 100 kg animal liveweight; high = twice the pressure). The experimental design was randomized complete blocks with five treatments and three replications. Grazing was initiated in January 1986. Replications were utilized as paddocks of a 15-day grazing, 30-day rest rotation. Brown Swiss and Holstein-Cebu halfbreeds were used. Two esophagus-fistulated steers were always kept in the same treatment; intact animals were used as grazers. Animals were weighed before entering each replication, but only to adjust the grazing pressure.

Slope was used as a blocking criterion. Replication I was located on 0-5% slope, and replications II and III were located on 75% slopes. Soil was a Pucallpa series Paleudult. Selected soil properties at the initiation of the experiment are given in Table 1.

Serious problems in establishing the *C. pubescens/B. decumbens* mixture forced us to discard this treatment.

**Table 1. Selected soil properties at the initiation of the experiment. 0-15 cm. December 1985.**

| Rep | Sand | Clay | pH | P | Al | Ca | Mg | K | O.M. | N | Al sat. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ——%—— | | | µg/ml | ——cmol/L—— | | | | ——%—— | | |
| I | 25.4 | 25.2 | 4.6 | 5.4 | 2.3 | 1.83 | 0.66 | 0.17 | 2.33 | 0.09 | 48 |
| II | 44.3 | 25.2 | 4.5 | 5.7 | 1.8 | 1.90 | 0.66 | 0.14 | 2.34 | 0.10 | 40 |
| III | 51.9 | 22.2 | 4.7 | 4.1 | 2.1 | 1.68 | 0.54 | 0.11 | 2.19 | 0.08 | 45 |

## Results

*Forage availability*

Dry matter availability and botanical composition were evaluated using a double-sampling dry-weight rank procedure with 100 samples per 0.33-ha paddock, just before grazing began. Dry-matter yield and botanical composition are shown in Table 2, and the corresponding ANOVA for dry matter available to the treatments is shown in Table 3. No response was obtained for dry-matter availability to the treatments, although a trend of N response is evident. Legume contents are adequate, but hover at high grazing pressure, as expected.

*Nitrogen content and nitrogen yield*

This year we were able to install a micro-Kjeldahl unit at the IVITA soils laboratory. Results of N content and yield are the first from this laboratory. Unlike dry-matter availability, treatment effects on N content and N yield of *B. decumbens* were well expressed (Table 2). The N fertilizer effect on N content and N yield was linear, with no quadratic component (Figures 1 and 2). The presence of the legume significantly increased the N content of the grass by an average of 44% (1.06 vs. 1.53% N). The effect of grazing pressure of mixed pastures on grass N content was not significant.

On the average, mixtures gave a higher grass N yield than grass alone with no N fertilizer, equivalent to 151 kg of N (from the regression equation). This amount is contributed by 28% of the legume component in the high-grazing-pressure treatment and 35% in the normal-grazing-pressure treatment. These numbers do not include the N content of the legume per se. Consequently, they provide an early indication that legumes contribute the equivalent of about 150 kg N/ha/yr to the associated grass during the first ten months of grazing.

**Table 2. Forage on offer and botanical composition of *B. decumbens* pastures fertilized with N or mixed with *D. ovalifolium* at two grazing pressures. Mean of three replications.**

| N source | Grazing pressure | Forage dry matter* | Legume | Grass N content Compos. | Grass N content Uptake |
|---|---|---|---|---|---|
| kg/ha/yr | | tDM/ha/cycle | % | % N | kg/ha/cycle |
| 0 | Normal | 1.34 | - | 1.06 a | 140 |
| 150 | Normal | 1.56 | - | 1.42 b | 222 |
| 300 | Normal | 1.66 | - | 1.85 c | 308 |
| Legume | Normal | 1.42 | 35 | 1.38 b | 218 |
| Legume | High | 1.38 | 28 | 1.58 b | 230 |

*Mean of seven grazing cycles of 45 days duration each.

**Table 3. ANOVA for forage dry matter available.**

| | Degrees of freedom | Mean squares | |
|---|---|---|---|
| Replications | 2 | 46.3047 | ns |
| Treatments | 4 | 140.8177 | ns |
| N linear | 1 | 398.53 | ns |
| N quadratic | 1 | 21.12 | ns |
| Mixtures vs. NQ | 1 | 18.40 | ns |
| HGP vs. LGP | 1 | 5.23 | ns |

*Leaf litter N accumulation*

Four 0.5 x 0.5 m squares were selected in each legume paddock to cover the range of legume composition. The squares were fixed with iron stakes, and the *D. ovalifolium* leaf litter was collected, dried, and weighed. Leaf litter dry matter accumulation averaged 14 g/0.5 m²/18 months for the high grazing pressure treatment and 29 g/0.5 m²/18 months for the normal grazing pressure treatment.

Nitrogen content of the leaf litter averaged 1.60%. Nitrogen accumulation in litter form during this 18-month period averaged 4.6 kg N/ha for the high grazing pressure treatment and 10.1 kg N/ha for the normal grazing pressure treatment. Consequently, the lower the grazing pressure, the more important will be the N transfer through the litter. This effect is being measured concurrently with N intake by animals and in excreta to fully calculate the N contribution of legumes to mixed pastures.

## Conclusions to Date

1. There is a strong linear response of *B. decumbens*-grazed pastures to N fertilization as high as 300 kg N/ha/yr.

2. Including *D. ovalifolium* in the mixture contributes about 151 kg N/ha/yr to the

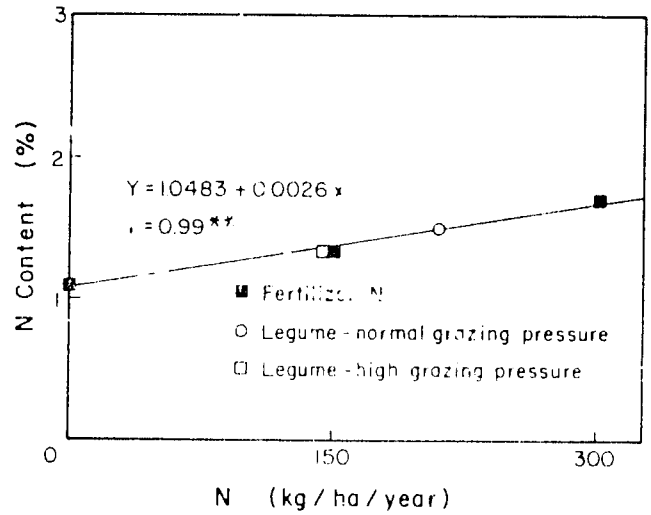


**Figure 1. Effect of fertilizer N and legume presence on N content of *Brachiaria decumbens* pasture during the first grazing year in Pucallpa, Peru.**

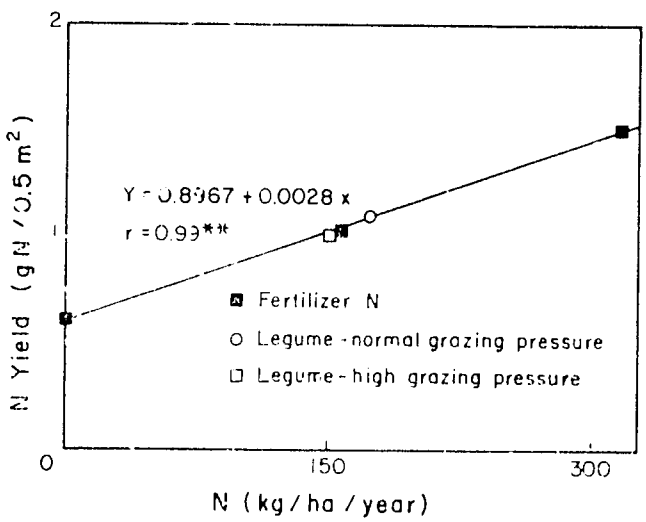


**Figure 2. Apparent N contribution of legumes in relation to N accumulation by fertilized *Brachiaria decumbens* pastures in Pucallpa, Peru.**

grass, in addition to the legume's N content.

3. Leaf litter N accumulation in mixed pastures decreases with increasing grazing pasture.

### Implications

These first-year data show the obvious need for some sort of N input in *B. decumbens* pastures established in land that previously had degraded pastures. Addition of a legume in the mixture apparently makes a large contribution to meet this need. Continuing to gather data will demonstrate the effect on animal production and elucidate some of the N-transfer processes involved.

## Potassium Dynamics in Legume-Based Pastures

*Miguel A. Ayarza, N. C. State University*
*Pedro A. Sanchez, N. C. State University*

Tropical pastures on acid soils are stable and productive only when nutrients are sufficient to sustain a vigorous forage crop. Maintaining this fertility requires a management method that takes into account the nutrient leaching common in areas of high rainfall, as well as the cycling of nutrients among soil, forage and animals. This study, which was conducted at the Yurimaguas Experiment Station, concentrated on one nutrient, potassium, and one of our most promising mixtures (*Brachiaria humidicola/ Desmodium ovalifolium*).

### Objectives

The objectives of this study are 1) to quantify leaching losses of K in pastures under clipping and grazing; 2) to monitor the effect of K levels on the productivity of the pasture and on the dynamics of K in the soil; 3) to estimate the effect of K return by animal excretions, and 4) to compare estimated K losses from pastures with losses from crops grown in the same area.

### Procedures

The grazing experiment was a factorial of three annual rates of K fertilization (0, 50 and 100 kg K/ha) applied only once by two stocking rates (3.3 and 6.6 animals/ha), with three replications. Two additional experiments were established on 3 x 4 m plots with K rates of 0, 25, 50, 75 and 100 kg K/ha/yr. The first, a clipping experiment in which some plots had clippings removed while others had clippings returned, provides a comparison of the effect of grazing on K dynamics. The second was a bare-plot experiment designed to account for soil chemical and physical properties related to K leaching, and to estimate the effect of plant growth on K dynamics.

Four hectares were planted with a mixture of *Brachiaria humidicola* and *Desmodium ovalifolium* in December 1984. Potassium treatments were applied on May 13, 1985, and grazing began on July 4 of that year and terminated two years later. Potassium distribution in the soil with depth was

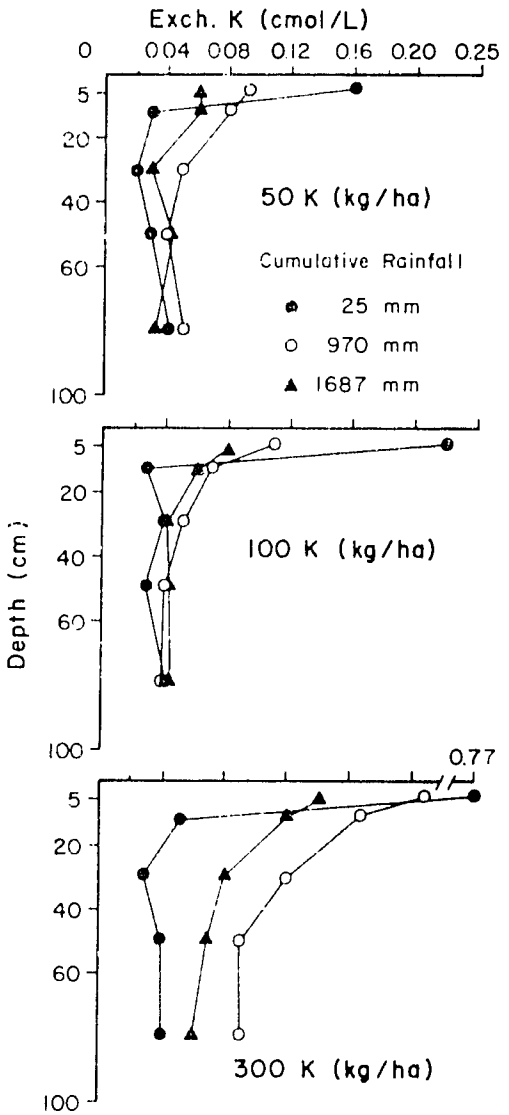


**Figure 1. Effect of potassium additions and cumulative rainfall on distribution of exchangeable K in bare plots.**

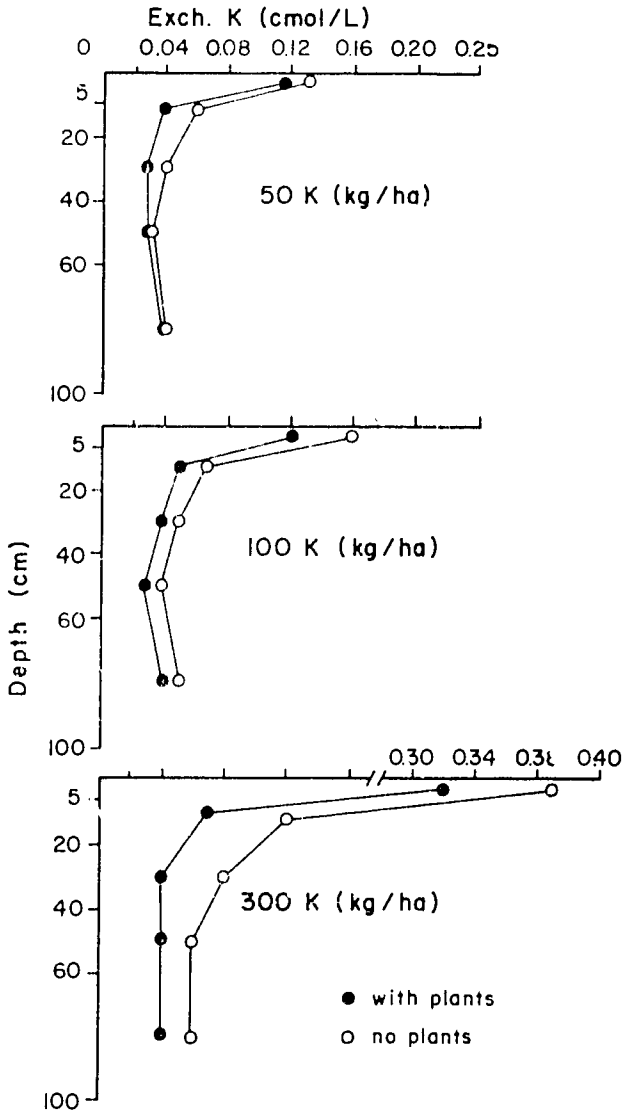


**Figure 2. Effect of plants on the distribution of exchangeable K in the profile at three potassium rates (mean of seven sampling dates).**

monitored as a function of precipitation. Changes in soil and plant K were determined in the small plots and grazing experiments. Amounts and composition of plant residues were evaluated under grazing. The effect of urine on the return of K to the soil is being studied, comparing plant growth and changes in soil K in affected vs. unaffected areas under grazing.

## Results

Soil characterization of the area showed very low levels of exchangeable K in the soil profile (0.05-0.06 cmol/L), except for the 0-5 cm layer, which averaged 0.16 cmol/L. Soil texture was classified as sandy loam with topsoil clay contents of 17%.

**Table 1. Effect of the return of plant residues on the cumulative yields of a mixture of *B. humidicola* + *D. ovalifolium* (sum of six cuttings).**

| Applied K | No residue return | Residue returned | Increase |
|---|---|---|---|
| kg/ha | ——t dry matter/ha—— | | % |
| 0 | 9.75 | 14.87 | 34 |
| 50 | 11.74 | 15.34 | 23 |
| 100 | 13.30 | 17.93 | 26 |
| 300 | 15.96 | 18.05 | 11 |

Application of K treatments produced a significant increase in exchangeable K in the 0-5 cm of the small plot experiment. Applied K, however, moved down the profile as a function of precipitation and K rates. There were significant changes in the 0-5 and 5-20 cm depths after 970 and 1678 mm cumulative rainfall, especially in the 300 kg K rate (Figure 1). The presence of plants significantly reduced the levels of exchangeable K in the soil, and this effect increased with the level applied (Figure 2). Preliminary results about the effect of K rates and plant residues on the productivity of the association indicated a positive effect of the addition of residues on yields (Table 1). There was also a response to K on the cumulative yields in both treatments.

There were no significant differences of the effect. The return of plant residues on the soil properties after one year is shown in Table 2.

After 255 days of grazing, the effect of K and stocking rates on aboveground biomass available for grazing are summarized in Table 3. There was an increase of forage dry matter in response to the treatments; however, it was not significant, probably due to differences among grazing cycles. On-site studies of the effect of plant cover on soil moisture were started in September 1986. In addition, K in the soil solution is being measured in the small plot experiment.

## Conclusions to Date

1. There was a movement of applied K in the soil used in the experiment; however, the degree of movement depended on the rates applied and on rainfall.

2. Plants seemed to be able to significantly reduce the amounts of K susceptible to leaching by absorbing most of the available K in the soil.

3. Plant residues appear to be an important component in the stability of pastures.

**Table 2. Effect of plants and residue return on topsoil (0-5 cm) properties under a pasture of *B. humidicola + D. ovalifolium* after one year (mean of three replications).***

| Plots | P | Al | Ca | Mg | K |
|---|---|---|---|---|---|
| | ppm | cmol/L | | | |
| Bare | 10.5 b | 2.77 a | 0.54 a | 0.20 a | 0.08 a |
| Planted, no residues returned | 8.9 a | 2.53 a | 0.49 a | 0.09 b | 0.06 a |
| Planted, residues returned | 7.8 a | 2.63 a | 0.54 a | 0.15 a | 0.07 a |

*Columns and rows with the same letters are not statistically significant at P = 0.05.

**Table 3. Effect of two stocking rates and three potassium rates on levels of available forage before grazing (mean of five grazing cycles).**

| Stocking rate | K applied | Green dry-matter forage | Grass |
|---|---|---|---|
| animals/ha | kg/ha | t/ha/cycle | % |
| 3.3 | 0 | 3.04 | 46 |
| | 50 | 3.73 | 51 |
| | 100 | 3.85 | 50 |
| 6.6 | 0 | 3.26 | 50 |
| | 50 | 4.20 | 54 |
| | 100 | 4.48 | 58 |

# Sulfur Accumulation In Grazed Pastures

*Miguel A. Ayarza, N. C. State University*
*Pedro A. Sanchez, N. C. State University*

Ultisols have increasing clay contents with depth and often accumulate S in their subsoil because of their higher S sorption capacity. This situation is well documented in the Southeastern United States and is therefore expected to occur in Ultisols of Yurimaguas.

## Procedures

Soil samples were taken from a *Brachiaria decumbens*/ *Desmodium ovalifolium* pasture under grazing for three years. The pasture had received 116 kg S/ha from yearly additions of ordinary superphosphate and magnesium sulfate. The topsoil of a degraded and not fertilized nearby pasture was also sampled to serve as a control. Twenty subsamples per site were composited and extracted with 0.01M $Ca(H_2PO_4)_2$ for $SO_4^=$ determination.

## Results

Sulfur distribution in the profile of the fertilized pasture is shown in Table 1. Applied S apparently moved down and accumulated in the subsoil as expected. Nevertheless, S concentrations in the topsoil of the fertilized pasture were significantly higher than those in the degraded pasture.

Responses to S applications were observed in a pasture of *D. ovalifolium* grown in an Oxisol in Carimagua, Colombia, when extracted $SO_4^=$ was 12 ppm. Thus if S assessment of the fertilized pasture were based solely on S status of the topsoil, a probable response would be predicted. This should not be the case when the potential contribution from sorbed S in the subsoil is taken into account. In addition, grass and legume components of this pasture are Al-tolerant species with extensive root systems in the B horizon.

Use of the weighed profile mean to make better predictions of S responses in soils has been suggested, and a critical level of 4 ppm of $SO_4^=$ below which S responses must be expected was established by Australian researchers. Sulfur requirements in Ultisols of the humid tropics should be established using this approach.

**Table 1. Extractable sulfur in an Ultisol under pasture in Yurimaguas.**

| Site | Sampling depth | $SO_4^=$* |
|---|---|---|
| | cm | ppm |
| Not fertilized | 0-20 | 10.30 d |
| Fertilized | 0-20 | 13.20 c |
| | 20-40 | 26.58 a |
| | 40-60 | 21.42 b |
| | 60-100 | 14.06 c |

*Figures with the same letter are not statistically significant at P = 0.05.

# Pasture Reclamation in Degraded Steeplands

*Miguel A. Ayarza, N. C. State University*
*Rolando Dextre, INIPA*

There are several million hectares of degraded, unproductive pastures in the Amazon, often on steep slopes. The purpose of this project is to develop a simple technique for reclaiming degraded pastures in Ultisol steeplands, using different establishment techniques.

## Procedures

A two-factor experiment was installed in a degraded pasture occupying a 5.18-ha watershed with sideslopes of 20 to 50%. Treatments were established in an amphitheater fashion, following slope contours, with tillage methods as main plots and improved species as subplots. The tillage treatments are 1) zero tillage (pastures planted in an array of holes 20 cm in diameter); 2) minimum tillage (pastures planted in 50-cm wide, rototilled furrows 2 m apart); and 3) total tillage (50-cm wide furrows, with spaces between furrows gradually cultivated as pastures grow). The only fertilizer was Bayovar rock phosphate, applied at the rate of 12 kg P/ha in the hole or furrow.

The species included *Brachiaria decumbens*, *Brachiaria humidicola*, *Desmodium ovalifolium* 350, and *Centrosema pubescens* 438. The species were planted in rows 2 m apart from each other. Initial soil chemical and physical properties are supplied in Table 1. The main degraded pasture species were of torourco complex. The experiment was initiated in June 1986. Improved grasses were planted using vegetative propagules and legumes using several seeds. After one month, a standardization cut was done on grasses and a minimum hand-weeding on the zero-tillage plots.

Performance of species was determined on the basis of percentage cover two months after planting and the production of biomass six months after planting. Cover was measured using quadrants 4 x 1 m in size. The number of introduced species was counted and the percentage of cover estimated. Biomass production was determined in a 4 x 1 m area in the center of each plot. Two rows and two strips were included in the sampling area. Results were expressed as fresh weight of planted species and percentage of the total biomass.

## Results

Soil physical properties appeared more limiting than chemical properties. Penetrometer resistance values indicated that a compacted layer was present in the 5-10 cm depth, perhaps due to overgrazing (Figure 1). Relatively high pH and Ca values (Table 1) were associated with the age of the pasture. The area was burned and cleared three years ago to favor the regrowth of natural grasses.

Fresh biomass production of the four species five months after establishment is shown in Table 2. The two grasses were successfully established without tillage while the two legumes responded significantly to minimum or total tillage. The ability of the improved species to take over the degraded pasture is shown in Figure 2. More than half the area was covered by the improved species in all cases except where the legumes were planted without tillage. Total tillage, done progressively in order to avoid contiguous areas of exposed surfaces, resulted in

**Table 1. Initial soil properties of the steepland Ultisol area used for pasture reclamation in Yurimaguas (mean of seven samples).**

| Depth | pH | P | Al | Ca | Mg | K | Bulk Density |
|---|---|---|---|---|---|---|---|
| | | ppm | cmol/L | | | | g/cm³ |
| 0-20 | 4.7 | 8.1 | 3.8 | 2.88 | 0.73 | 0.12 | 1.37 |
| 20-40 | 4.8 | 4.4 | 5.9 | 2.42 | 0.64 | 0.10 | - |

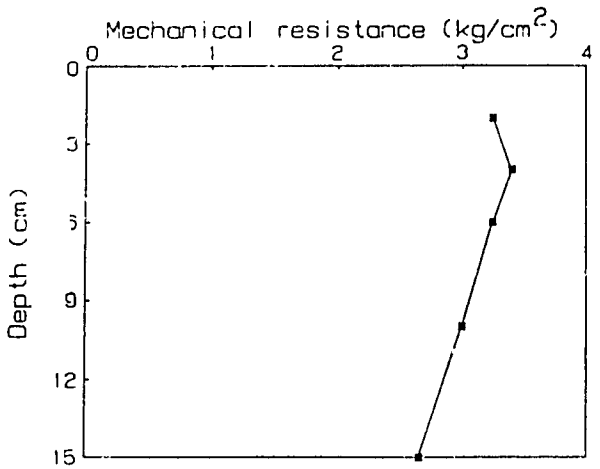


**Figure 1. Soil mechanical resistance measured by a penetrometer in degraded pasture prior to treatment initiation (average of 36 observations per depth).**

almost complete cover within five months.

These results suggest that minimum soil disturbance is needed to establish grasses such as those used in the experiment. The stoloniferous species are able to rapidly cover new areas and compete strongly with species already present. On the other hand, legumes require at least minimum tillage. In general, *Centrosema* performed better than *D. ovalifolium*, due to a faster growth habit and a more aggressive tendency of *Centrosema* than *D. ovalifolium* to cover.

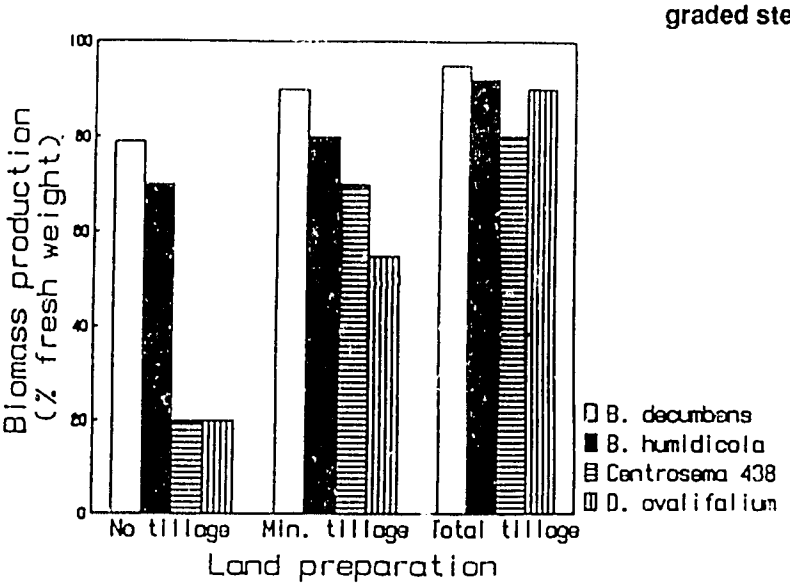


**Figure 2. Effect of tillage method on percentage of biomass produced by four introduced species invading a degraded pasture.**

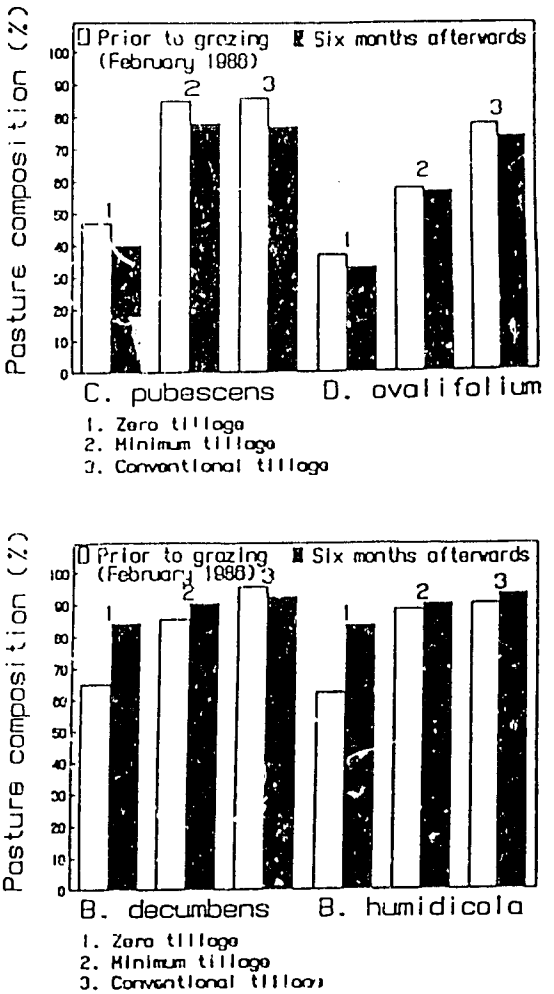


**Figure 3. Effect of grazing on persistence of two grasses and two legumes established on a degraded steepland area in Yurimaguas.**

### Phase Two

A second phase of the study was initiated in February 1986 to determine whether the persistence of a species depends upon grazing.

The experimental area was divided into three paddocks, each containing the four species and the three methods of establishment. Two 150-kg steers started grazing by replication. Animal management was adjusted to give the animals the chance to consume all available forage (18 days grazing and 36 days resting). Persistence was monitored by using transects across the plots for each species x treatment combination before each grazing period. Results were expressed as percentage of presence of shoots of the species over the total number of countings every 50 cm along the transect.

After six months of grazing, the percentage of grasses increased, whereas that of legumes decreased (Figure 3). This is probably the result of the capacity of these *Brachiaria* species to compete and displace existing vegetation. Although the legume population is decreasing, an excellent stand of *Centrosema* is present.

### Conclusions

Promising methods exist to establish improved grasses and legumes in degraded pastures. The results of this experiment indicate that simple establishment methods can be successful in compacted Ultisol steeplands but that some minimum tillage is needed to establish the legumes. Although minimum tillage was performed by a hand tractor, it is also possible to use animal power.

**Table 2. Effect of three tillage methods on the production of green forage of two grasses and two legumes after five months of establishment.***

| Species | Tillage treatment | | |
|---|---|---|---|
| | Zero | Minimum | Total |
| | t fresh wt/ha | | |
| *Brachiaria decumbens* | 7.70 a | 10.60 a | 10.30 a |
| *Brachiaria humidicola* | 6.67 a | 10.7 0a | 12.40 a |
| *Desmodium ovalifolium* | 0.32 a | 1.78 a | 4.65 b |
| *Centrosema* 438 | 0.76 a | 4.41 b | 2.72 b |

*Figures followed by the same letter are not statistically different according to Duncan's multiple range test (P = 0.05).

## Pasture Reclamation With Herbicides

*Jorge W. Vela, INIPA*
*Miguel A. Ara, N. C. State University*

Another approach to pasture reclamation is the eradication of the unsuitable species using herbicides. This approach is important in the Pucallpa region of the Peruvian Amazon where chemical inputs are more available than in Yurimaguas.

### Objective

The objective of this study is to obtain the optimum combination of herbicide rate and time of application after tilling for effective weed control during the establishment phase of *Brachiaria decumbens* and *Andropogon gayanus*.

### Procedures

A trial was carried out from February to July 1986 at the IVITA station near Pucallpa. Factors under study were three times of herbicide application and planting after land preparation (after 30, after 45, and after 60 days) and three glyphosate rates (1, 2 and 4 L/ha) as Round-up. The treatment structure was a 3 x 3 factorial. The experimental layout consisted of 2 x 6 m plots in a randomized complete block design with six replications. Variables measured were dry-matter yield of *Andropogon* and *Brachiaria* at establishment (120 days of growth); weed reinfestation at 30, 60, 90 and 120 days after tilling, and pasture cover at the same times.

The experiment was laid out on a degraded native pasture. Selected soil properties at initiation of the experiment are shown in Table 1.

### Results

Predominant weeds before land preparation by rototilling and 30 days after tilling are shown in Table 2. Predominance of weeds changed from before land preparation: grasses comprised 70% of the weeds before but only 10% 30 days after tilling. Cyperaceae comprised only 1.6% in the early stage but had the highest percentage (39%) after tilling.

The weed-control treatments had similar results in both *Andropogon* and *Brachiaria* so we will discuss only *Brachiaria*.

**Table 1. Selected soil properties at initiation of the experiment, 0-20 cm depth.**

| Sand | Clay | pH | P | Al | Ca | Mg | K | O.M. | Al sat. |
|---|---|---|---|---|---|---|---|---|---|
| —%— | | | µg/ml | —cmol/L— | | | | —%— | |
| 43 | 20 | 4.7 | 3.8 | 2.2 | 2.07 | 0.53 | 0.15 | 2.73 | 44 |

Treatment effects of glyphosate on weed cover 30 days after herbicide application and crop planting (reinfestation) were highly significant, both for herbicide rates and times (Table 3), and for their linear and quadratic interactions. The lowest rate (1 L/ha), applied 30 days after tilling, reduced weed cover by 41%, but the highest reduction was for the highest rate (4 L/ha), applied 60 days after tilling, which reduced weed cover by 85%. Higher weed covers for the lowest rate applied at both 30 and 60 days after tilling were the product of a combination of effects—reinfestation at the "30 days after" treatment and insufficient herbicide at the "60 days after" treatment. This condition was more or less the same after 60 and 90 days, after herbicide application and rate. At 90 days, maximum reinfestation occurred for the "30 days after" treatment (60% weed cover). After that, the weed cover reflected more the competition with an already developed *Brachiaria* than the treatment effect (no significant effect of treatments).

Effect on the pasture itself is less clear. Thirty days after herbicide application and crop planting, the percentage of *Brachiaria* cover did not reflect any treatment effect, but *Andropogon* showed a highly linear interaction between rates and times, which is believed to reflect seed quality and season more than the treatment itself (Table 4). At 60 and 90 days after herbicide application and planting, the *Brachiaria* cover slightly reflected weed-control effects, but at 120 days no treatment effect was observed and cover exceeded 50%. This condition was also observed in the pasture dry-matter yield at establishment, which was not affected by any treatments.

## Conclusions

No significant differences among the different treatments in dry-matter yield at establishment were present, and it was concluded that the lowest rate, 1 L glyphosate/ha, is as good as 4 L/ha and could be recommended. With regard to the "times after" treatments, convenience depends on particular cases, but when low grazing pressure is planned at the early establishment phase it could be advisable to wait 60 days after tilling before herbicide application and planting.

**Table 2. Predominant weeds before rototilling and 30 days later.**

| Local name | Scientific name | Approx. coverage: Before rototilling | Approx. coverage: 30 days after rototilling |
|---|---|---|---|
| | | —%— | |
| Torourco | *Homolepis, Axonopus, Paspalum* sp. | 70 | 10 |
| Pega-Pega | *Desmodium* sp. | 8 | 4 |
| Mimosa | *Mimosa pudica* | 6 | 2 |
| Matapacto | *Pseudoelephantopus* | 6 | 3 |
| Sinchipichana | unknown | 4 | 19 |
| Cyperaceae | *Cyperus* sp. | 2 | 39 |
| Guayaba | *Psidium guayaba* | 3 | 0 |
| Broadleaved weeds | | 0 | 24 |

Table 3. Weed cover at 30 days after glyphosate application and *Brachiaria* planting. Treatment means of six replications. Highly significant linear times x rates interaction.

| Rate of application | Time of application | | |
|---|---|---|---|
| | 30 days | 45 days | 60 days |
| L/ha | | % | |
| 1 | 59 | 63 | 67 |
| 2 | 43 | 63 | 34 |
| 4 | 45 | 35 | 15 |

Table 4. Pasture cover for *Brachiaria decumbens* and *Andropogon gayanus*. Means of six replications. *Brachiaria:* no significance. *Andropogon:* highly significant linear times x rates interaction.

| Rate of application | Time of application | | |
|---|---|---|---|
| | 30 days | 45 days | 60 days |
| L/ha | | % | |
| *Brachiaria* | | | |
| 1 | 4 | 3 | 4 |
| 2 | 4 | 3 | 5 |
| 4 | 4 | 3 | 4 |
| *Andropogon* | | | |
| 1 | 5 | 2 | 0.3 |
| 2 | 2 | 1 | 0.5 |
| 3 | 2 | 2 | 0.3 |

## Legume Shade Tolerance

*Jorge W. Vela, INIPA*
*Miguel A. Ara, N. C. State University*

Acid-tolerant legumes used in the TropSoils pasture-management options may play an important role in agroforestry systems where cattle grazing may take place under trees. Experience in Southeast Asia indicates a wide variability of legume response to shade.

### Objective

The objective of this study is to test our most promising legume germ plasm under shade of a mature oil palm plantation, in order to determine their adaptability to this factor.

### Procedures

This experiment was established in November 1985 under an oil palm plantation managed by CIPA XXIII at km 44 of the Pucallpa-Lima highway. Three legumes (*Desmodium ovalifolium*, *Pueraria phaseoloides* and *Stylosanthes guianensis*) are being evaluated for their dry-matter productivity and feed quality in the presence and absence of oil palm shade. The experimental design is randomized complete blocks with five replications. Plots are 8 x 16 m, and each plot has two oil palm trees in the same position. A similar but smaller (3 x 5 plot) experiment was established outside the palm plantation and will be used as a reference; all the variables will be analyzed as percentages of full sunlight.

### Results

Dry-matter production of all three legumes was severely affected by oil palm shade (24% of full sunlight radiation). *Desmodium ovalifolium* and *P. phaseoloides* performed similarly but yielded only about 22% of the full sunlight value even though they outperformed *S. guianensis*, which gave a poor 8% of the reference value. Crude protein content values for *D. ovalifolium* and *S. guianensis* were higher than full sunlight values, but *D. ovalifolium* values were highest (Table 1).

Preliminary data suggest that *D. ovalifolium* is the most shade-tolerant legume tested. Visual observations show *S. guianensis* performs quite poorly and tends to disappear. The stands of both *D. ovalifolium* and kudzu were quite acceptable under shade in absolute terms. Since kudzu is a climber, periodic cutting around trees is required, whereas *D. ovalifolium* does not require such cutting.

**Table 1. Percentage of dry matter yield and crude protein content (CPC) of the legumes under shade relative to full sunlight (means of five replications).***

| | *S. guianensis* | *D. ovalifolium* | *P. phaseoloides* |
|---|---|---|---|
| | % of full sunlight | | |
| Dry matter | 7.7 b | 23.3 a | 21.8 a |
| Crude protein | 113.2 b | 128.4 a | 84.2 b |

*Means with the same letter in the horizontal rows are not significant at P = 0.01.

## Extrapolation in Farmer Fields

*Miguel A. Ayarza, N. C. State University*
*Rolando Dextre, INIPA*

After six years of work in the Yurimaguas Station, *Brachiaria humidicola*, *Centrosema pubescens*, *Stylosanthes guianensis* and *Desmodium ovalifolium* have shown a high potential to increase animal production and good persistence under grazing. On the basis of the experience gained over the years, it was decided to test the potential of improved pastures to replace degraded native pastures, which are common in the area.

### Procedures

A validation trial was set up to demonstrate that degraded pastures can be put into production by substituting present vegetation or improvement of present pasture plus incorporation of new species. An agreement was signed with the Empresa Ganadera Amazonas to conduct a 20-ha validation trial in an area covered by degraded pastures.

Four pasture renovation options were designed:

1. Introduction of a legume on a degraded pasture of *Brachiaria ruzisensis*;
2. Use of a crop as precursor to establishing improved grass-legume pasture;
3. Improvement of native pasture through introduction of a legume;
4. Reclamation of a steepland pasture using improved grasses, legumes and trees with minimum tillage.

Work started in December 1985 with soil characterization of the area. Extremely low native fertility and a predominantly sandy texture existed in this sandy Ultisol (Table 1).

For option 1, 4 ha of a ten-year-old *B. ruzisensis* field were disked slightly to break the soil surface and facilitate planting of *C. pubescens* 438 and to promote grass regrowth. The legume was broadcast over the area at a rate of 1 kg/ha. Rock phosphate was applied to supply 25 kg $P_2O_5$ and dolomitic limestone was applied to supply 50 kg Ca + 10 kg Mg.

Option 2 was installed on a flat area infested by weeds and unpalatable grass species. Two diskings and two rototiller passes were needed to completely till 3 ha to eliminate existing vegetation. Cv. Africano desconocido, an upland rice variety known to be tolerant to Al toxicity, was planted in strips 12 m wide. The crop received 60 kg N, 40 kg $K_2O$ and 50 kg $P_2O_5$ per ha. *Brachiaria humidicola* was planted in alternate strips two months later.

After rice harvest, cowpea was planted in rows 50 cm apart and *B. humidicola* + *D. ovalifolium* was planted between rows.

Option 3 was installed on a 2-ha native pasture of torourco (*Axonopus compresus*). Strips 4 m wide were opened every 20 m and planted with *Stylosanthes guianensis* accessions 136 and 184. Phosphorus was applied at a rate of 12 kg P/ha using rock phosphate.

Option 4 was installed in a degraded pasture on a 20% slope. The area was tilled in strips 1 m wide and 4 m apart in contour. Land preparation was carried out with a 1.5 HP manual rototiller. Areas between rows remained untouched. *Brachiaria humidicola* and *C. pubescens* 438 were planted in alternate strips, and *Erythrina popigiana* was planted in rows every 12 m along the contour.

**Table 1. Topsoil chemical property of the soil used for the extrapolation work in K-17 (Ganadera Amazonas area) (mean of five samples). December 1985.**

| pH | P | Al | Ca | Mg | K | ECEC | Al sat. | Sand | Clay |
|---|---|---|---|---|---|---|---|---|---|
| | ppm | cmol/L | | | | | % | | |
| 4.0 | 3.4 | 1.1 | 0.3 | 0.08 | 0.05 | 1.53 | 72 | 82 | 14 |

**Results**

After eight months, all pasture-renovation options were fully established. In option 1, *B. ruzisensis* reacted positively to tillage and *C. pubescens* was spreading very well over the area. Measurements of botanical composition indicated 20% of *Centrosema* in the total biomass, a highly desirable legume content of a mixed pasture.

In option 2, rice yields were affected by short dry spells during January and February 1986. In spite of limitations, 1.5 t/ha of rice were harvested and cowpea yields reached about 800 kg/ha. Both are acceptable yields for low-input systems. After harvesting the cowpea, *B. humidicola* was almost fully established, although it was infested by annual weeds.

In option 3, *Stylosanthes* established rather quickly, although some hand-weeding was required.

Introduced pastures in the steepland covered almost the entire area in option 4. Both *Centrosema* and *B. humidicola* replaced most of the native species in the nontilled bands. On the other hand, *Erythrina* did not establish well. Growth was affected by soil conditions (sandy texture and K deficiency). Only two of six rows have established.

Costs of renovating degraded pastures are presented in Table 2. Total investment varied among systems. The most expensive system was the one with crops (option 2) because of labor and machine costs. Returns from crop yields were enough to pay for pasture renovation, however, and leave some extra profit before grazing.

**Conclusions**

Overall results showed that renovation of degraded pastures can be accomplished with low monetary inputs in some instances. In other cases, where a complete renovation is required, crops as precursors pay for the entire cost of pasture re-establishment.

A second phase calls for milk production from cows grazed on the pastures in every system. This phase will start in 1987 as work supported by INIPA and the Ganadera Amazonas S.A., and will serve as a thesis for an undergraduate student from the Universidad Agraria at La Molina.

**Table 2. Cost of renovating a degraded pasture by three methods of introduction of improved species.**

| | Option 1 | | Option 2 | | Option 3 | |
|---|---|---|---|---|---|---|
| | *B. ruzisensis* + *C. pubescens* | | Rice-cowpea-pasture | | Native pasture + *Stylosanthes* | |
| | U.S.$/ha | % | U.S.$/ha | % | U.S.$/ha | % |
| Labor | 7 | 11 | 86 | 39 | 20 | 16 |
| Machinery | 9 | 13 | 65 | 29 | 43 | 34 |
| Fertilizer | 35 | 53 | 53 | 24 | 6 | 4 |
| Seed | 12 | 17 | 16 | 7 | 50 | 40 |
| Other | 3 | 5 | 11 | 5 | 6 | 5 |
| Total | 66 | 99 | 231 | 104 | 125 | 99 |

# Low-Input Systems

A low-input cropping system, reported last year as a transition technology between shifting cultivation and permanent agriculture, collapsed after seven crops in three years due to P and K deficiencies and increasing weed pressure. This year we report on the nutrient cycling and economic aspects of this first cropping period, the success of a one-year kudzu fallow in overcoming weed constraints, the successful transition to other systems, and in-depth data on weed build-ups during the first cropping period.

Nutrient cycling from above and below plant residues returned to the soil more than 80% of the K and Ca accumulated by plants, about half the biomass produced and half the N and Mg accumulation, but only 37% of the P accumulated, largely because of grain removal. The system was highly profitable both with and without fertilizer applications: purchased chemical inputs accounted for only 8% of the total costs without fertilizer and 16% with fertilizer. After one year of kudzu fallow, the fields were largely devoid of weeds and showed a higher fertility status. A second low-input cropping period started with high yields, and the transition to fertilizer-based continuous cultivation was successful. Weed-control studies indicate the inability to grow more than five or six low-input crops continuously with the best combination of herbicides and manual weed control. The main problem is controlling weeds in upland rice.

## Central Experiment: Transition To Other Technologies

*José R. Benites, N. C. State University*
*Pedro A. Sanchez, N. C. State University*

A low-input cropping system has been developed in Yurimaguas, Peru, to serve as a transition technology between shifting and continuous cultivation for acid soils of the humid tropics. Its principal components are 1) traditional slash-and-burn clearing of forest fallow; 2) selection of acid-tolerant cultivars capable of high yields without liming; 3) rotation of upland rice and cowpea cultivars (no tillage) and removing only the grain; 4) no fertilizers, lime or organic inputs are brought in and soil pH remains at about 4.5, and 5) the rotation continues for three years, but increasing weed pressure and decreases in available P and K cause the system to collapse in agronomic and economic terms. A total of five upland rice and two cowpea crops were harvested during a three-year period, as opposed to one rice crop under traditional cultivation. Crop yields and effects on soil properties during this first period were presented in the *Trop-Soils Technical Report, 1985-1986*. This report covers the nutrient cycling effects and economic analysis of the first cropping period and the transition phase initiated after the system collapsed at the seventh continuous harvest on June 30, 1985.

### Nutrient Removal Cycling

Low-input systems should be efficient recyclers of nutrients in order to minimize nutritional inputs that must replace nutrients extracted by crop harvests.

The nutrient composition of the acid-tolerant rice (cv. Africano) and cowpea (Vita 7) plant parts at harvest obtained in neighboring experiments are presented in Table 1. The calculated amount of nutrient accumulation by the seven crops is shown in Table 2. Even though only the rice grain and cowpea pods plus grain were exported from the field, the harvested products during the three year period represented considerable nutrient removal from the field (Table 2). The amounts of nutrients accumulated by the crops but returned to the soil as above- or below-ground organic inputs was larger than the amount removed except for P. Crop residues plus root runover returned to the soil 62% of the dry matter produced, 54% of the N, 59% of the Mg, 87% of the K, 94% of the Ca, but only 37% of the P accumulated by crops (Table 2). Root turnover, assuming 100% fine root decomposition, accounted for a relatively

**Table 1. Nutrient concentrations of rice (cv. Africano desconocido) and cowpea (cv. Vita 7) grain and straw at harvest, and fine roots at anthesis, under low-input systems in Yurimaguas. Mean values of seven rice harvests and three cowpea harvests for aboveground parts, and two crop harvests each for roots.**

| Crop | N | P | K | Ca | Mg |
|---|---|---|---|---|---|
| | % | | | | |
| Rice | | | | | |
| Grain | 1.40 | 0.23 | 0.36 | 0.03 | 0.11 |
| Straw | 1.01 | 0.07 | 2.85 | 0.28 | 0.18 |
| Roots | 1.19 | 0.09 | 0.93 | 0.21 | 0.05 |
| Cowpea | | | | | |
| Grain | 3.86 | 0.35 | 1.36 | 0.06 | 0.21 |
| Straw | 1.86 | 0.13 | 3.97 | 0.95 | 0.23 |
| Pods | 0.70 | 0.06 | 2.17 | 0.17 | 0.22 |
| Roots | 1.23 | 0.12 | 0.71 | 0.59 | 0.19 |

**Table 2. Total dry matter and nutrient accumulation by five rice and two cowpea crops harvested in 34 months without fertilization, and amounts returned to the soil.**

| Plant part | Dry matter* | N | P | K | Ca | Mg |
|---|---|---|---|---|---|---|
| | t/ha | kg/ha | | | | |
| Grain + pods | 14.2 | 256 | 34 | 87 | 65 | 18 |
| Straw | 18.1 | 232 | 15 | 565 | 80 | 35 |
| Roots | 5.2 | 63 | 5 | 32 | 18 | 5 |
| Total | 37.5 | 551 | 54 | 684 | 104 | 58 |
| % returned to soil | 62 | 54 | 37 | 87 | 94 | 59 |

*Based on mean grain:straw ratios of 0.84 for rice and 0.52 for cowpea; mean cowpea pod weight of 0.32 t/ha per crop, and fine root biomass of 0.65 and 0.97 t/ha per crop for rice and cowpea in the top 30 cm of soil.

minor proportion of amounts recycled (14% of dry matter, 21% of N, 25% of P, 5% of K, 18% of Ca, and 12% of Mg). The actual amounts returned, therefore, are equivalent to an annual fertilization rate of 98-7-199-33-13 kg/ha of N-P-K-Ca-Mg. A proportion of the N returned as aboveground residue, however, may be lost before it enters the soil, via denitrification that may take place on the mulch-soil surface interface. Biological N fixation by cowpea, however, may counteract such losses, but neither process was measured. The P, K, Ca and Mg inputs, however, are likely to be transferred entirely to the soil. Phosphorus, therefore, appears to be the critical nutrient, since about two-thirds of the crop uptake was removed in the harvested products, giving this element the lowest percentage of recycling and the lowest absolute amounts returned to the soil among the five nutrients evaluated.

### Weed Pressure

In the authors' view, increasing weed control difficulty was the single most important factor for the instability of this low-input system during its third year. The initial weed population was mainly broad-leaved, which is typical of shifting cultivation fields in the area. With time, the weed population gradually shifted to grasses that are more aggressive and not subject to economically sound control by commercially available herbicides. Of particular importance was the spread of *Rottboelia excelsa*, a non-rhizomatous grass, particularly during rice growth. Cowpea was more competitive with weeds than upland rice because cowpea covered the soil surface more thoroughly.

Studies on weed control in low-input systems at Yurimaguas indicate that the absence of tillage and burning promotes weed build-up (see next report). Rice straw mulch may decrease weed growth in cowpea, but cowpea residues do not have the same effect on rice, perhaps because of the fast decomposition rate visually observed with cowpea residues.

### Economics

Cost records were kept in this 1-ha experiment. The summary for the first seven crops in the plots without fertilization is shown in Table 3. Labor inputs for the first crop include land clearing; thus the subsequent crops averaged two-thirds of the first crop's labor. Returning and redistributing crop residues averaged ten man-days/ha, or approximately U.S. $20/ha per crop. Another major labor input was bird watchers near harvest time. The next major cost items were interest on crop loans from the Banco Agrario and government fees for receiving and processing rice at the mills. Shifting cultivators

**Table 3. Labor input, production costs, and revenues incurred in the low-input system with seven crops without fertilization.**

| | Crop sequence | | | | | | |
|---|---|---|---|---|---|---|---|
| Input or output | 1 Rice | 2 Rice | 3 Cowpea | 4 Rice | 5 Cowpea | 6 Rice | 7 Rice |
| Labor (man-day/ha) | 172 | 79 | 99 | 79 | 99 | 79 | 79 |
| Cost (U.S. $/ha): | | | | | | | |
| Labor | 380 | 140 | 113 | 134 | 167 | 130 | 95 |
| Herbicides | 21 | 21 | 25 | 26 | 25 | 24 | 25 |
| Insecticides | 0 | 11 | 14 | 14 | 13 | 0 | 0 |
| Seed | 19 | 17 | 75 | 18 | 51 | 16 | 17 |
| Bags | 16 | 18 | 8 | 20 | 7 | 18 | 50 |
| Thresher rent | 0 | 34 | 0 | 38 | 0 | 34 | 80 |
| Transport to market | 12 | 12 | 14 | 14 | 14 | 12 | 14 |
| Loan interest and fees | 135 | 80 | 86 | 105 | 108 | 111 | 225 |
| Total cost | 583 | 333 | 335 | 369 | 385 | 345 | 506 |
| Revenue: | | | | | | | |
| Grain produced (t/ha) | 2.44 | 2.99 | 1.10 | 2.77 | 1.19 | 1.84 | 1.52 |
| Price (U.S. $/t) | 321 | 281 | 1420 | 305 | 1127 | 265 | 274 |
| Gross revenue (U.S. $/ha) | 783 | 840 | 1562 | 845 | 1341 | 488 | 416 |
| Net return (U.S. $/ha) | 200 | 507 | 1227 | 476 | 956 | 143 | -90 |
| Net return/Cost (%) | 34 | 152 | 366 | 129 | 248 | 41 | -18 |

routinely obtain bank loans, which are used primarily as an advance on their labor. Interest charges fluctuating from 40 to 101% on an annual basis in local currency reflect the high inflation rate in Peru, which averaged 125% annually during the study period. Even in U.S. dollar terms, the indirect costs averaged about 30% of the total production costs. In contrast, the cost of purchased chemical inputs (herbicides and insecticides) and others (seed, bags, thresher rent) comprised 8 and 19% of the total production costs, respectively.

The low-input system without fertilizer applications was highly profitable, averaging net returns of U.S. $1144/ha per year, or a 21% return over total costs (Table 4). The low-input system with fertilizers was also quite profitable, averaging an annual net return of U.S. $1125/ha and a 100% return over total costs. Fertilizers accounted for 9% of the total cost in the system, but also resulted in additional labor, interest, thresher use and transport costs. The low-input system either with or without fertilizers is vastly more profitable than traditional shifting cultivation (Table 4).

### Transition to Other Systems

This low-input system, therefore, is a transitional technology in both agronomic and economic terms. After three years, the field is devoid of felled logs and most of the remaining tree stumps are sufficiently decomposed to be destroyed with a good kick. The land clearing process is thus complete, providing several options to the farmer. One is to put the land into a managed fallow and then start a second cropping cycle. A second is to plow, lime, fertilize and rotate crops intensively; a third is pastures, and a fourth is agroforestry.

The experiment described above was modified to address some of these options after the seventh crop harvest in July 1985. The 1-ha field was divided into eight 1250 m² plots, providing four treatments in a randomized complete block design with two replications. The replicates were located on the previously fertilized and not fertilized treatments in order to block the residual effects. Two treatments were designed to test the weed-control factor by continuing the low-input system (cowpea-rice-cowpea), a third was planted to kudzu fallow, and the fourth was a high-input system.

### Continuing the Low-Input System

Prior crop yields suggest that the system collapsed after the seventh crop. This observation was confirmed by growing three more crops with a weed-control variable: full weed removal at economically unrealistic levels vs. the conventional treatment as previously described. The full treatment consisted of eliminating weeds by a pre-emergence application of

**Table 4. Cumulative production costs and returns actually incurred with seven crops in three years with and without fertilization and under shifting cultivation.**

| Inputs and outputs | Low-input system: Not fertilized | | Low-input system: Fertilized | | Shifting cultivation | |
|---|---|---|---|---|---|---|
| | U.S. $/ha | % | U.S. $/ha | % | U.S. $/ha | % |
| **Costs** | | | | | | |
| Labor inputs | 1159 | 41 | 1185 | 35 | 380 | 65 |
| Chemical inputs: | | | | | | |
| Fertilizers | 0 | 0 | 292 | 9 | 0 | 0 |
| Herbicides | 167 | 6 | 167 | 5 | 21 | 4 |
| Insecticides | 52 | 2 | 52 | 2 | 0 | 0 |
| Other inputs: | | | | | | |
| Seeds | 213 | 7 | 213 | 6 | 19 | 3 |
| Bags | 137 | 5 | 140 | 4 | 16 | 3 |
| Thresher use | 186 | 7 | 189 | 6 | 0 | 0 |
| Transport to market | 92 | 3 | 96 | 3 | 12 | 2 |
| Loan interest and fees | 850 | 30 | 1073 | 38 | 135 | 23 |
| Total costs | 2843 | 100 | 3351 | 100 | 583 | 100 |
| **Gross revenues** | 6275 | - | 6688 | - | 783 | - |
| **Net returns** | 3432 | - | 3377 | - | 200 | - |
| % Returns/cost | - | 121 | - | 100 | - | 30 |

**Table 5. Grain yields of three additional crop harvests in the low-input system at two levels of weed control.**

| Crop sequence | Planting date | Harvest date | Weed-control level: Conventional | Weed-control level: Full | $LSD_{0.05}$ |
|---|---|---|---|---|---|
| | | | t/ha | | |
| 8. Cowpea cv. Vita 7 | Aug. 19, '85 | Oct. 31, '85 | 0.58 | 0.58 | ns |
| 9. Rice cv. Africano* | Jan. 9, '86 | May 9, '86 | 0.09 | 1.60 | 0.19 |
| 10. Cowpea cv. Vita 7 | July 15, '86 | Sept. 25, '86 | 0.43 | 0.82 | 0.26 |

*Fertilized with 30-22-48 kg/ha of NPK as previously.

2.25 kg/ha active ingredient of metolachlor plus 2.5 L/ha of paraquat, followed by 0.28 kg ha active ingredient of sethoxydim supplemented by hand-weeding as needed. The actual cost of this treatment was U.S. $225/ha per crop, a totally unrealistic level. The conventional treatment was the pre-emergence application of 1.5 L/ha of 2,4D followed by 2.5 L/ha of paraquat five days later and no hand-weeding, with a total cost of $25/ha per crop. Both weed control plots received the same application of NPK fertilizers to rice as stated previously, in order to eliminate P and K deficiencies.

Grain yields of the eighth, ninth and tenth consecutive crops under conventional weed control were low with cowpea, and practically zero with rice (Table 5). When weeds were totally removed, yields of the ninth (rice) and tenth (cowpea) crops reached acceptable levels. Consequently, it seems reasonable to assume that the collapse of the system is directly related to weed-control problems.

### Kudzu Fallow and a Second Crop Cycle

Traditional shifting cultivation involves a secondary forest fallow period of four to 20 years, supposedly to replenish soil nutrient availability and control weeds, although the processes involved are not well understood. Farmer experience around Yurimaguas indicates that a minimum desired age of fallow is about 12 years, but population pressures effectively reduce this period to an average of four years. Slashing and burning young forest fallows results in faster grass weed invasion than would occur in older fallows because the weed seed pool declines with age. Considering the limited likelihood of long secondary fallow periods in developing humid tropical areas, the need for an improved fallow is apparent.

Following a farmer's suggestion, we studied the use of tropical kudzu (*Pueraria phaseoloides*) as a managed fallow. Unlike its temperate-region counterpart (*Pueraria lobata*), tropical kudzu does not produce storage roots and therefore is easy to eradicate by slash-and-burn. Kudzu fallows were grown in previously cultivated fields for different durations. In the most infertile and compacted soils of Yurimaguas, kudzu is slow to establish and initially shows several classic nutrient deficiency symptoms, but within three months a complete canopy is attained, the kudzu leaves become dark green, and weeds are smothered. Aboveground dry matter and ash biomass accumulation by kudzu peaks at about two years. We observed increases in exchangeable Ca and Mg and decreases in Al saturation on the topsoil of kudzu fallow plots that had a lime and fertilizer application history. But no improvements in these topsoil chemical properties were recorded in the kudzu fallow plots that had never been limed or fertilized during a previous cropping period. Consequently, the subsoils must have some nutrients available for recycling if significant recycling by a managed fallow is to take place in such acid soils.

The same kudzu ecotype was seeded in this low-input experiment, on August 28, 1985, after harvest-

**Table 6. Dry matter and nutrient content of one-year-old kudzu fallow ash one day after burning. Mean of 12 observations in the previously not fertilized treatments and 11 in the previously fertilized treatment. Date: September 24, 1986, 51 months after clearing.**

| Previous fertilizer treatments | Dry matter | N | P | K | Ca | Mg | Zn | Cu | Fe | Mn |
|---|---|---|---|---|---|---|---|---|---|---|
| | t/ha | kg/ha | | | | | | | | |
| Not fertilized | 1.45 | 21 | 7 | 42 | 58 | 14 | 0.17 | 0.08 | 1.07 | 0.82 |
| Fertilized | 2.29 | 26 | 21 | 103 | 92 | 20 | 0.29 | 0.12 | 0.99 | 1.34 |
| $LSD_{0.05}$ | 0.85 | ns | 9 | 51 | ns | ns | 0.12 | ns | ns | ns |

ing the seventh rice crop, which was heavily infested with *Rottboelia exaltata* and other weeds. No fertilizers were added to the kudzu plots, but one hand-weeding was used to pull tall *Rottboelia* plants. As before, kudzu was slow in establishing, but within 3 months it had developed a complete ground cover and a surface litter layer. Kudzu was slashed with machetes on September 13, 1986; after 10 days of dry weather, it was burned in a total time of four minutes for the 1250 $m^2$ plots. Ash sampled one day after the burn contained significant accounts of nutrients which were incorporated to the soil by the first rains (Table 6). A clear residual effect of the previous NPK fertilization is evident in the ash composition, particularly in P and K contents. A crop of Africano rice was planted three days after the kudzu burn and harvested on January 22, 1987. It received the 30-22-40 kg/ha of NPK as did all previous rice crops. Grain yields were the highest obtained to date at this site (Table 7). This is partly due to very favorable rainfall distribution for rice growth as evidenced by similar rice yields obtained in other experiments at that time, but also due to the absence of significant weed pressure. The one-year kudzu fallow, therefore, effectively suppressed weed growth in a way far superior to the herbicide combinations attempted to date. The plots are growing a subsequent crop of upland rice.

Changes in topsoil chemical properties in the kudzu fallow plots are shown in Table 8 at the end of the first cropping cycle, after one year of kudzu fallow (one day prior to burning it), and after the first harvest of the second cropping cycle. The effect of the kudzu fallow on topsoil chemical properties includes a significant decrease in exchangeable Ca and K, presumably due to plant uptake with no changes in acidity, Al saturation, or available P and K (Table 8). Differences in the last four properties

**Table 7. Dates of planting and harvesting kudzu fallow and subsequent crops and crop yield as affected by a fertilizer differential prior to planting kudzu.**

| Crop sequence | Planting date | Harvest date | Grain yield: Residual fertilizer level: None | Yes | $LSD_{0.05}$ |
|---|---|---|---|---|---|
| | | | t/ha | | |
| 8. Kudzu fallow | Aug. 28, '85 | Sep. 13, '86 | — | — | — |
| 9. Rice cv. Africano | Sep. 26, '86 | Jan. 22, '87 | 3.86 | 3.98 | 0.41 |
| 10. Rice cv. Africano | Feb. 13, '87 | | in progress | | |

**Table 8. Changes in selected topsoil (0-15 cm) chemical properties prior to and after one-year fallow, and after harvest of a subsequent crop in the kudzu fallow plots.**

| Plot status | Months after burning | Prior fertili-zation | pH ($H_2O$) | Exchangeable Al | Exchangeable Ca | Exchangeable Mg | Exchangeable K | Al sat. | Avail. P | Org. mat. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | cmol/L | | | | % | mg/dm³ | % |
| End of first cropping cycle (seven crops) | 35 | No | 4.5 | 1.9 | 0.98 | 0.10 | 0.26 | 50 | 4 | 1.92 |
| | | Yes | 4.5 | 1.2 | 0.98 | 0.16 | 0.19 | 46 | 14 | 1.77 |
| After one year in kuzdu fallow (before burning) | 52 | No | 4.5 | 1.8 | 0.60 | 0.09 | 0.13 | 68 | 7 | |
| | | Yes | 4.6 | 1.1 | 0.57 | 0.13 | 0.11 | 57 | 14 | |
| At first harvest of second cropping cycle | 54 | No | 4.8 | 1.6 | 1.05 | 0.18 | 0.23 | 52 | 14 | 2.44 |
| | | Yes | 4.5 | 1.1 | 0.76 | 0.20 | 0.14 | 49 | 25 | 2.71 |
| $LSD_{0.05}$ | | | 0.2 | 0.3 | 0.25 | 0.05 | 0.05 | 11 | 6 | ns |
| CV | | | 4 | 25 | 35 | 32 | 39 | 21 | 48 | 15 |

are significant in terms of prior fertilization treatment, which the kudzu fallow maintains.

Topsoil chemical properties after the first harvest of the second cropping cycle show fewer differences due to previous fertilization than at the end of the first cropping cycle, partly because the entire area was fertilized with 30-22-48 NPK formula. Nevertheless, there is an overall trend of increasing available P, K, Ca and Mg that may be related to the nutrient content of the ash and prior fertilization during the first cropping cycle. Topsoil properties at 54 months after burning, representing seven crop harvests, one year of kudzu fallow, and one crop harvest afterwards, are about as good or better than three months after burning the original forest (see previous technical report). Topsoil total organic matter contents have increased, probably as a result of kudzu-fallow litter inputs (Table 8). It appears reasonable to speculate that organic-matter contents will decrease slightly with subsequent cropping, as they did during the first cropping cycle.

The second cropping cycle continues in order to determine how long it will last, except that no fertilizer is being applied and weed control will only be at the conventional level.

### High-Input Crop Production

Another option is for the low-input system to serve as a three-year transitional period to intensive, fertilizer-based, continuous cropping systems for areas that have developed a sufficient road, credit and market infrastructure to make this possibility attractive. The fields are certainly ready for mechanized tillage, provided slopes are suitable, because most of the felled vegetation has decomposed. One treatment of this field experiment was tilled to 25 cm with a 50-HP tractor, limed with 3 t/ha of dolomitic lime, fertilized with 25 kg/ha P as triple super-

**Table 9. Grain yields of the first three intensively managed continuous crops after shifting from a low- to high-input system.**

| Crop sequence | Planting date | Harvest date | Grain yield |
|---|---|---|---|
| | | | t/ha |
| 8. Corn cv. Marginal 28 | Sept. 9, '85 | Jan. 19, '86 | 3.86 |
| 9. Corn cv. Marginal 28 | March 22, '86 | July 24, '86 | 2.90 |
| 10. Soybean cv. Jupiter | Sept. 11, '86 | Dec. 23, '86 | 1.87 |
| Totals | | 15 months | 8.63 |

phosphate, 25 kg/ha Mg as $MgSO_4$, 1 kg Zn as $ZnSO_4$, 1 kg Cu as $CuSO_4$, and 1 kg B as borax. Lime and fertilizers were incorporated with tillage. Marginal 28, an adapted corn variety, was planted in ridges at a population of 56,000 plants/ha. This crop then received 100 kg N/ha as urea and 100 kg/ha of K as KCl in three split applications. Weeds remaining after tillage were controlled by 2.25 kg/ha active ingredient of metalochlor. A second crop of corn was then planted after mechanically incorporating corn stover. It received an application of 100-25-100 kg/ha NPK and metalochlor, at the same rate. The corn was followed by soybean (cv. Jupiter), which received an application of 30-25-100 kg NPK/ha. Insecticides were used in corn and soybean as needed to control mild insect attacks to these crops.

Corn yields were normal for high-input systems for the planting season (3-4 t/ha), while soybean yields were somewhat lower than normal (2 t/ha) partly because of unusually heavy rains (Table 9). The system appears stable and of similar productivity to long-term high-input systems grown at Yurimaguas. A combined total of 8.6 t/ha of high value grain (corn and soybean) was produced in approximately 15 months. Total productivity of the entire sequence was 22.4 t/ha of grain in four years and four months, or 5.2 t/ha per year. In order to decrease weed infestations, using the kudzu fallow prior to shifting to high input cropping may be advisable.

### Legume-Based Pasture

The low-input system can also serve as a precursor to establishing improved, acid-tolerant pastures, beginning with the clearing of secondary forests. Income-generating food crops can be grown and the pasture species may be planted either vegetatively or by seed under a rice canopy. Several combinations of persistent, acid-tolerant grasses and legumes produced high and sustained liveweight gains in Yurimaguas for six years, as reported in the legume-based section. The kudzu fallow itself could be used as a pasture in rotation with grass-based pastures. Although we have not shifted from low-input cropping to pastures in an actual experiment, the possibility appears feasible. Since weed encroachment is a major limiting factor in pasture establishment, it may be advantageous to limit the number of crops in order to minimize the weed build-up that occurred during the sixth and seventh crops. Planting kudzu fallow, burning it after one year, and then establishing the pastures may be a better approach.

### Agroforestry

The low-input cropping system is a good way of providing cash income and ground cover during the establishment phase of tree plantations. The decision, however, has to be made early in order to transplant or seed the tree crops at adequate spacing shortly after clearing and burning the second forest. Unless liming is contemplated, the choice of tree crops should be limited to acid-tolerant ones. Examples of acid-tolerant crops for industrial purposes are rubber (*Hevea brasiliensis*), oil palm (*Elaeis guineensis*) and guaraná (*Paulinia cupana*); for food production, peach palm (*Gulielma gasipaes*); for alley-cropping, perhaps *Inga edulis*. Woody species known to be sensitive to soil acidity such as *Theobroma cacao* or *Leucaena leucocephala* should be avoided.

The low-input system has been used successfully in nearby experiments for the establishment of peach palm and multipurpose tree-production systems that include fast-growing (*Inga edulis*) and slow-growing (*Cedrelinga cataeniformis*) species. For peach palm, seedlings are transplanted with the first rice crop. Within 18 months, the peach palm produces too much shade for further crop growth; kudzu is then planted as an understory.

### Implications

The low-input system has several potentially positive environmental impacts. It provides a low-cost alternative for shifting cultivation in highly acid soils. In order to produce the grain yields reported for the first cropping period, a shifting cultivator would need to clear about 14 ha in three years, in comparison to 1 ha in this low-input system. Furthermore, the use of secondary forest fallows instead of primary forests is emphasized, although the system should work well starting from primary forest.

Erosion hazards are largely eliminated by the absence of tillage and the presence of a plant canopy on the soil surface, be it slash-and-burn debris, crop canopies, crop residue mulch, or a managed fallow. Nutrient recycling is maximized, but nutrients exported as grain must be replenished by outside inputs in soils so low in nutrient reserves. Perhaps just as importantly, the low-input system does not lead the farmer into a corner; it provides a wide range of options after the first cropping cycle is complete.

There are many unanswered questions about the technology just described. Although its feasibility during the first cropping cycle followed by a managed fallow period has been demonstrated, information about the second cropping cycle is limited to one crop harvest. It cannot be stated at this point that a modified form of shifting cultivation with a 3:1 crop to managed fallow ratio is feasible on a long-term basis.

More in-depth knowledge of weed population shifts and fertility dynamics is needed. Zero tillage poses a major constraint to long-term weed control. Soil data have been confined to readily determined chemical parameters; soil physical and biological dynamics are now being intensively studied. Tropical kudzu is but one of several promising species for managed fallows, and others are being investigated in terms of above- and below ground biomass accumulation, nutrient cycling and weed suppression. A fresh look at the management of organic inputs and soil organic matter is being researched.

The effect of age of fallow should be studied in greater detail, to answer such questions as, What are the trade-offs with a longer fallow? and, Can the weed problem be reduced by having a shorter time period between harvesting and planting?

## Weed Control in Low-Input Cropping Systems

*Jane Mt. Pleasant, N. C. State University*
*Robert E. McCollum, N. C. State University*

Weed control in low-input cropping systems must rely on cultural practices to increase the crop's ability to compete against weeds and thereby reduce the amount of herbicide and manual weeding inputs that are needed to maintain crop yields. Mulching, tillage, timely fertilization, increasing crop density and the use of competitive cultivars are all examples of cultural practices that can aid in controlling weeds.

### Objective

The objective of this study is to identify cultural practices that can form the basis of a weed management program for a continuously cropped rice-cowpea rotation under low-input conditions.

### Procedures

The experiment was established after cutting and burning a five- to ten-year-old secondary forest at Yurimaguas. Five consecutive crops, identified as Cycles 1 through 5 (rice- rice-cowpea-rice-cowpea), were planted. The experimental design was a split-plot, with tillage and residue management as main plots. There were three main-plot treatments: 1) rototill with previous crop residues incorporated, 2) rototill with residues mulched and, 3) no-till with residues mulched. A factorial arrangement of two crop densities (high and low) and three weed-control practices (hand-weeding, herbicide and no control) comprised the subplot treatments. Oxadiazon and propanil were the herbicides used on rice, and metolachlor was applied to cowpea.

Data from Cycles 2 through 5 were combined and analyzed as a single experiment. Cycle 1 was not included in this combined analysis because there was no residue management variable in the first crop that succeeded the forest fallow. The remaining four cycles were consistent in treatment through the duration of the experiment. Although the emphasis in this report is on the combined analysis, some data from individual crop cycles are also reported.

## Results and Discussion

*Crop species*

Rice had more weeds and lower relative yields than cowpea (Figure 1), and failure to control weeds had a much greater effect on rice than on cowpea yields (Figure 2). Because cowpea establishes quickly, we hypothesize that it covers the row and shades out emerging weed seedlings. Rice, in contrast, is much slower in forming a canopy. With the ground left unshaded, weed seedlings in rice quickly become competitors.

*Time*

Weed infestation was also more severe the longer the field was cropped (Figure 1). Weed levels in Cycle-4 rice were much higher than in Cycle-2 rice. The same pattern was seen in cowpea: weed infestation was higher in Cycle 5 than in Cycle 3.

*Residue management*

Mulching was ineffective as a weed-control practice, but relative crop yields were higher when residue was incorporated (Figure 3). In this experiment the primary role of residue management appears to be related to nutrient release rather than weed control. We hypothesize that rapid decomposition of residues following incorporation releases nutrients more quickly for immediate recycling than when they are allowed to decompose on the surface.

*Tillage*

No-till plots had more weeds and lower yields than rototilled plots in the combined analysis, but the effect of tillage on weed growth changed over the course of the experiment (Figure 4). In the first cycle, rototilled plots had many more weeds than no-till plots. By Cycle 5, however, the no-till treatment had the greater weed infestation.

Rototilling in Cycle 1 provided an ideal seedbed for weed seed germination. With tillage, weed seeds were brought to the surface where they germinated in a flush. In contrast, weed infestation in Cycle-1 no-till plots was low. Fire destroyed both standing vegetation and surface seeds. Without soil disturbance to bring buried weed seeds to the surface, weed infestation in the first crop was minimal.

When the field is cropped continuously, however, lack of tillage through several cropping cycles

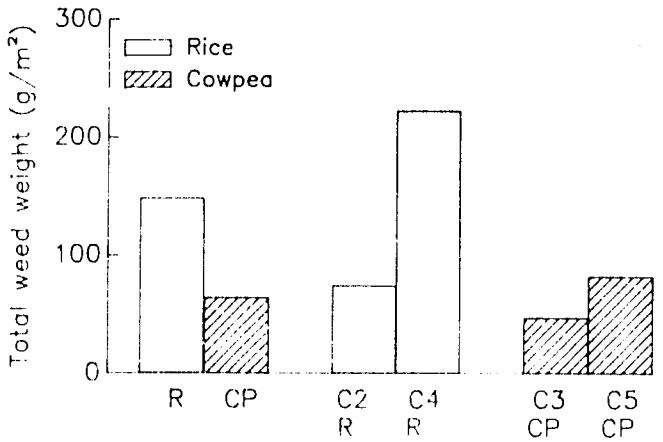


**Figure 1. Effect of crop species and number of cropping cycles on weed infestation in four consecutively planted short-season crops. Yurimaguas 1984-1985. R = rice; CP = cowpea; C2 = Cycle 2; C3 = Cycle 3; C4 = Cycle 4; C5 = Cycle 5.**

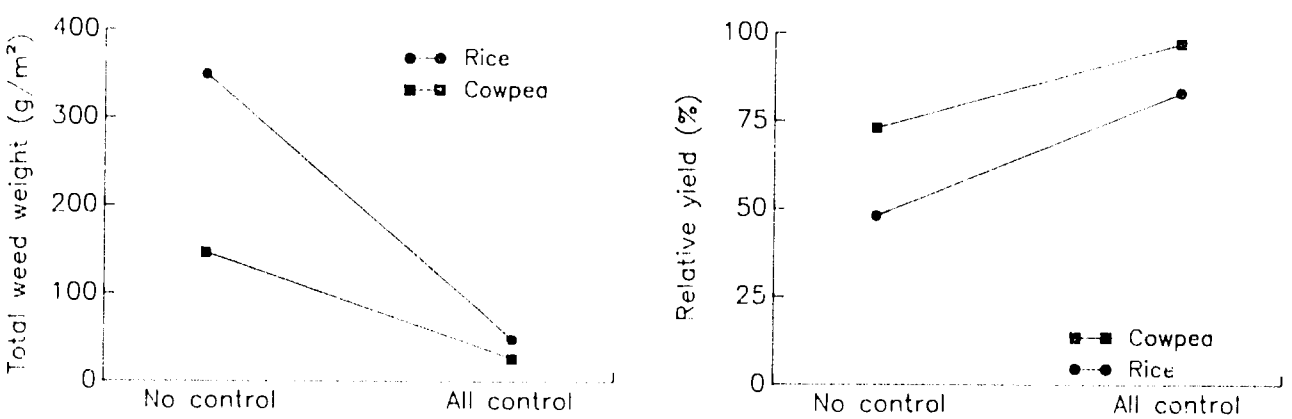


**Figure 2. Effect of weed control on weed infestation and relative yield in rice and cowpea in four consecutively planted short-season crops. Yurimaguas 1984-1985. No control = no weed control; All control = treated with herbicide or hand-weeded.**

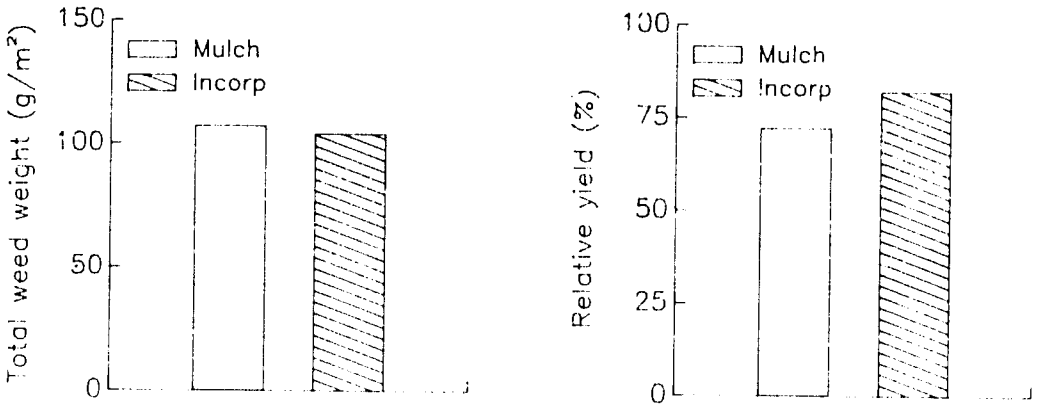


**Figure 3. Effect of residue management on weed infestation and relative yield in four consecutively planted short-season crops. Yurimaguas 1984-1985.**

brings increased weed problems. Soil disturbance has a positive effect in a continuous cropping system because existing vegetation can be completely eliminated between crops. While weeds in no-till plots were burned back with a pre-plant application of paraquat between crops, they quickly regrew. Consequently, after five consecutive no-till cropping cycles, untilled plots had a much larger weed infestation than rototilled treatments.

*Crop density*

Increasing crop density was an effective weed control measure (Figure 5). In most cycles there were fewer weeds and higher product yields when the crops were planted at the higher density. But yields, particularly of rice, increased at the higher density even when weed growth was not affected. Apparently closer-spaced rice was more efficient in intercepting sunlight for photosynthetic production, and the higher yields were independent of the effect of crop density on weed growth.

*Weed-control practice*

Failure to control weeds reduced product yields in both rice and cowpea, but the weed-control method (manual or chemical) had little effect on yield (Figure 5).

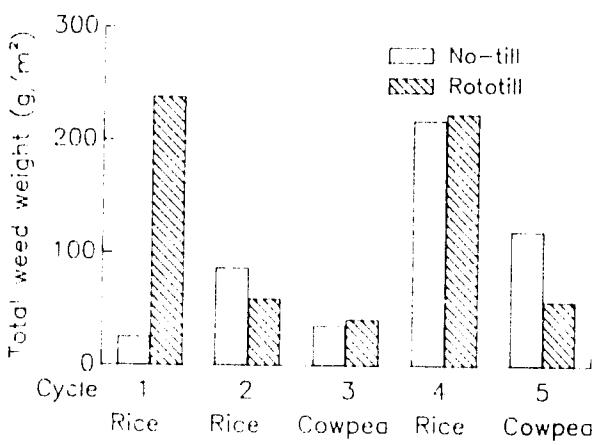


**Figure 4. Effect of tillage on weed infestation in each crop cycle of a five-cycle experiment. Yurimaguas 1983-1985.**

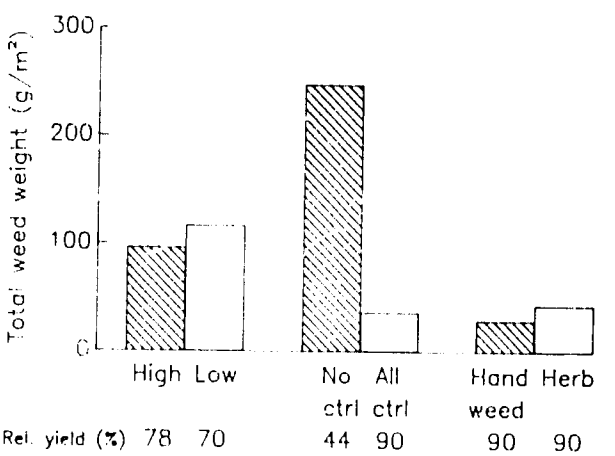


**Figure 5. Effect of crop density and weed-control practice on weed infestation and relative yield in four consecutively planted short-season crops. Yurimaguas 1984-1985. High = high crop density; Low = low crop density; No ctrl = no weed control; All ctrl = treated with herbicide or hand-weeded; Herb = treated with herbicide.**

**Management and Research Implications**

If a viable low-input continuous cropping system is to evolve in the Peruvian Amazon, it will depend on upland rice as the central cash crop, and the rice or any associated crop will be planted without tillage. It is now apparent that we cannot control weeds through repeated cycles of rice-cowpea rotations without large and unprofitable inputs for weed control. For this reason, such a cropping system must be considered transitional. It may form a bridge between shifting cultivation and a more permanent agriculture, but it is not a stable, long-term alternative to shifting cultivation.

Lack of tillage and the poor competitive ability of upland rice are the primary causes of the weed-control problem. Weed infestation in rice increases dramatically with time when a field is cropped continuously without tillage, even when rice is rotated with cowpea. Because upland rice is such a poor competitor, grasses invade vigorously and crop yields decline sharply with successive rice crops.

It is possible to control weeds (either manually or with herbicides) and maintain yields, but the cost of control is prohibitive for a low-input system within the present price-profit structure in Peru. With rice yields of 2 to 3 t/ha and cowpea yields of 1 to 2 t/ha, weed-control costs represent 25 to 40% of the value of the crop.

Based on our present knowledge, a realistic "lifespan" for the low-input system is probably five or six crop cycles, after which the cropping system must be interrupted by a fallow period or tillage in order to disrupt and displace the weed community. Research should now focus on developing effective and economic weed-control strategies for this transitional low-input system comprised of no more than six consecutive crop cycles. Our work suggests several avenues that may be productive.

Weed-control inputs are unnecessary or minimal in the first rice crop after a forest fallow and in all cycles with cowpea. The majority of weed-control costs will be concentrated in the second, third and fourth rice crops.

Increasing the planting density of rice is an effective and cheap form of weed control. Work is needed to establish optimum planting densities for rice cultivars in this environment. As demonstrated with cowpea, an aggressive, fast-growing crop is another form of inexpensive weed control. Rice cultivars used in the low-input system should be selected for their competitive abilities. Early canopy formation, to shade out weed seedlings, is probably a critical characteristic for rice cultivars in this management system.

We have shown that herbicides can provide excellent weed control in upland rice. Furthermore, we suggest that this control method may become economic if herbicide use can be integrated with other control practices so that the rate and number of applications can be reduced. A practical and effective weed-management program for a low-input system will combine cultural practices with chemical and manual methods of control.

# Agroforestry Systems

Tree crop-based systems constitute a major soil-management option for the humid tropics. Agroforestry research on acid soils of the humid tropics is very limited, and most statements about tree-soil relationships in the humid tropics are not based on solid data. Agroforestry options at Yurimaguas are conducted in close collaboration with INIPA's Agroforestry Project, sponsored by the International Development and Research Centre of Canada and the International Council for Research in Agroforestry (ICRAF). The three main options are alley-cropping, improved fallows and fruit tree production.

Highlights of this year include 1) the first characterization of acid-tolerant, multipurpose legume shrubs for litter quality; 2) the very high potential of *Inga edulis* as a hedgerow species; 3) the limitations of agroforestry as a nutrient recycler on acid Ultisols, and its good behavior in high base status alluvial soils; 4) the strong competition between hedgerow and food crops; and 5) the completion of long-term experiments on fertilizer response by peach palm and *Gmelina arborea*.

# Multipurpose Tree Selection For Alley-Cropping

*Angel Salazar, INIPA*
*Cheryl A. Palm, N. C. State University*
*Jorge M. Pérez, INIPA*
*Charles B. Davey, N. C. State University*

Alley-cropping is an agroforestry system consisting of growing food crops between alleys of tree hedgerows. Trees are pruned periodically to avoid competition and to provide organic inputs as mulch to the growing crop.

The tree species most generally used as the hedgerow is *Leucaena leucocephala*, a fast-growing species from Central America that produces a high amount of biomass and survives continuous pruning. *Leucaena leucocephala* grows well in fairly rich soils with a pH above 6.0 but does not produce well in acid soils with Al toxicity, as shown in previous annual reports. This experiment was designed to select trees that can be used as hedgerows in acid soils with a high percentage of Al saturation.

**Table 1. Species under investigation as of October 1986.**

| Species | Date of planting |
|---|---|
| | mo-day-yr |
| *Samanea saman* | 26-09-85 |
| *Gliricidia sepium* | 26-09-85 |
| *Pithecellobium dulce* | 26-09-85 |
| *Albizzia procera* | 26-09-85 |
| *Flemingia congesta* | 26-09-85 |
| *Calliandra callothyrsus* | 26-09-85 |
| *Inga* sp. (*Pacae*) | 26-09-85 |
| *Schizolobium amazonicum* | 18-12-85 |
| *Acacia auriculiformis* | 18-12-85 |
| *Cassia* sp. (1) *Retama chancho* | 02-05-86 |
| *Cassia* sp. (2) *Quillocisa* | 02-05-86 |

## Objectives

The objectives of this study are 1) to assess the preadaptation of some leguminous trees or woody shrubs to the soil and climatic conditions of Yurimaguas (growth rate and survival); 2) to assess the susceptibility of the same species to insect attack and diseases (long-term survival); 3) to assess biomass production (g dry matter per tree); 4) to assess mulch quality in terms of nutrient content, rate of decomposition, and nutrient release, and 5) to assess root production and distribution and rhizobial infection per tree.

## Procedures

A complete randomized block design with two replications was installed to evaluate the trees. Treatments were the different tree species obtained from local collections as well as from Hawaii, Central America and Africa (Table 1). Each treatment consisted of a row of 20 trees planted at 1-m intervals; each treatment row was separated by 5 m from other rows. Half the trees were pruned periodically to measure biomass production and response to repeated prunings.

The study was located on a typical Ultisol, which was previously under fallow; the fallow was cleared and burned. General soil characteristics of the site are shown in Table 2.

**Table 2. Soil chemical characteristics of the study area, before burning.**

| Depth | pH | P | Al | Ca | Mg | K | Al sat. |
|---|---|---|---|---|---|---|---|
| cm | | ppm | cmol/L | | | | % |
| 0-15 | 4.4 | 10.2 | 3.47 | 0.88 | 0.18 | 0.08 | 75 |
| 15-30 | 4.4 | 6.3 | 5.18 | 0.56 | 0.09 | 0.05 | 88 |
| 30-45 | 4.4 | 4.3 | 6.17 | 0.55 | 0.08 | 0.05 | 89 |

## Results

*Growth rate and survival*

*Cassia* sp. (1) *Retama chancho, Inga* . (*Pacae*), *Caliandra callothrysus* and *Samanea saman* were the fastest-growing species and, except for *C. callothrysus*, showed a high percentage of survival. Growth rates are shown in Table 3 and percentage of survival in Table 4.

*Susceptibility to insect and disease attack*

The main problem in plant establishment was attack by leaf-cutting ants. *Schizolobium amazonicum, Acacia auriculiformis, Albizzia procera* and *Flemingia congesta* were attacked the hardest, and survival was practically nil (Table 4). *Gliricidia sepium* was attacked by aphids and radicular fungi, which caused 15% mortality.

*Biomass production*

To date, only five species have been pruned (Table 5). Trees were pruned five and ten months after planting, when they were at least 2 m in height, except *Cassia* sp. (1) *Retama chancho*, which was only pruned five months after planting. In practice it should be possible to prune the trees when they are 1.5 m tall.

*Mulch quality*

The lignin/nitrogen ratio (L/N) and total soluble polyphenolic contents of leaves are possible indicators of mulch quality. Low L/N ratios and low polyphenolic contents may predict the rate of decomposition of such organic input sources. The first determinations of these parameters for species used in this trial as well as others, including creeping legumes with potential use for green manures, pastures and managed fallows, are shown in Table 6. Wide differences are obvious. Since the interpretation of these values is the subject of other research, these characteristics represent the beginning of our data base on organic input quality.

## Conclusions

*Cassia* sp. (1) *Retama chancho* seems to have the greatest potential of species already pruned. It grows fastest and has a 100% survival rate. It is not attacked by leaf-cutting ants. When pruned the first time it produced 403 g dry matter per tree. Although a legume, it is not believed to be a N fixer, although its leaf N content is as high as many N-fixing legumes.

*Inga* sp. (*Pacae*) is the second fastest-growing species; survival is also 100%. The first pruning

**Table 3. Growth rate (ranked from the fastest to the slowest growing).**

| Species | Height | Months after planting | Growth rate |
|---|---|---|---|
| | cm | | cm/month |
| *Cassia* sp. (1) *Retama chancho* | 204 | 5 | 40.9 |
| *Inga* sp. (*Pacae*) | 371 | 12 | 30.9 |
| *Calliandra callothyrsus* | 276 | 12 | 23.0 |
| *Samanea saman* | 243 | 12 | 20.3 |
| *Gliricidia sepium* | 191 | 12 | 15.9 |
| *Cassia* sp. (2) *Quillocisa* | 62 | 5 | 12.4 |
| *Schizolobium amazonicum* | 121 | 12 | 10.1 |
| *Pithecellobium dulce* | 114 | 12 | 9.5 |
| *Acacia auriculiformis* | 52 | 7 | 7.5 |
| *Flemingia congesta* | 42 | 7 | 6.0 |
| *Albizzia procera* | 11 | 5 | 2.2 |

**Table 4. Percentage of plants surviving.**

| Species | Months after planting 1 | 2 | 5 | 7 | 10 |
|---|---|---|---|---|---|
| *Cassia* sp. (1) *Retama chancho* | 100 | 100 | 100 | 100 | 100 |
| *Cassia* sp. (2) *Quillocisa* | 100 | 100 | 100 | 100 | 100 |
| *Inga* sp. (*Pacae*) | 100 | 100 | 100 | 100 | 100 |
| *Samanea saman* | 100 | 100 | 100 | 100 | 100 |
| *Phithecellobium dulce* | 100 | 100 | 100 | 100 | 100 |
| *Gliricidia sepium* | 100 | 95 | 95 | 85 | 85 |
| *Calliandra callothyrsus* | 100 | 85 | 85 | 80 | 70 |
| *Schizolobium amazonicum* | 95 | 90 | 75 | 70 | 50 |
| *Acacia auriculiformis* | 95 | 85 | 80 | 70 | 25 |
| *Albizzia procera* | 95 | 75 | 40 | 0 | 0 |
| *Flemingia congesta* | 60 | 55 | 35 | 0 | 0 |

Table 5. Biomass production of pruned species.

| Species | | Pruning 1st* | Pruning 2d** | Cumulative |
|---|---|---|---|---|
| | | gDM/tree | | |
| *Inga* sp. (*Pacae*) | Total | 167 | 614 | 781 |
| | Leaves | 107 | 322 | 439 |
| *Gliricidia sepium* | Total | 112 | 291 | 403 |
| | Leaves | 66 | 172 | 283 |
| *Samanea saman* | Total | 119 | 186 | 305 |
| | Leaves | 74 | 115 | 283 |
| *Calliandra* | Total | 17 | 94 | 111 |
| *callothyrsus* | Leaves | 9 | 51 | 6 |
| *Cassia* sp. | Total | 403 | — | 403 |
| (1) *Retama chancho* | Leaves | 201 | — | 201 |

*Five mo. after planting.
**Ten mo. after planting.

Table 6. Lignin,* nitrogen and total soluble polyphenolic** percentage of leaf dry weight of various multipurpose trees and other legumes being studied at Yurimaguas.

| Species | Lignin | N | L/N ratio | Total soluble polyphenolics |
|---|---|---|---|---|
| | % | | | % |
| *Inga edulis* | 16.5 | 3.18 | 5.2 | 4.2 |
| *Erythrina* sp. | 9.5 | 3.52 | 2.7 | 0.7 |
| *Cajanus cajan* | 9.7 | 3.48 | 2.8 | 3.7 |
| *Desmodium gyroides* | 11.3 | 2.90 | 3.9 | 1.9 |
| *Leucaena leucocephala* | 7.0 | 3.90 | 1.8 | 2.0 |
| *Centrosema macrocarpum* | 8.7 | 3.73 | 2.3 | 1.5 |
| *Stylosanthes guianensis* | 5.7 | 3.20 | 1.8 | 1.1 |
| *Desmodium ovalifolium* 350 | 6.2 | 2.37 | 2.6 | 4.5 |
| *Pueraria phaseoloides* | 8.8 | 4.00 | 2.2 | 1.1 |
| *Mucuna conchinelinensis* | 5.3 | - | - | 1.4 |
| *Samanea saman* | 5.8 | 3.30 | 1.8 | 0.9 |
| *Gliricidia sepium* | 7.9 | 3.74 | 2.1 | 0.5 |
| *Calliandra callothyrsus* | 11.3 | 3.03 | 3.0 | 3.9 |
| *Inga* sp. (*Pacae*) | 18.6 | 2.99 | 6.2 | 1.2 |
| *Mucuna rajada* | 10.2 | 4.43 | 2.3 | - |
| *Cassia* sp. (1) *Retama chancho* | - | 2.49 | - | - |

*Lignin determined by the acid fiber detergent method.
**Total soluble polyphenolics determined by the Folin-Denis method.

produced less biomass than *Retama chancho* but biomass production increased considerably at the second pruning. *Pacae* has a high L/N ration but low polyphenolic content.

*Caltiandra callothyrsus* is the third fastest-growing species but the last in terms of biomass production per tree. This species was hit hard by leaf-cutting ants in the early establishment phase, which reduced the rate of growth, survival and biomass production.

*Samanea saman* performed as the fourth fastest-growing species and had 100% survival, but it is the third in biomass production.

*Gliricidia sepium* ranks as the fifth fastest-growing species and the second in cumulative biomass production, but has only 85% survival.

*Cassia* sp. (2) *Quillocisa* is not yet big enough to be pruned, and appears to be a slow-growing species. *Pithecellobium dulce* is a spiny shrub, not suitable for alley-cropping purposes. *Schizolobium amazonicum* is not a fast-growing species and is attacked hard by leaf-cutting ants. This species does not coppice after pruning but regrows only one stem.

*Acacia auriculiformis*, *Flemingia congesta* and *Albizzia procera* were hit hard by leaf-cutting ants to the point of no survival, despite several replantings.

## Implications

Data from this ongoing study, combined with other studies being conducted at Yurimaguas, will aid in selecting trees for and design of efficient alley-cropping systems on acid soils. Some implications are already apparent at this early stage. Species collected in the Amazon (such as *Cassia*, *Inga* and *Samanea*) tend to survive better, in large part because of their tolerance to attacks by leaf-cutting ants. Exotic trees from Africa or the Pacific tend to show less survivability. A wide range in mulch quality indicators will enable scientists to choose germ plasm varying in this property for more studies on management of organic inputs.

# Mulch Quality and Nitrogen Cycling

*Cheryl A. Palm, N. C. State University*
*Pedro A. Sanchez, N. C. State University*

The use of green manures or leguminous mulches is commonly advocated as a biologically and economically efficient means of restoring or maintaining soil N levels for crop production. The availability and release of the N held in these organic fertilizers, however, differs drastically with the chemical composition of the leaves. In the past the general rule followed to predict the rate of decomposition and release of N was related to the C/N of the plant material: the higher the ratio, the slower the decomposition, and vice versa. Recent studies indicate that the overriding factor in determining the rate of decomposition is the type of carbon compound rather than the total C content. More specifically, there is an indirect relationship between the rate of decomposition and the lignin/N ratio. Organic materials with a high lignin/N are defined as having low litter quality and slow decomposition, and those with a low ratio as high litter quality and rapid decomposition.

In addition to releasing N at different rates, the decomposition of leaves containing different carbon compounds may affect the content and composition of the soil organic matter. Low-quality litter contains the building blocks for humic and fulvic acids, which comprise the slow and passive soil organic matter pools. High-quality litter contains energy-rich carbon compounds, which are primarily lost as $CO_2$ and therefore contribute little to the maintenance of soil organic matter.

To date there has been virtually no work using green manures or leguminous mulches of different litter quality. Based on the limited information available on litter quality, decomposition and the formation of soil organic matter, one would predict that:

1. Use of green manures or mulches of high quality release sufficient nutrients to sustain crop growth but would do little to maintain soil organic-matter levels.

2. Use of low-quality green manure mulches would not supply sufficient nutrients for crop needs, but may contribute to the maintenance and formation of soil organic matter, which, in turn, releases nutrients at a slow but constant rate.

In the short term, the first option is most likely preferable, but for long-term sustainability, the second option or a combination of the two may be the best.

## Objective

The objective of this study is to compare crop yields, nutrient-release patterns and soil organic matter dynamics when prunings of different litter quality are applied to the crop.

## Procedures

An experiment based on alley-cropping technology was designed in November 1985.

### *Litter quality*

The selection of leguminous tree species with leaves of different quality was based on observations of litter persistence in a previous alley-cropping experiment in Yurimaguas (Y-405A). Species selected included *Inga edulis*, *Cajanus cajan* and *Erythrina* sp. Analysis for litter quality included percentage of N (semi-micro-Kjeldahl), lignin (acid detergent fiber) and soluble polyphenolics (Folin-Denis).

### *Experimental design and crop management*

A split-plot randomized complete block design with three replications was chosen. The main treatment was litter quality of the tree species (*I. edulis*, *C. cajan* and *Erythrina* sp.), while the split-plot treatment was the amount of prunings (or mulch) applied. Mulch levels were 0, 3.33 and 6.66 t/ha dry material per crop (or 0, 10 and 20 t/ha/yr). There were two replications of the split-plot treatment per block. Rice (cv. Africano desconocido) was planted at 25 x 50 cm spacing. Prunings were applied to the crop about three weeks after planting to avoid inhibition of rice seedling emergence. In addition, three other treatments were included for comparative purposes: a 10 t/ha mixture of *Inga* and *Erythrina*; plots with fertilizer applications (100 kg N/ha, 25 kg P/ha, 100 kg K/ha) and incorporation; and 3.3 t/ha *Inga* mulch incorporated. The experiment is now with its third consecutive crop of rice. Rice straw was removed after harvest to avoid confounding factors in nutrient mineralization and immobilization.

*Decomposition*

The rate of decomposition and nutrient release from the leaves of the prunings was followed by using litter bags (20 x 20 cm, 2-mm mesh). Litter bags filled with 15 g air-dry leaves were placed in their respective subplots containing 3.3 t/ha on November 25, 1985, along with the first application of mulch. Bags were collected at one, two, four, six, eight, 12, 16, 20, 24, 28 and 32 weeks. Due to contamination from the mineral soil, it was necessary to clean the litter by hand. Litter was then dried (70° C), weighed and analyzed for N, P, K, Ca and Mg. Subsamples were also ashed (500° C, 3 hr) to correct for contamination.

*Mineralization*

Mineralization was measured *in situ* (at 0-15 cm) using undisturbed cores. PVC tubes were pounded into the soil, covered, and left in the field for two weeks, after which they were extracted for $NH_4^+$ and $NO_3^-$. The difference in mineral N levels at zero and two weeks was considered net mineralization.

*Soil organic matter*

At the end of year one and subsequent years the soils will be analyzed for total C content, light fraction, microbial biomass, and humic and fulvic acid content.

## Results

*Litter quality*

The percentages of N, lignin, polyphenolics and lignin/N for leaves of the three species are given in Table 1. All three are legumes and had fairly high N contents. According to the lignin/N ratios one would predict that *I. edulis* would decompose more slowly than the other two, which would decompose at about the same rate. The role of polyphenolics in decomposition is being contested, but it may inhibit the process.

**Table 1. Litter quality of leaves of the three leguminous shrub species.**

| | N | Lignin | L/N ratio | Polyphenolics |
|---|---|---|---|---|
| | —— % —— | | | % |
| *Inga edulis* | 3.18 | 16.5 | 5.2 | 4.2 |
| *Cajanus cajan* | 3.48 | 9.7 | 2.8 | 3.7 |
| *Erythrina* sp. | 3.52 | 9.5 | 2.7 | 0.7 |

**Table 2. Effect of different mulch qualities on grain yields of the second upland rice crop.**

| Type of input | Mulch rate* (t/ha) 0 | 3.3 | 6.6 |
|---|---|---|---|
| | —— Yields (t/ha) —— | | |
| *Inga* mulch | 0.95 a | 1.97 a | 2.24 a |
| *Cajanus* mulch | 0.75 a | 1.35 b | 1.43 c |
| *Erythrina* mulch | 0.60 a | 1.22 b | 1.70 b |
| *Inga-Erythrina* mulch | — | 1.65 | — |
| *Inga*-incorporated | — | 1.65 | — |
| None | 0.74 | — | — |
| Fertilized (100 kg N/ha) | 0.97 | — | — |

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

*Rates of decomposition and nitrogen release*

The percentage of original biomass remaining over time is shown in Figure 1. As predicted, *Inga edulis* is decomposing more slowly than the other two, with 55% of the original biomass still remaining after eight months. *Cajanus cajan* is decomposing somewhat faster than *I. edulis*, but much slower than *Erythrina* sp. This difference was not predicted by the similar lignin/N ratios.

The N release patterns that coincide with the decomposition patterns are shown in Figure 2. It is interesting to note that the greatest release occurred during the first month for all three species.

To estimate and compare the amount of N released during decomposition, it is necessary to consider the fact that it is the leaves that are decomposing and releasing N. The stems would decompose little and contribute little during the time span of crop growth. The three species contain different proportions of leaves: 68% for *I. edulis*, 44% for *C. cajan*, and 44% for *Erythrina*. This was taken into account in Figure 2. Although *I. edulis* decomposes more slowly, it has a higher proportion of leaves and therefore releases more N than expected. During the

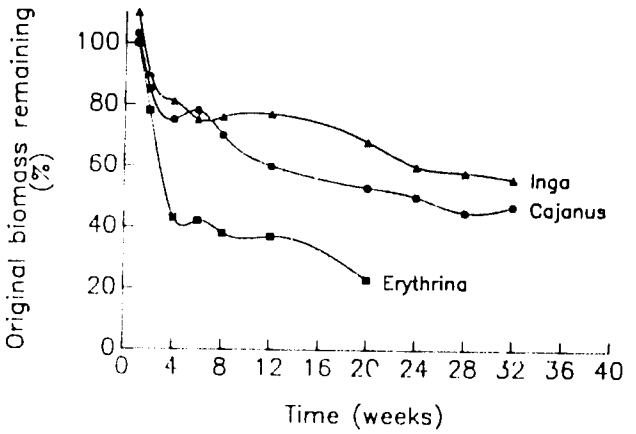


**Figure 1. Dry matter decomposition rates of three mulch sources applied at the rate of 3.3 t/ha using litter bags.**

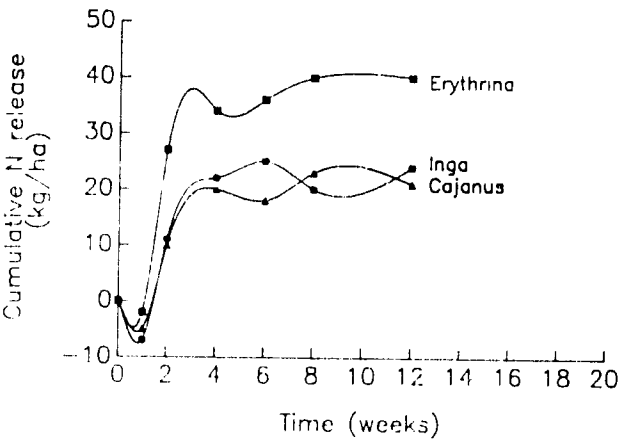


**Figure 2. Cumulative nitrogen release by three mulch sources applied at the rate of 3.3 t/ha using undisturbed cores.**

course of the first crop (four months), 27 kg N/ha were released by *I. edulis*, 24 kg N/ha by *C. cajan*, and 40 kg N/ha by *Erythrina* sp. in the plots where 3.3 t/ha/crop of pruning were applied. This leaves 45, 27 and 12 kg N/ha in the decomposing leaves for subsequent crops. These values double for the higher mulch rate.

*Crop yield and N uptake*

To date, two crops of rice have been harvested. The first crop could be considered an establishment and trial crop. Average yield was 1.83 t/ha, and essentially no differences existed among the treatments or levels of mulch, even in comparison with the treatment with fertilizer application. Plots with *Inga* mulch did have slightly lower yields, but this was due to inhibition of seedling emergence caused by the thick layer of leaves. In the first rice crop, mulch was applied prior to planting; to avoid inhibition of emergence in subsequent crops, mulch was applied after seedling emergence and establishment (three to four weeks).

Yields for the second crop are shown in Table 2. In contrast to the first crop, significant differences were found in the yields according to species of mulch as well as level of mulch. Yields obtained from applications of *Inga* or a mix of *Inga/Erythrina* mulch were significantly higher than those obtained by *Cajanus* or *Erythrina* mulch. Yields also increased significantly with increasing level of mulch.

When crop yield was plotted against the amount of N released from mulch, a significant ($P < 0.0001$)

**Table 3. Nitrogen uptake and percentage of recovery, second crop of rice.**

| | N added* | N uptake | N recov.** |
|---|---|---|---|
| | kg/ha | kg/ha | % |
| No mulch | 22.9 | 22.9 | |
| *Inga* | | | |
| 3.33 t/ha | 27.0 | 51.2 | 105 |
| 6.66 t/ha | 54.0 | 61.0 | 71 |
| 3.33 t/ha incorporated | 27.0 | 39.0 | 60 |
| *Cajanus* | | | |
| 3.33 t/ha | 24.0 | 40.8 | 75 |
| 6.66 t/ha | 48.0 | 46.7 | 50 |
| *Erythrina* | | | |
| 3.33 t/ha | 40.0 | 41.4 | 46 |
| 6.66 t/ha | 80.0 | 48.0 | 31 |
| *Inga/Erythrina* | | | |
| 3.33 t/ha | 33.5 | 43.9 | 63 |
| Fertilized | 100.0 | 52.5 | 30 |

* Considered to be the amount of N released by the mulch during the four-month period of crop growth.
**Determined according to the equation: Percentage of recovery = (N uptake at applied rate = N uptake without N / N rate) x 100.

quadratic expression resulted, explaining 60% of the variation in crop yields.

Nitrogen uptake and percentage of N recovery values are presented in Table 3. Percentage of N recovery levels were quite high for *Inga* mulch applications but low under *Erythrina* or the fertilizer application.

*Mineralization and soil organic matter*

Measurements of *in situ* mineralization and composition of soil organic matter are being taken during the third crop.

## Conclusions and Implications

Despite the faster decomposition and higher nutrient release by *Erythrina*, crop yields for the second rice crop were higher under *Inga edulis* mulch. Several factors might contribute to this apparent contradiction: soil moisture content, weeds and residual N.

The thick litter layer produced by the slowly decomposing *Inga* prunings reduces evaporation and hence maintains a higher soil moisture content. This was shown to be so by preliminary measurements made with porous cup tensiometers. High moisture content not only provides more water for the rice but also could result in higher rates of N mineralization and hence N availability. Soil moisture content, and how it correlates with crop growth and mineralization rate, is being monitored in the third crop.

The thick litter layer in the *Inga* treatments also aids in controlling weeds. The *Erythrina* litter disappears quickly and the *Cajanus* leaves are small so that in both cases there is bare soil, and weeds readily germinate and emerge. However, in the *Inga* plots virtually no bare ground exists, and few weeds germinate. Reduced weed competition could easily account for some of the differences in yields observed.

Only about one-fourth of the N applied in the *Inga* mulch was released during the four-month period of crop growth. This means that for each subsequent crop there is release of residual N in addition to the N released from the new mulch applications. The residual N from *Erythrina* was much less, more than two-thirds being released during the first four months. Over the long term, this release of residual N may be an important factor for long-term sustainability of the system.

During the next year, work will continue focusing on the relative importance of nutrients and water in affecting differences in crop yields and will focus on correlations between litter quality and *in situ* mineralization and between litter quality and soil organic matter changes. This information will aid in efficient management of green manure and mulch applications for sustained crop yields.

## Alley-Cropping in Ultisols

*Cheryl A. Palm, N. C. State University*
*Lawrence T. Szott, N. C. State University*
*Charles B. Davey, N. C. State University*

An experiment was begun in September 1984 to see if alley-cropping is a feasible land-use option on acid soils. Previous work in alley-cropping at IITA had been done on high base status soils.

### Objectives

The primary objectives of the project were 1) to assess the suitability of various leguminous trees or shrubs for alley-cropping systems, the assessment being based on survival, biomass production, and response to repeated pruning; 2) to determine the appropriate spacing between tree rows, as it affects crop yield; 3) to study changes in soil chemical properties and how they are affected by the amount of prunings added; and 4) to measure the effects of pruning additions on crop yields and yield sustainability.

### Preliminary Results

The experimental design, procedures and initial data have been described in the previous TropSoils technical report. Since full statistical analysis of the completed project is not available at the time of this writing, the following preliminary conclusions are reported:

1. *Inga edulis*, *Erythrina* sp. and *Desmodium gyroides* all produce sufficient biomass and respond to pruning to be good candidates for alley-cropping on acid soils. Longer term trials are still necessary for *Erythrina* sp. and *D. gyroides*.

2. The slower decomposing leaves of *I. edulis* maintain a thick litter layer, which provides better weed control.

3. Crop yields tend to increase with wider spacing between rows of trees, despite the fact that the areas with wider spacing have less mulch applied.

4. Crop yields were uniformly low in the experiment, but varied drastically with topsoil clay contents, even through the entire field was classified as a Typic Paleudult. The loamy sand topsoils showed markedly decreased yields from the sandy loam topsoils. Since this spatial variability could not be blocked out, at present we cannot say that alley-cropping is a viable system on acid soils of the tropics, but neither can we say that it is not.

5. There is a fundamental question about the potential of alley-cropping in acid soils: can adapted trees recycle bases effectively if the subsoil is extremely low in K, Ca and Mg? There must be something to recycle if recycling by well-adapted trees is going to be a major feature of this system. No such problem exists in high base status Alfisols and Andisols where alley-cropping has been successful and where the subsoils are loaded with bases.

This first alley-cropping experiment on Ultisols has been discontinued after discussion with Dr. P.K. Nair of ICRAF and our staff. The plots are allowed to grow into a managed fallow and are available for other uses. Since the performance of the annual crops on the sandy loam portions of the field were promising, a new study on such soils is warranted and therefore is being planned for early 1987.

### New Project Update

*This project has not been under way long enough to yield a substantive report, but should be mentioned because of its importance to the program.*

## Alley-Cropping in Alluvial Soils

*Angel Salazar, INIPA*
*Cheryl A. Palm, N. C. State University*
*Manuel Villavicencio, INIPA*

Alley-cropping might be a low-input alternative for food production in alluvial soils of the Yurimaguas area, since they are usually high in bases.

### Objectives

An experiment was designed with the following objectives: 1) to assess the suitability of three leguminous trees in an alley-cropping system based on survival, biomass production and possibility of withstanding repeated pruning; 2) to determine the effects of pruning on crop yields and yield stability; 3) to measure changes in soil chemical characteristics due to mulch additions and residue management, and 4) to measure changes in weed biomass and floral composition of weeds.

### Procedures

A nonflooded alluvial terrace with a three-year-old fallow was cleaned and burned. The soil is a fine loamy, mixed, isohyperthermic Typic Tropudalf, with much higher fertility levels than the upland Ultisols (Table 1); available P levels, however, were low. The experiment consisted of three species (*Inga edulis*, *Erythrina* sp. and *Leucaena leucocephala*) as treatments and using two spacings (4 and 8 m) between tree rows as split-plot treatments. There were four replications. Two check treatments were also installed, one in which the residues were not added to the plots, and the other in which the residues of the previous crop were added.

*Inga edulis* was planted by seeds, which are vivaporous. *Leucaena leucocephala* also was planted by seeds, but due to low germination, this treatment needs replanting. Seeds must be scarified by immersion for two minutes in water at 80° C and for 24 hours in cold water. *Erythrina* was planted by stacks.

Hedgerows consisted of two rows of trees 25 cm apart, with 50 cm spacing within rows. Trees were planted at the same time as the first rice crop.

Crops were planted in a rice-cowpea-maize rotation. Crop residues were added to the plots after each harvest. Trees were pruned soon after the next crop was planted; biomass produced by the hedgerows was measured. Soil chemical characteristics were measured after each crop; bulk density was measured after each rotation; weed biomass was measured by treatments as needed. Crop yield was measured for each treatment and by distance from the trees.

**Table 2. Tree survival at one and three months after planting in an alluvial soil of Yurimaguas (mean of three replications and two alley widths).**

| Tree species | Survival 1 month | Survival 3 months |
|---|---|---|
| | —— % —— | |
| *I. edulis* | 98 | 97 |
| *Erythrina* sp. | 84 | 93 |
| *L. leucocephala* | 24 | 79* |

*Reseeded.

**Table 1. Initial soil properties of a Typic Tropudalf on an alluvial terrace at Yurimaguas where the alley-cropping experiment was planted (mean of nine determinations).**

| Depth | pH | O.M. | P | Al | Ca | Mg | K | ECEC | Al sat. |
|---|---|---|---|---|---|---|---|---|---|
| cm | | % | ppm | ——— | cmol/L | ——— | | | % |
| 0-15 | 5.6 | 3.0 | 3.3 | 0.5 | 15.9 | 2.8 | 0.2 | 19.4 | 3 |
| 15-30 | 5.2 | nd | 1.0 | 7.0 | 10.4 | 2.3 | 0.1 | 19.8 | 35 |

nd = not determined

**Table 3. Biomass dry weight production of the first two prunings in an alluvial soil.**

| Species | 1st pruning (4 mos.) | 2nd pruning (11 mos.) | Increment | Cumulative |
|---|---|---|---|---|
| | kg/ha | | % | kg/ha |
| **8-m alley** | | | | |
| *I. edulis* | 1670 | 2238 | 34 | 3908 |
| *Erythrina* sp. | 1368 | 1706 | 25 | 3074 |
| *L. leucocephala* | 378 | 1488 | 299 | 1866 |
| **4-m alley** | | | | |
| *I. edulis* | 4047 | 5250 | 30 | 9297 |
| *Erythrina* sp. | 3935 | 4631 | 18 | 8566 |
| *L. leucocephala* | 439 | 2519 | 474 | 2958 |

## Results

*Tree growth and biomass production*

The three species showed a high percentage of survival at three months, but *I. edulis* and *L. leucocephala* grew slowly and were attacked by leaf-cutter ants (Table 2).

The trees were pruned twice: at seven and 11 months after planting. Biomass production increased moderately for *Inga* and *Erythrina*, but drastically increased for *Leucaena* (Table 3). At 11 months after planting *Inga* and *Erythrina* had produced 9.3 and 8.6 t/ha of prunings, but *Leucaena* reached about a third of that value in the 4-m alley widths.

Prunings of *I. edulis* contained 75% leaves, of *Erythrina* sp. 43%, and of *L. leucocephala* 59%. Because leaves decompose faster than stems, they are important for nutrient release. Leaves of *Leucaena* contained much more K, Ca and Mg than *Inga* leaves but similar levels of P and N (Table 4).

**Table 4. Nutrient content of the tree leaves (percentage of dry matter).**

| Species | N | P | K | Ca | Mg |
|---|---|---|---|---|---|
| | % | | | | |
| *I. edulis* | 2.76 | 0.42 | 1.18 | 0.83 | 0.16 |
| *Erythrina* sp. | 2.80 | 0.49 | 2.16 | 1.66 | 0.35 |
| *L. leucocephala* | 3.02 | 0.48 | 2.24 | 1.41 | 0.38 |

**Table 5. Effect of alleycrop species and alley width on cowpea grain yields in an alluvial soil of Yurimaguas.**

| Row | *Inga edulis* | *Erythrina* sp. | *Leucaena leucocephala* |
|---|---|---|---|
| | kg/ha | | |
| **4-m alley width** | | | |
| 1 | 638 | 842 | 1217 |
| 2 | 1298 | 1117 | 1439 |
| 3 | 2991 | 1052 | 1177 |
| 4 | 1926 | 1594 | 1941 |
| Mean | 1213 | 1151 | 1444 |
| **8-m alley width** | | | |
| 1 | 938 | 865 | 1262 |
| 2 | 1037 | 1244 | 1300 |
| 3 | 1520 | 1615 | 1388 |
| 4 | 1675 | 1359 | 1512 |
| 5 | 1542 | 1282 | 1490 |
| 6 | 1814 | 1371 | 1719 |
| 7 | 1842 | 1423 | 1127 |
| 8 | 2601 | 1827 | 2298 |
| Mean | 1544 | 1373 | 1512 |

*Crop yields*

The first rice crop did not receive mulch prunings because trees were too small to be pruned. Crop yield was 1600 kg/ha. The second crop, cowpea, received mulch from the first pruning. Cowpea growing in alleys yielded more than cowpea grown as a sole crop. Alleys 8-m wide were more productive than alleys 4-m wide, probably due to the competition effect in the interface area between crops and because trees decrease crop production closer to the trees. Alleys of 4-m width have a higher percentage of crop area in competition with trees (Table 5). There appeared to be no effect of alley-crop species on cowpea grain yields.

*Weed control*

Weed biomass was measured 11 months after

Table 6. Average weed biomass 11 mo. after establishing the alley-cropping experiment on alluvial soil.

| Treatment | Weed biomass |
|---|---|
| | kg/ha |
| **8-m alleys** | |
| *Inga* | 241 |
| *Erythrina* sp. | 627 |
| *Leucaena* | 253 |
| **4-m alleys** | |
| *Inga* | 177 |
| *Erythrina* sp. | 374 |
| *Leucaena* | 225 |
| **Check** | |
| No residues | 1654 |
| Previous crop residues | 479 |

planting the second crop (Table 6). *Inga edulis* showed the least weed biomass because its leaves decompose slowly and arrest weed emergence by forming a thick layer of leaves covering the soil surface. *Erythrina* sp. leaves decompose faster and release nutrients but do not form a leaf layer that inhibits weed emergence. *Leucaena* performed similarly to *Inga* in weed-control properties. In the check plots in which residues were not added, weed biomass was as high as crop yield.

### Conclusions

Alley-cropping seems to work well in alluvial soils of higher base status than the upland Ultisols, where its performance is in doubt. *Leucaena leucocephala*, although slower to establish than the two native species, produced similar cowpea yields and degree of weed control. The two acid-tolerant tree species, *Inga edulis* and *Erythrina* sp., appear to work well in this high base status alluvial soil.

Data are being collected to obtain more information about soil dynamics, root distribution and biomass in order to infer the degree of competition between trees and crops.

## *Inga*–Rice Interface In Alluvial Soils

*Angel Salazar, INIPA*
*Cheryl A. Palm, N. C. State University*
*Manuel Villavicencio, INIPA*
*Peter A. Huxley, ICRAF*

Alley-cropping is being advocated as a sustainable, low-input system for food production in the tropics. The majority of research in alley-cropping has been done in relatively fertile soils using *Leucaena leucocephala* as the hedgerow.

Work in Yurimaguas has shown other leguminous trees to be promising for both acid infertile soils as well as more fertile alluvial soils. More detailed information is still necessary to design an efficient alley-cropping layout that optimizes the spacing between tree hedgerows to maximize crop yields. This optimization requires a balance between maximizing tree biomass production per area and minimizing competition between the trees and food crops. The first indicates close spacing between tree rows, whereas the second indicates wide spacing. The optimal spacing will differ with different tree species according to their biomass production and rooting patterns.

### Objectives

The objectives of this study are 1) to assess the effects of different mulch levels of *Inga edulis*, *Erythrina* sp. and *Leucaena leucocephala* on rice yield in alluvial soil; 2) to assess the interface effects between the trees and rice crop growing between the hedgerows; and 3) to assess the effects of mulch levels on soil chemical and physical characteristics.

### Procedures

An alluvial area under three-year-old fallow was cleared and burned, and rice was planted. Its properties are described in the previously reported experiment, but the site had higher topsoil pH values (6.2-6.6). This first crop did not receive mulch application and was considered a standard crop.

A split plot in complete randomized block design was installed with tree species as main plots, position as subplots, and mulch level as sub-subplots in a similar manner as the previously reported mulch

**Table 1. Rice yield per species and per mulch level.**

| Species | Mulch level | Grain yield |
|---|---|---|
| | t/ha/yr | kg/ha |
| *Inga* | 0 | 1815 |
| | 10 | 1961 |
| | 20 | 1722 |
| *Erythrina* | 0 | 1799 |
| | 10 | 1656 |
| | 20 | 2195 |
| *Leucaena* | 0 | 1818 |
| | 10 | 2163 |
| | 20 | 2385 |
| Mixed* | 10 | 2303 |

*Mixed mulch: 5 t/ha of *L. leucocephala* + 5 t/ha of *I. edulis*.

quality experiment in Ultisols. Three main plot treatments (*I. edulis*, *Erythrina* sp. and *L. leucocephala*) were planted as a single hedgerow consisting of two rows of trees separated by 0.25 m; trees within rows were planted 0.5 m apart. Subplots were established on both sides of the hedgerow in north and south positions; each subplot was divided into sub-subplots for annual mulch levels of 0, 10 and 20 t/ha of prunings split in three applications per year. A treatment of mixed mulch (5 t/ha of *L. leucocephala* + 5 t/ha of *I. edulis*) was also included.

The parameters measured were grain and straw yield per treatment, mulch level and row position (distance from tree row), and changes in chemical and physical characteristics of the soil, per treatment and mulch level.

## Results

### *Yield*

Rice that received *Leucaena* mulch yielded more for all mulch rates than rice that received *Inga* or *Erythrina* mulch (Table 1). With *L. leucocephala* there were also increasing yields with increasing mulch level. With *Inga*, the highest mulch level had the lowest yield, which perhaps was due to inhibition of seedling emergence by the thick layer of *Inga* leaves.

**Table 2. Grain yield of rice as a function of distance from the hedgerow.**

| Species | Position | Yield |
|---|---|---|
| | row from tree | kg/ha |
| *Inga* | 1 | 723 |
| | 2 | 1942 |
| | 3 | 2162 |
| | 4 | 1986 |
| | 5 | 1975 |
| | 6 | 2052 |
| | 8 | 1923 |
| | 10 | 1875 |
| *Erythrina* | 1 | 1582 |
| | 2 | 2014 |
| | 3 | 1888 |
| | 4 | 2059 |
| | 5 | 2056 |
| | 6 | 2044 |
| | 8 | 2107 |
| | 10 | 1997 |
| *Leucaena* | 1 | 1718 |
| | 2 | 2084 |
| | 3 | 1948 |
| | 4 | 2128 |
| | 5 | 2253 |
| | 6 | 2321 |
| | 8 | 2106 |
| | 10 | 2419 |

### *Interface*

*Inga edulis* showed a strong interface effect: the rows closer to the hedgerow yielded less rice than rows at similar position relative to *Erythrina* and *Leucaena* hedgerows (Table 2). In all cases, however, there was lower yield in the rice rows close to the trees. The stronger competition exhibited by *I. edulis* could be due to rooting pattern or shading effects. These factors are being investigated.

### *Soil characteristics*

At both the 0-15 and 15-30 cm depths, P and K decreased, but Ca and Mg increased for all mulch levels. Acidity and Al saturation slightly increased,

**Table 3. Soil chemical characteristics before mulch treatments.**

| Mulch | Depth | pH | P | Al | Ca | Mg | K | O.M. | Al sat. |
|---|---|---|---|---|---|---|---|---|---|
| | | | ppm | cmol/L | | | | % | |
| ***Inga edulis*** | | | | | | | | | |
| 0 | 0-15 | 6.2 | 5.1 | 0.00 | 15.99 | 1.81 | 0.19 | - | 0 |
| | 15-30 | 5.7 | 2.0 | 1.10 | 12.25 | 1.28 | 0.09 | - | 8 |
| 10 t/ha | 0-15 | 6.5 | 5.7 | 0.03 | 17.20 | 1.86 | 0.21 | - | 0 |
| | 15-30 | 5.9 | 2.7 | 0.67 | 13.17 | 1.42 | 0.09 | - | 4 |
| 20 t/ha | 0-15 | 6.4 | 4.4 | 0.00 | 16.82 | 1.91 | 0.23 | - | 0 |
| | 15-30 | 5.7 | 1.1 | 0.90 | 14.77 | 1.68 | 0.09 | - | 0 |
| Mixed* | 0-15 | 6.6 | 8.7 | 0.00 | 18.00 | 1.91 | 0.24 | 3.00 | 0 |
| | 15-30 | 5.9 | 2.9 | 0.90 | 13.00 | 1.43 | 0.09 | - | 5 |
| ***Erythrina* sp.** | | | | | | | | | |
| 0 | 0-15 | 6.6 | 5.7 | 0.03 | 17.31 | 1.99 | 0.17 | 2.87 | 0 |
| | 15-30 | 5.8 | 1.6 | 2.00 | 14.78 | 1.82 | 0.11 | - | 9 |
| 10 t/ha | 0-15 | 6.3 | 5.7 | 0.00 | 16.73 | 1.99 | 0.18 | - | 0 |
| | 15-30 | 5.7 | 1.1 | 1.80 | 14.92 | 1.74 | 1.10 | - | 7 |
| 20 t/ha | 0-15 | 6.2 | 5.3 | 1.20 | 15.34 | 1.89 | 0.15 | - | 0 |
| | 15-30 | 5.9 | 1.0 | 1.77 | 14.80 | 1.67 | 0.09 | - | 8 |
| ***Leucaena leucocephala*** | | | | | | | | | |
| 0 | 0-15 | 6.3 | 6.1 | 0.03 | 18.56 | 2.05 | 0.15 | 3.00 | 0 |
| | 15-30 | 6.1 | 1.4 | 0.57 | 17.27 | 1.80 | 0.10 | - | 5 |
| 10 t/ha | 0-15 | 6.4 | 1.2 | 0.03 | 17.36 | 1.89 | 0.21 | - | 0 |
| | 15-30 | 5.8 | 2.4 | 1.00 | 16.79 | 1.83 | 0.14 | - | 4 |
| 20 t/ha | 0-15 | 6.5 | 5.1 | 0.10 | 18.17 | 1.95 | 0.18 | - | 0 |
| | 15-30 | 5.9 | 1.6 | 1.33 | 16.89 | 1.67 | 1.29 | - | 5 |

*Mixed mulch: 5 t/ha *L. leucocephala* + 5 t/ha *I. edulis*.

too, but pH and available P decreased with all levels of mulch, perhaps due to secondary acidity or crop uptake (Tables 3 and 4).

The interface effect of competition must be observed from a different point of view from light competition alone. When trees are pruned at the same time, *Inga* still shows a strong competition effect. Root sampling is being done in an attempt to explain that effect.

## Conclusions and Implications

*Inga edulis* is definitely more competitive with rice than *Erythrina* or *Leucaena*. In addition to litter quality and nutrient content differences noted in other experiments, a possible root effect is suspected. A better understanding of the interface between the tree and the food crop is likely to be an important factor in understanding alley-cropping systems. The absence of a specific tree species effect on changes in soil properties is noteworthy. The experiment is being continued to determine long-term effects.

**Table 4. Soil chemical characteristics after first mulch application.**

| Mulch | Depth | pH | P | Al | Ca | Mg | K | Al sat. |
|---|---|---|---|---|---|---|---|---|
| | | | ppm | ——cmol/L—— | | | | % |
| ***Inga edulis*** | | | | | | | | |
| 0 | 0-15 | 5.7 | 3.3 | 0.17 | 19.39 | 2.40 | 0.18 | 0 |
| | 15-30 | 5.2 | 0.8 | 1.03 | 14.38 | 1.61 | 0.11 | 5 |
| 10 t/ha | 0-15 | 5.9 | 4.0 | 0.17 | 19.71 | 2.45 | 0.17 | 0 |
| | 15-30 | 5.4 | 1.7 | 0.70 | 15.19 | 1.47 | 0.06 | 4 |
| 20 t/ha | 0-15 | 5.8 | 3.4 | 0.17 | 20.60 | 2.64 | 0.19 | 0 |
| | 15-30 | 5.2 | 0.6 | 1.67 | 15.36 | 1.80 | 0.12 | 3 |
| Mixed* | 0-15 | 6.0 | 3.2 | 0.17 | 20.93 | 2.74 | 0.20 | 0 |
| | 15-30 | 5.3 | 0.6 | 0.83 | 15.51 | 1.71 | 0.11 | 4 |
| ***Erythrina*** sp. | | | | | | | | |
| 0 | 0-15 | 5.7 | 2.3 | 0.17 | 19.86 | 2.73 | 0.14 | 0 |
| | 15-30 | 4.5 | 0.6 | 2.43 | 15.31 | 2.18 | 0.12 | 10 |
| 10 t/ha | 0-15 | 5.8 | 2.7 | 0.13 | 20.00 | 2.76 | 0.15 | 0 |
| | 15-30 | 4.6 | 0.7 | 1.77 | 18.06 | 2.35 | 0.13 | 6 |
| 20 t/ha | 0-15 | 5.9 | 2.9 | 0.10 | 21.68 | 17.01 | 0.17 | 0 |
| | 15-30 | 5.1 | 0.7 | 2.27 | 17.01 | 2.34 | 0.12 | 10 |
| ***Leucaena leucocephala*** | | | | | | | | |
| 0 | 0-15 | 5.9 | 3.4 | 0.10 | 22.81 | 2.84 | 0.15 | 0 |
| | 15-30 | 5.4 | 1.0 | 0.80 | 20.12 | 2.17 | 0.12 | 2 |
| 10 t/ha | 0-15 | 6.0 | 2.8 | 0.10 | 21.59 | 2.58 | 0.17 | 0 |
| | 15-30 | 5.3 | 1.4 | 1.57 | 20.03 | 2.17 | 0.12 | 5 |
| 20 t/ha | 0-15 | 5.9 | 5.5 | 0.10 | 22.99 | 2.61 | 0.17 | 0 |
| | 15-30 | 5.3 | 1.4 | 1.57 | 20.03 | 2.23 | 0.13 | 5 |

*Mixed mulch: 5 t/ha *L. leucocephala* + 5 t/ha *I. edulis*.

## Improved Fallows

*Cheryl A. Palm, N. C. State University*
*Lawrence T. Szott, N. C. State University*

Much of the land available to shifting cultivators remains idle each year, due to the long fallow periods required for secondary forests to restore the productivity of abandoned agricultural fields.

### Objective

The objective of this study is to determine whether productivity in such fields might be regenerated more rapidly with the use of selected, high-biomass, nitrogen-fixing fallow species.

### Procedures

A 1-ha, 15-to-20-year-old secondary forest on a loamy topsoil and clay loam subsoil was cut, burned, and planted with upland rice. One rice was harvested in January 1984, and the following treatments were installed in 100 $m^2$ plots, with four replications, in a randomized complete block design: purma (natural secondary vegetation), *Cajanus cajan*, *Inga edulis*, *Stylosanthes guianensis* 136, *Centrosema macrocarpum*, *Desmodium ovalifolium* 350, *Pueraria phaseoloides* (kudzu).

Changes in soil and vegetation properties during the first 16 months after fallow establishment were reported previously.

The two-and-a-half-year sampling for the improved fallows was carried out in July 1986. Sampling methodology was identical to that of July 1985, except that infiltration was not measured and tree biomass was estimated by allometry rather than by destructive sampling.

### Results

Preliminary analysis of the data indicates interesting patterns in biomass accumulation (Table 1). In comparison with the July 1985 values for total aboveground biomass there has been surprisingly little change for most of the treatments except that of *I. edulis*. In the *Inga* plot, aboveground biomass more than doubled to a total of 34 t/ha. Root biomass was virtually the same in 1986 as in 1985.

In terms of species composition in the various improved fallow treatments, *C. macrocarpum* continued to dominate and did not allow invasion of other species. *Stylosanthes guianensis* appeared to be dying out and grasses and trees invading. *Inga edulis* continued to grow well, although it was occasionally attacked heavily by leaf-cutter ants. Some other trees invaded and established themselves in the *Inga* plots, but *Inga* dominated in number and biomass. *Cajanus cajan* disappeared completely from all the plots. These plots now appear to be like a natural purma. Kudzu, like *Centrosema*, allowed few invading species. Kudzu, however, seemed to die back periodically, unlike *Centrosema*. *Desmodium ovalifolium* was still present in all replications, but, in contrast to *Centrosema* and kudzu, the plots contained many trees, which added to the biomass accumulation. The natural purmas did not seem to have changed much in biomass during the past year, which may reflect shifts in species and life-form composition. The natural purma at this point had only half the biomass of the *Inga* purmas.

Nutrient analyses were not yet available to compare stocks in the vegetation and soils of the different purmas. Changes in biomass, in nutrient stocks in the vegetation and soils, and in soil physical properties will continue to be measured.

**Table 1. Above- and below ground biomass in improved fallows after two-and-a-half years.**

| | Dry matter | | | | | | |
|---|---|---|---|---|---|---|---|
| Biomass | *Centrosema* | *Stylosanthes* | *Inga* | *Cajanus* | *Desmodium* | Kudzu | Purma* |
| | t/ha | | | | | | |
| Leaves and stems | 9.62 | 9.24 | 35.02 | 14.25 | 21.04 | 7.66 | 15.41 |
| Roots (0-50 cm) | 2.19 | 2.91 | 3.28 | 2.85 | 1.93 | 2.02 | 3.11 |

*Secondary forest fallow.

# Legume Cover Crops For Peach Palm

*Jorge M. Pérez, INIPA*

Peach palm (*Bractis gasipaes*) is a promising indigenous Amazonian species for agroforestry systems because of its tolerance to acid soil and its multiple products: fruit, heart of palm and parquet wood. Research on collection and propagation of peach palm ecotypes and the nutrient composition of the fruits were described in the previous technical reports.

Many legumes could potentially be used as cover crops for peach palm. In addition to their use as cover crops, legumes fix N, which is required for the normal growth of plants. The main nutritional constraint for peach palm growth is the lack of N.

## Objective

The objective of this study is to identify a legume that covers the ground quickly and also serves as an inexpensive N source for peach palm plantations, which require N levels of 80-100 kg/ha per year.

## Procedures

In August 1986, 10- to 12-year-old forest fallow was cleared by the traditional slash-and-burn method on a loamy sand Ultisol at Yurimaguas. The experimental area is 9450 m²; the experimental design is a complete randomized block with 14 treatments and three replications. Replications were blocked according to topsoil texture changes, which differed very little (14.8% vs. 16.0% clay); replication II was on fine sand. The 14 treatments were:

1. Peach palm, no legume cover crop, no fertilizers, and weeding every six months (check).
2. Peach palm, one crop of upland rice, no legume cover crop, low-input levels of fertilizers, and periodic hand-weeding as necessary.
3. Peach palm, rice, cassava, and periodic hand-weeding, no legume.
4. Peach palm, rice, rice, cowpea, kudzu (*Pueraria phaseoloides*).
5. Peach palm, rice, rice, cowpea, rice, rice, cowpea, kudzu.
6. Peach palm, rice, rice, cowpea, *Centrosema macrocarpum*.
7. Peach palm, rice, rice, cowpea, *Desmodium ovalifolium*.
8. Peach palm, rice, rice, cowpea, *Arachis pintoi*.
9. Peach palm, rice, rice, cowpea, *Mucuna cochinchinensis*.
10. Peach palm with kudzu.
11. Peach palm with *C. macrocarpum*.
12. Peach palm with *D. ovalifolium*.
13. Peach palm with *A. pintoi*.
14. Peach palm with *M. cochinchinensis*.

Rice was planted along with the cover crops on 20-27 September 1986, and the peach palm plants were transplanted from the nursery on 14-15 October.

Measured parameters include: 1) percentage of each legume cover as a function of area and time, 2) cover height, 3) percentage of legume dry matter, 4) height and diameter of peach palm, 5) flowering time, fruiting and peach palm production, 6) crop yields (rice and cowpea), and 7) N availability and N uptake in some treatments. Nitrogen availability will be determined by *in situ* mineralization.

## Results

*Mucuna cochinchinensis* grew most rapidly,

**Table 1. Growth of legume cover crops and peach palm 90 days after planting in a slashed-and-burned Ultisol field. Mean of three replications.**

| Cover | Legume cover | Legume height | Legume dry matter | Peach palm height |
|---|---|---|---|---|
| | % | cm | t/ha | cm |
| None (mean of several treatments) | - | - | - | 32 |
| Rice | - | - | - | 32 |
| *Pueraria phaseoloides* | 31 | 31 | 1.57 | 29 |
| *Centrosema macrocarpum* | 27 | 40 | 1.68 | 26 |
| *Desmodium ovalifolium* | 56 | 20 | 0.96 | 29 |
| *Arachis pintoi* | 2 | - | - | 23 |
| *Mucuna cochinchinensis* | 90 | 61 | 2.34 | 26 |

covering an average area of 90% of the total area 90 days after legume establishment. *Desmodium ovalifolium* covered about half, kudzu and *C. macrocarpum* about one-third, and *A. pintoi* very little (Table 1). *Mucuna* also grew tallest, to an average of 61 cm, followed by *Centrosema* 40 cm, kudzu 31 cm, *Desmodium* 20 cm, and *Arachis* less than 1 cm.

*Mucuna* also led in dry-matter production, with an average of 2342 kg/ha, followed by *Centrosema* 1688 kg/ha, kudzu 1567 kg/ha, *Desmodium* 959 kg/ha, and *Arachis* less than 1 kg/ha.

Average tree height of peach palm 90 days after transplanting ranged from 23 to 35 cm, with shorter heights in the legume cover.

### Implications

Although several legume cover crops were rapidly established after slash-and-burn, *M. cochinchinensis* cover was by far the fastest growing, covering more than twice the area and producing about 50% more dry matter than kudzu or *C. macrocarpum*, our "standard" legume covers. *Mucuna* leaves grew over the young peach palm trees, but with no apparent negative effect. The young tree leaves were greener but not taller than in the check plots. A similar effect was observed, but to a lesser extent, with kudzu and *C. macrocarpum*. The first 90 days' data imply that *Mucuna cochinchinensis* may have major potential in low-input systems at Yurimaguas.

## Mycorrhizae Inoculation In Tropical Palm Nurseries

*Pedro O. Ruíz, International Potato Center*

Vesicular-arbuscular mycorrhizae (VAM) provide a symbiosis between plants and beneficial fungi. Most wild and cultivated plant species are mycorrhizal hosts. The effects of mycorrhizae include transplant recovery and survival, enhanced growth rate, and drought resistance. These effects are thought to be directly or indirectly due to the ability of the fungus to aid in P uptake.

Mycorrhizae are known to occur in several palm genera, including *Gulielma*, *Jessenia* and *Oenocarpus*, and they have been experimentally shown to be significant in *Gulielma* and *Jessenia*. Future experiments will indicate whether palms in general depend on this symbiosis.

### *New Project Update*

*This project has not been under way long enough to yield a substantive report, but should be mentioned because of its importance to the program.*

The relative dependence of species on VAM is indicated in part by the presence and character of root hairs and the diameter of the roots. The functions of mycorrhizal hyphae are paralleled to some extent by root hairs, so that plant species without root hairs tend to depend most on VAM. Root hairs are uncommon or absent among the palms.

Nursery conditions often exclude native symbionts through use of sterilized soil, artificial substrates, pesticides, high rates of fertilizers, or other incompatible practices. Surveys made on nurseries showed that in most cases the fungi were absent. Reintroduction of VAM fungi through inoculation will improve plant growth and percentage of survival after transplanting, and in some cases inoculated plants will require less time in the nursery.

### Objectives

The objective of this study is to determine the effects of VAM fungi inoculation on transplant

recovery and temperature in five tropical palm species: *Gulielma, Euterpe, Jessenia, Oenocarpus* and *Orbygnia.*

**Procedures**

Two experiments were initiated in 1986 at the Yurimaguas Experiment Station.

*Experiment 1: transplant recovery and survival*

Seeds of the five palm species were sown in the nursery in a soil fumigated with methylbromide with 2% chloropicrin applied at a rate of 600 kg/ha. Plants were placed in plastic bags containing sterilized soil when they had three leaves. Treatments are inoculated and noninoculated plants. Inoculum will be applied at a rate of 50 g/bag and consists of material (soil, fresh roots and litter) from *I. eaulis*. Noninoculated plants will be applied with an infusion from fresh inoculum where mycorrhizal propagules were separated, to supply them with other microorganisms involved in organic-matter decomposition processes. After six months, plants will be transplanted to the field.

A complete randomized block design is being used with 50 replications per species. Leaf production rate, foliar NPK contents, dry and fresh weight of roots and shoots, transplant survival, mycorrhizal infection, plant height, and presence of spores will be determined.

*Experiment 2: temperature effects*

Inoculated plants were established as in the previous experiment. When plants have three leaves they will be placed in plastic bags containing soil from the same source, and then bags will be placed in the field. Treatments under study are with and without shade. The experiment has a complete randomized block design with 15 replications per species. Soil temperature, plant height, foliar NPK contents, mycorrhizal infection, presence of spores, and dry and fresh weight of roots and shoots will be determined.

First results from this study are expected in 1987.

# Nutritional Requirements Of Peach Palm

*Jorge M. Pérez, INIPA*
*Charles B. Davey, N. C. State University*
*José R. Benites, N. C. State University*

A fertilization experiment was established in peach palms transplanted in August 1982 in order to determine optimum levels of N, P, K and Mg and the response to lime and Zn in peach palm production. Trees were set at a 3 x 3 m spacing on an Ultisol with topsoil of pH 4.4, 0.1 cmol/L of Ca + Mg, 90% Al saturation, and 3.5 ppm available P. The main response has been to N. This response was linear during the second year but developed a clear optimum rate of 100 kg N/ha by the third year. Trees without N showed strong chlorosis. No response to P, Mg or lime has been detected. Potassium responses became evident the second year with a clear peak at 50 kg K/ha/yr. There was also a clear response to 2 kg Zn/ha the third year.

Evaluations have been done every six months. Measurements of diameter were discontinued because the peach palm reached its maximum diameter at 30 months and then plants only increased in total height. Response during the fourth year is therefore expressed as height.

## Results

Peach palm responded clearly to N (to 100 kg/ha/year), during the fourth year, to P up to 50 kg/ha ($P_2O_5$) (Figure 1) and to K up to 100 kg/ha ($K_2O$) (Figure 2). There was no response to Mg ($MgSO_4$). As the trees approach their reproductive phase, expected in the fifth year, it seems the palms are now responding to N, P and K unlike previous years, when N responses were most obvious. Lack of response to lime or Mg continues to indicate the Al tolerance of this palm.

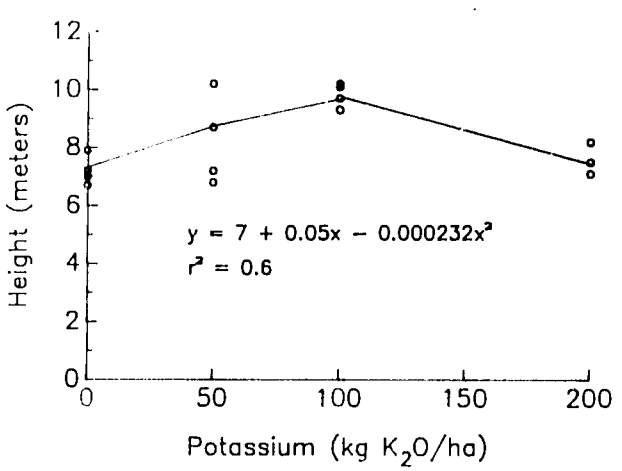


**Figure 2. Potassium response by peach palm during its fourth year of growth. Dots represent each replication.**

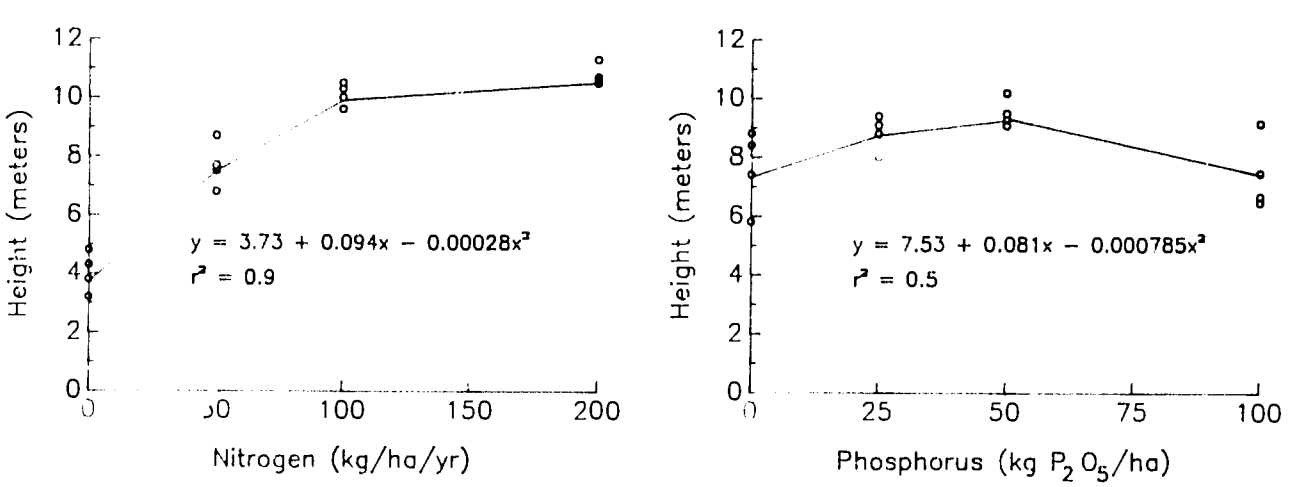


**Figure 1. Effects of nitrogen and phosphorus on peach palm growth during its fourth year. Dots represent each replication.**

# Nutritional Requirements Of Other Amazonian Fruit Trees

*Beto Pashanasi, INIPA*

The Amazon area has many native fruit trees, which have a great agroindustrial potential. Collection and propagation of native fruits will provide species with desirable phenologic and genetic characteristics.

*Arazá* is a shrub that reaches its maximum average height of 3 m and a canopy of 2.50 to 3.15 m in five years. It requires a planting distance of 3 x 3 m. It is the most precocious of the perennial crops because it starts production after 15 months.

This species is characterized by continuous fruit production throughout the year. Its pleasant and penetrating fragrance, high percentage of useful pulp, and high protein content are desirable characteristics for an agro-industrial fruit.

## Objective

The objective of this study is to obtain homogenous *arazá* material characterized by high productivity and palatability, which is easy to harvest and conserve, and which has resistance to pests and diseases.

## Procedures

Species collected during the different flowering and fruit production stages were:

| Local name | Scientific name | No. of accessions |
|---|---|---|
| *Arazá* | *Eugenia stipitata* | 3 |
| *Ungurahui* | *Jessenia bataua* | 4 |
| *Sinamillo* | *Oenocarpus* sp. | 2 |
| *Metohuayo* | *Caryoderdrum* sp. | 1 |
| *Camu-camu* | *Myrcyaria dubia* | 2 |
| *Castaña* | *Bertholletia excelsa* | 1 |

Some of these species were raised in the nursery, others were planted directly into the field; in both cases, adaptation and morphological characteristics were measured.

The relevant characteristics of some of these species are:

*Arazá*: This species is well-adapted to acid soils with pH 4.9, low P supply, and 80% Al saturation.

*Ungurahui*: This species was planted in a soil with pH 4.4, low P, and high Al saturation (73%). It has a slow pattern of growth; after 20 months in the field, plants have an average height of 0.62 m. During the first growth phase shade is required.

*Sinamillo*: This species is well-adapted to soils with low P and high Al saturation (75%); after 20 months in the field the average height was 1.51 m.

*Metohuayo*: Apparently this species is well-adapted to fertile and well-drained soils; fruiting begins three years after planting.

**Table 1. Yields of *arazá* (*Eugenia stipitata*) during its third year with two different nutrient sources.**

| Sources | Yield* |
|---|---|
| | kg/ha/yr |
| NPK (120-60-80)/yr | 6568 |
| Organic manure (corn cob) | 3764 |
| Nonfertilized | 3359 |

*Through December 1986.

## Results

Once production began, *arazá* yields increased with physiological maturity. Average plot yields were as follows: first year (1984), 767 kg/ha; second year (1985), 3274 kg/ha; and third year (up to September 1986), 2683 kg/ha. Exceptional yields of 30 to 40 t/ha/yr from five- to nine-year-old trees have been reported in other areas.

*Arazá* responded well to fertilizers NPK (120-60-80), but there was no response to organic manures (corn cob) due to its poor quality and slow decomposition (Table 1).

Yields of *arazá* were closely related to rainfall; higher yields were obtained in the rainier season (September to April) and lower yields in the drier season (June to August).

## Conclusions

The high yield levels of *arazá* are encouraging as another option among Amazonian fruit tree species.

# Nutritional Requirements Of *Gmelina arborea*

*Jorge M. Pérez, INIPA*
*Charles P. Davey, N. C. State University*
*José R. Benites, N. C. State University*

It is common to find a large diversity of tree species in tropical acid soils. At present, little is known about the growth response of broadleaved tree species to fertilizers.

*Gmelina arborea* grows vigorously during the first three years, as has been described in previous annual reports. With fertilization, *G. arborea* should increase its height and diameter.

## Objective

The objective of this study is to determine optimum levels of fertilization for the establishment period.

## Procedures

The experiment was installed in an area previously cleared by bulldozer in which the topsoil was removed. After a fallow of two years, the area was cleared by the traditional method and the experiment was established.

Seeds were obtained from Jari, Brazil. Seedlings were grown in the nursery at the Yurimaguas Experiment Station. When the plants were 30 cm high, they were packaged and then transplanted to the field; 99% of the plants survived.

A complete randomized block design was used with three replications and 18 treatments. The effects of fertilization were determined by the missing element method. Treatments are shown in Table 1. An additional treatment was considered, including 1000 kg/ha $CaCO_3$. A blanket application of 2 kg/ha of Zn was added at transplanting, except on the check.

First application: at transplanting, fertilizer was spread over a 0.16 $m^2$ area and incorporated into 0.48 $m^3$ of soil (in a hole 30 x 30 x 40 cm).

Second application: three months after transplanting, fertilizer was broadcast over a 1 $m^2$ area.

Third application: six months after transplanting, fertilizer was broadcast over a 4 $m^2$ area.

Fourth application: 12 months after transplanting, fertilizer was broadcast over a 9 $m^2$ area.

During the second, third and fourth years, fertilizers were added over a 9 $m^2$ area, since planting distance was 3 x 3 m between trees.

Measurements of diameter (DBH) and height were taken every six months. Pruning, every two months in the first year and every three months in the second year, was an important cultural practice during the first two years. After the second year, it was observed that the trees "pruned" themselves due to the close distance between the trees. As a result of this activity, there were straight trunks in most of the plantation.

## Results

*Gmelina arborea* did not respond to fertilizers under the experimental conditions. There was no response of height and diameter of *G. arborea* to the fertilizer treatments (Table 1).

Pruning every two months helped form straight trunks.

*Gmelina arborea* grows poorly in badly drained soils and is also severely affected by leaf-cutting ants; these are the two most constraining factors affecting their growth.

Attack by leaf-cutting ants was critical during the first year but decreased during the second year and was not significant during the third year. Control is recommended during the first year.

The experiment is terminated as these very fast-growing trees reach harvest height at four years. Given the lack of data on *Gmelina* fertilization, the results of Table 1 represent an important data base for this species in highly acid Ultisols.

**Table 1. Comparison of fertilization on height and diameter of four-year-old *Gmelina arborea*.**

| Treatment | Average Height | Average Diameter | Significance* |
|---|---|---|---|
| | m | cm | |
| No fertilizer | 12.0 | 13.46 | a |
| Nitrogen | | | |
| 0 kg/ha | 12.3 | 13.20 | a |
| 50 " | 12.3 | 12.48 | a |
| 100 " | 12.6 | 13.19 | a |
| 200 " | 12.6 | 12.16 | a |
| Phosphorus ($P_2O_5$) | | | |
| 0 kg/ha | 11.6 | 12.19 | a |
| 25 " | 12.7 | 13.04 | a |
| 50 " | 12.6 | 13.19 | a |
| 100 " | 12.0 | 12.29 | a |
| Potassium ($K_2O$) | | | |
| 0 kg/ha | 13.3 | 13.51 | a |
| 50 " | 13.2 | 14.53 | a |
| 100 " | 12.6 | 13.19 | a |
| 200 " | 13.0 | 13.79 | a |
| Magnesium ($MgSO_4$) | | | |
| 0 kg/ha | 12.7 | 12.20 | a |
| 10 " | 11.6 | 12.79 | a |
| 20 " | 12.6 | 13.19 | a |
| 40 " | 12.6 | 13.74 | a |
| Lime | | | |
| 0 kg/ha | 12.6 | 13.19 | a |
| 100 " | 10.6 | 13.38 | a |
| Zinc | | | |
| 0 kg/ha | 11.6 | 13.19 | a |
| 2 " | 11.6 | 13.29 | a |
| SD | 0.64 | 0.59 | |
| CV (%) | 5.22 | 4.50 | |

*Values followed by the same letter are not significant.

# Continuous Cultivation

The feasibility of continuous cultivation of food crop rotations in acid soils of the humid tropics has been demonstrated by 30 harvests during 13 years in this project. A stable system of continuous cultivation is based on overcoming soil constraints and is only applicable to areas that have an adequate market, road and credit infrastructure capable of handling high inputs and high crop values. Work during this period has concentrated on incorporation of conservation tillage practices and on evaluation of rainfall intensity, soil trafficability, fertility management and weed population shifts. Perhaps the most salient result is the difficulty in economically controlling weeds in upland rice. Consequently, we are now recommending that continuous cropping systems use more competitive crops such as corn or grain legumes, which also need lime because of their Al sensitivity.

# Conservation Tillage Under Continuous Cropping

*Julio C. Alegre, N. C. State University*
*D. Keith Cassel, N. C. State University*
*George C. Naderman, Jr., N. C. State University*

The potential for soil erosion is high in continuously cultivated Ultisols of the humid tropics because much of the rainfall occurs during brief, intense storms. In spite of the high annual rainfall levels, crops often suffer from severe moisture stress during rainless periods of two or more weeks. Management of excess water, as well as of soil moisture shortages, is important for successful settled agriculture.

Conservation tillage systems—such as stubble mulch tillage, minimum or reduced tillage and no-till—have been suggested and are currently in use in many parts of the world. These management practices could be adapted to the Amazon to reduce soil erosion and compaction and to conserve water while increasing yields.

When conservation tillage practices of any kind are imposed on cropland, some changes in the soil water balance or moisture regime occur. For example, the presence of residues on the soil surface will likely change the moisture regime from that of land where a clean tillage system is used and residue is incorporated into the plowed layer. Crop residues on the soil surface will reduce or eliminate the impact of falling raindrops, increase the infiltration rate, reduce surface runoff, and increase the amount of water percolating out of the rooting zone. More percolating water may give rise to greater downward transport of Ca and Mg from lime sources but may also leach more plant nutrients out of the root zone. In addition to changes in moisture regime, conservation tillage is also expected to alter other soil physical and chemical properties.

Changes in the soil moisture balance and other physical properties affected by various conservation tillage systems are expected to have a pronounced effect on soil trafficability. The range in soil water content over which the soil may be worked using tractor-drawn machinery may be different with different tillage practices.

The general objectives are to develop proper soil management practices for maintenance of soil physical properties for sustained fertilizer-based continuous crop production systems in humid tropical areas with favorable infrastructure development.

This project consists of four experiments: conservation tillage (Y-113), rainfall intensity (Y-115), water balance (Y-112) and soil trafficability (Y-111).

## Experiment 1: Conservation Tillage (Y-119)

### Objectives

The objectives of this experiment are 1) to determine the feasibility of introducing minimum and no-till planting practices into continuous crop production systems in the humid tropics, and 2) to determine their effects on soil physical and chemical properties compared with those of conventional planting practices.

### Procedures

The experimental area is in Chacra 1, Yurimaguas, Peru, in a Typic Paleudult cropped intensively since 1972.

The last crop before initiation of this experiment was corn, harvested in September 1986. Corn was planted in the conventional way with a disk plow for lime (2 t/ha) incorporation, and P was banded at planting time.

The new experiment started in October 1986, with a complete randomized block design with six treatments and four replications. Plots are 30 x 8 m, and total area of the experiment is 5760 m$^2$. Corn was planted again. The whole area was cut with a bush-hog and the treatments imposed were:

1. No-till, ripper: bush-hog, burn with herbicide (Dual + paraquat) and no-till planting with ripper (Coulter-ripper and planter with banded P).
2. Same as (1) without ripper.
3. Minimum till, ripper: bush-hog, treated with herbicide (Dual + paraquat) and no-till planting (Coulter-ripper and planter with banded P). Lime will be incorporated every two years using a disk harrow.
4. Minimum till: same as (3) without ripper.
5. Conventional till ripper: (a) bush-hog, (b) disk plow, (c) S-tyne field cultivator, (d) disk bedder and ripper, (e) bed shaper, planter and banded P. A subsoiler will be used once a year. Weed control will be by herbicide (Dual).

6. Conventional till: same as (5) without ripper.

Before installing the experiment, the following physical properties were measured: bulk density; hydraulic conductivity and soil water characteristics at 0-10 and 10-20 cm depths; mechanical impedance at 0-60 cm depth. Soil moisture will be monitored during the study using the neutron probe and tensiometers. Soil temperature will be measured at 0-2, 2-5 and 5-10 cm depths for each treatment. For nutrient analyses, soil samples were taken at 0-20, 20-40 and 40-60 cm depths. Porous cup tension lysimeters were located at a depth of 1 m to measure leaching of nutrients. Runoff plots will be installed in two replications for the six treatments (total of 12 runoff plots).

**Results**

Data are not yet available.

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## Experiment 2: Rainfall Intensity (Y-115)

**Objective**

The objective of this experiment is to obtain a long-term record of rainfall intensities and relate them to management under intensive continuous cropping.

**Procedures**

A continuous recording rain gauge equipped with weekly bands has been in operation since August 20, 1985.

**Results**

Measurements of rainfall events of intensity greater than 10 mm/hr during the first 13-month period are shown in Table 1. From September 1985 to September 1986 there were several intense rainfall events, the highest being 49.5 mm/hr for 1 hr. The average intensity of 38 rainfall events with more than 10 mm/hr was 21.1 mm/hr. Runoff and erosion will be quantified in the coming years and related to rainfall intensity. Several of the storms measured during the 13-month period produced soil and water erosion in areas where the soil was bare (furrows) despite slopes of less than 1%. This could create problems under continuous cropping if proper soil management is not used, such as conservation tillage, green manures, leaving residues on the surface, or using cover crops.

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## Experiment 3: Water Balance (Y-112)

**Objective**

The objective of this experiment is to better understand soil-water relationships under no-till and minimum-till planting practices.

**Procedures**

A detailed water balance model will be developed for several of the tillage systems described in Y-113. Soil water content at 10-15 cm depth intervals in the crop rooting zone will be monitored periodically during the corn-growing season by neutron probe and tensiometers, which are located 30 and 60 cm below the rooting zone. The flux of solutes below the soil root zone will be monitored using a suction lysimeter. Runoff will be evaluated with runoff plots.

**Results**

Data are not yet available.

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## Experiment 4: Soil Trafficability (Y-111)

Intensive continuous cropping using improper mechanization in the humid tropics often results in a decline of crop yields and soil degradation. This is the result of using machinery under inappropriate soil moisture conditions.

**Objectives**

The objectives of this experiment are 1) to examine soil compaction caused by tractor passes on an Ultisol in the Amazon Basin that has varying water contents, and 2) to detect the effects or quantify the reduction in corn yields that one might anticipate from compaction.

**Procedures**

The experimental area was in a sandy loam soil that has been continuously cropped since August 1980. The whole area was treated with herbicide, and lime and P were incorporated with a disk harrow.

**Table 1. Record of high intensity (>10 mm/hr) storms at Yurimaguas Station during September 1985 to September 1986.**

| Date | Time | Time interval | Rainfall | Intensity | Monthly rainfall | Monthly rainfall |
|---|---|---|---|---|---|---|
| | | minutes | mm | mm/hr | % | mm |
| **1985** | | | | | | |
| **September** | | | | | | 249.0 |
| 6 | 3PM-4PM | 60 | 22.9 | 22.9 | 9.2 | |
| 25 | 11AM-2PM | 180 | 148.6 | 49.5 | 59.6 | |
| **October** | | | | | | 160.3 |
| 14 | 3AM-5AM | 120 | 27.9 | 14.0 | 17.4 | |
| 23 | 8AM-9AM | 60 | 14.2 | 14.2 | 8.9 | |
| **November** | | | | | | 198.0 |
| 1 | 6:45AM-8AM | 75 | 13.9 | 11.1 | 7.0 | |
| 5 | 2PM-3PM | 60 | 12.7 | 12.7 | 6.4 | |
| 6 | 6AM-9AM | 180 | 33.0 | 11.0 | 0.2 | |
| 6 | 4:15PM-5:45PM | 90 | 31.8 | 21.2 | 16.1 | |
| **December** | | | | | | 99.8 |
| 7 | 4PM-5PM | 60 | 17.1 | 17.1 | 17.1 | |
| 8 | 1AM-2AM | 60 | 15.2 | 15.2 | 6.4 | |
| 13 | 12:30AM-2AM | 90 | 22.2 | 14.8 | 22.2 | |
| **1986** | | | | | | |
| **January** | | | | | | 180.9 |
| 20 | 1:30PM-4:15PM | 165 | 54.6 | 19.9 | 30.2 | |
| 24 | 2PM-3PM | 60 | 47.0 | 47.0 | 26.0 | |
| 28 | 12PM-3:30PM | 210 | 35.6 | 10.1 | 19.7 | |
| **February** | | | | | | 264.7 |
| 5 | 1:30PM-3PM | 90 | 71.1 | 47.4 | 26.9 | |
| 7 | 6:30AM-8AM | 90 | 20.3 | 13.5 | 7.7 | |
| **March** | | | | | | 403.0 |
| 3 | 9:30AM-10:30AM | 60 | 12.7 | 12.7 | 3.2 | |
| 6 | 9:45AM-11:15AM | 90 | 49.5 | 33.0 | 12.2 | |
| 18 | 8:30AM-10AM | 90 | 54.6 | 36.4 | 13.5 | |
| 23 | 10AM-12AM | 120 | 55.9 | 28.0 | 13.9 | |
| **April** | | | | | | 273.6 |
| 12 | 11AM-12AM | 60 | 13.0 | 13.0 | 4.8 | |
| 15 | 6AM-8AM | 120 | 25.4 | 12.7 | 9.3 | |
| 27 | 1:30PM-3:30PM | 120 | 64.8 | 32.4 | 23.7 | |
| **May** | | | | | | 196.0 |
| 7 | 2PM-3PM | 60 | 46.9 | 46.9 | 24.0 | |
| 22 | 5:15AM-8:30AM | 195 | 37.5 | 11.5 | 19.1 | |
| **June** | | | | | | 36.9 |
| 10 | 1:30PM-2:30PM | 60 | 21.6 | 21.6 | 58.5 | |
| **July** | | | | | | 173.7 |
| 1 | 11PM-12PM | 60 | 19.1 | 19.1 | 11.0 | |
| 17 | 12PM-1AM | 60 | 39.4 | 39.4 | 22.7 | |
| 21 | 1PM-2PM | 60 | 19.1 | 19.1 | 11.0 | |
| **August** | | | | | | 233.2 |
| 1 | 1AM-3AM | 120 | 24.1 | 12.1 | 10.3 | |
| 5 | 1AM-2AM | 60 | 12.7 | 12.7 | 5.4 | |
| 12 | 10AM-11AM | 60 | 14.0 | 14.0 | 6.0 | |
| 18 | 12AM-1AM | 60 | 12.7 | 12.7 | 5.4 | |
| 18 | 4AM-5AM | 60 | 33.2 | 33.2 | 14.2 | |
| 27 | 2AM-4AM | 120 | 25.4 | 12.7 | 10.9 | |
| 30 | 3PM-4PM | 60 | 14.0 | 14.0 | 6.0 | |
| **September** | | | | | | 92.7 |
| 5 | 9AM-10AM | 60 | 12.7 | 12.7 | 13.7 | |
| 10 | 6AM-8AM | 120 | 20.3 | 10.1 | 21.9 | |

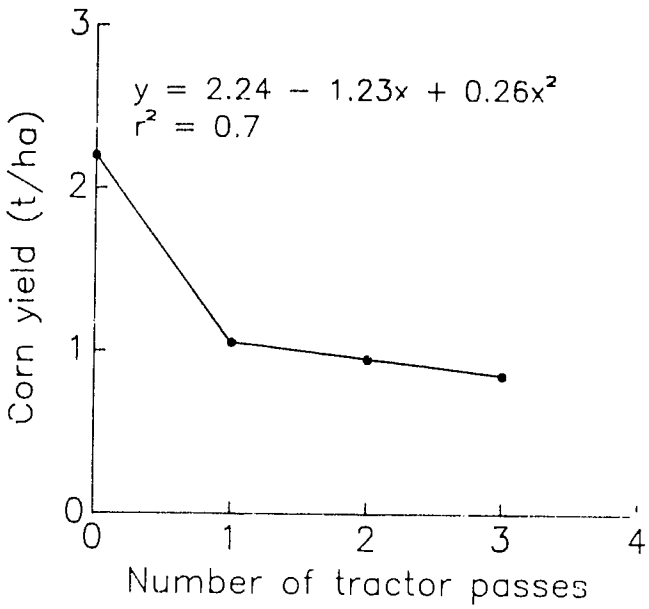


**Figure 1. Effect of tractor passes on corn yield, with 36% soil water content (quadratic regression).**

The experimental design was split-plot with three soil moisture contents (20, 27 and 36% by volume) as main plots and zero to three tractor passes (using a Kubota 65 HP with disk harrow) as subplots. Corn was planted on the wheel track with a planting stick (0.75 x 0.20 m).

## Results

Soil bulk density after tractor passes under different soil moisture contents is shown in Table 2. The greatest increase occurred after one tractor pass at the highest soil moisture content; there was not much change with subsequent passes.

The increase of bulk density caused a 10% reduction in total porosity. The same pattern occurred for corn yields, with a 50% reduction in yield (Table 3) with only one pass of the tractor at 36% by volume soil moisture content. In the treatment with lower water content (27 to 20% by volume), there were no significant changes under different tractor passes. For the 36% water content by volume the relationship between corn yield and tractor passes was a quadratic regression (Figure 1). As the number of passes increased, corn yields were reduced. For one and three tractor passes, there was a linear regression between corn yield and different soil moisture contents (Figure 2). As soil moisture increased, corn yields were reduced linearly ($r^2 = 0.99$).

The depth of wheel track below the soil surface as a function of the number of tractor passes is shown in Figure 3. The depth of wheel track was greatest at the highest soil moisture content with only one pass of the tractor; then no significant differences occurred with two or three tractor passes. For the 27% (field capacity) soil water content, three additional tractor passes were imposed (four, five and ten passes). We can see that with ten passes the depth of wheel track below the soil surface was similar to that with one pass under the highest soil water content.

**Table 2. Bulk density after tractor passes under different soil moisture contents (Y-111).**

| | Tractor passes | | | | |
|---|---|---|---|---|---|
| **Soil moisture** | **0** | **1** | **2** | **3** | **Mean** |
| (% by volume) | Bulk density (g/cc) | | | | |
| 36 | 1.33 | 1.57 | 1.58 | 1.59 | 1.52 |
| 27 | 1.35 | 1.46 | 1.52 | 1.56 | 1.47 |
| 20 | 1.36 | 1.42 | 1.49 | 1.50 | 1.45 |
| Mean | 1.35 | 1.48 | 1.53 | 1.55 | |

$LSD_{0.05}$ Soil moisture = 0.04
Tractor passes = 0.04
Two soil moistures in same tractor pass = 0.07
Two tractor passes in same soil moisture = 0.07

**Table 3. Corn grain yield as affected by soil moisture content and tractor passes (Y-111).**

| | Tractor passes | | | | |
|---|---|---|---|---|---|
| **Soil moisture** | **0** | **1** | **2** | **3** | **Mean** |
| (% by volume) | Grain yield (t/ha) | | | | |
| 36 | 2.28 | 1.13 | 0.93 | 0.81 | 1.29 |
| 27 | 2.61 | 2.14 | 2.33 | 1.91 | 2.25 |
| 20 | 2.48 | 2.83 | 2.12 | 2.44 | 2.47 |
| Mean | 2.46 | 2.03 | 1.79 | 1.72 | |

$LSD_{0.05}$ Soil moisture = 0.64
Tractor passes = 0.38
Two soil moistures in same tractor pass = 0.66
Two tractor passes in same soil moisture = 0.85

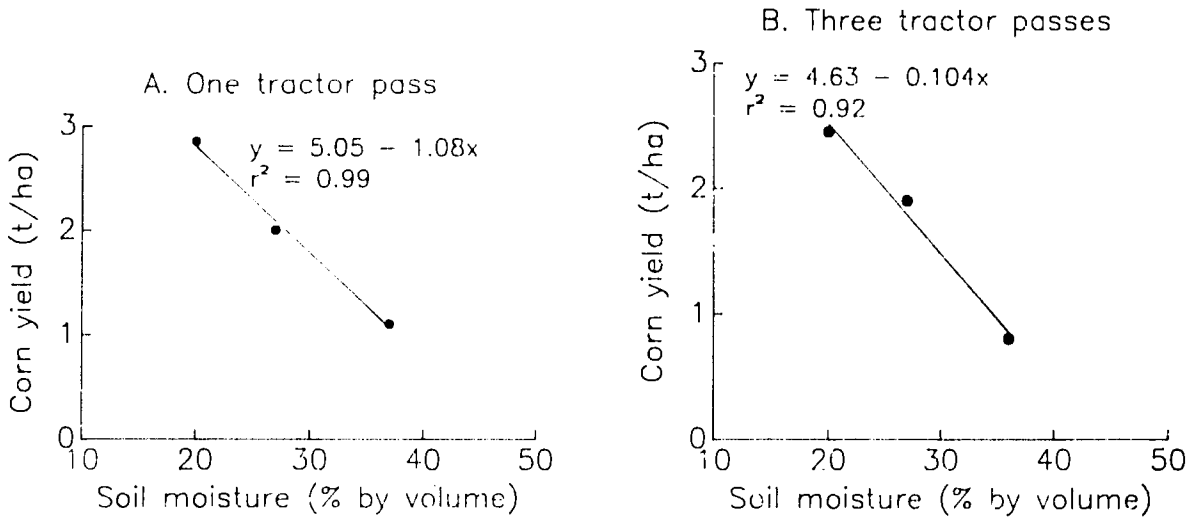


**Figure 2. Effect of soil moisture on corn grain yield for one and three tractor passes.**

## Conclusions

One tractor pass under the highest soil moisture content caused deeper wheel tracks, soil compaction and a 50% reduction in corn yield. One tractor pass under soil moisture contents at 20% and 27% by volume did not significantly reduce crop yields from the treatment without a tractor pass.

## Implications

Tillage management in humid tropical Ultisols depends on many aspects, among which rainfall intensity and the number of tractor passes are critical. Rainfall intensities should be compared with other tropical and temperate regions. The compaction by one tractor pass is important.

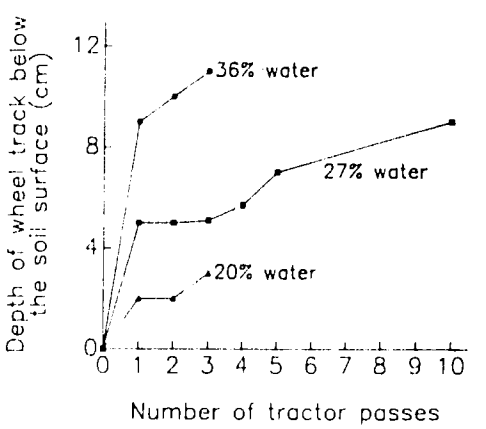


**Figure 3. Effect of tractor passes on the depth of wheel track below the soil surface (Kubota 65 HP tractor with disk harrow). Percentage of $H_2O$ by volume.**

# Conventional Tillage Under Continuous Cropping

*Julio C. Alegre, N. C. State University*
*Andres Aznarán, INIPA*

Two advantages of deep plowing (to 20-25 cm) have been demonstrated during the last two years: conventional tillage with tractor-mounted farm equipment was superior to shallow tillage with hand rototillers; banding P was superior to broadcasting when Zn was applied (*TropSoils Technical Report 1985-1986*). Despite these advantages, some of the equipment available at that time was not efficient. For example, the variability in seed made it difficult for the seed sorter to maintain a constant population of corn. In addition, the spectrum of seed plates for the planters was inadequate for the size of seeds available. There was not a good row bedder, bed shaper or subsoiler. Moreover, rototillers can severely damage soil structure.

In January 1986 new no-till equipment arrived in Yurimaguas:

1. An extend rip, no-till tool bar equipped for three-row capability. Two-row subsoiler (20-40 cm).
2. Two-row bedder equipment to be attached to the same tool bar in lieu of the no-till equipment. A 10 x 10 cm tool bar to which bedders can be attached. This bedder tool bar can be coupled either through a parallelogram linkage or through an alternative shorter linkage.
3. Three planters equipped for corn, soybean, cowpea, sorghum or peanut. The seed planters are designed to reduce seedbed crusting and compaction. Seed depth adjustments are easily made with a system that features a range of depth settings from 0 to 10 cm.
4. An extra three-point hitch, which permits use of the planters separately from the other tillage equipment.
5. An extra set of narrow, fluted coulters for use in no-till where subsoiling is not done.
6. A bed shaper designed to leave two shaped beds about 10 cm high. The bed shaper can also be used as a simple bed knocker to flatten off the top of the bed to any height desired.
7. S-tyne field cultivator with crumbler bars.
8. Fertilizer distributor boxes (Soda Flo applicator, for banded application).
9. Gandy spreader for broadcast application.
10. John Deere moldboard plow.

### Objective

The objective of this experiment is to use subsoiler and beds to break compacted soil and thus provide better root development and higher yields in continuous cropping systems.

### Procedures

Using different field-preparation methods as treatments, an experiment was designed to compare crop yields in an area (Chacra VII, Yurimaguas, Peru) cleared by bulldozer in 1980 and thereafter continuously cropped. Soil compaction was detected below the 10-cm depth, with cone penetrometer resistance (vertical cone penetrometer) greater than 15 kg/cm$^2$ and average bulk density of 1.55 g/cm$^3$.

The soil is a Typic Paleudult in the Yurimaguas Experiment Station. Two tons of lime, 100 kg $P_2O_5$ (only TRs 1, 2, 3 and 4), 4 kg Zn and Cu, and 2 kg B were incorporated in the whole plot with a disk harrow. The remaining vegetation was burned with paraquat.

The experiment is a complete randomized block design with six treatments and four replications. Plot size is 20 x 6.5 m. The treatments are:

1. Bedding, subsoiling: beds of 0.8-m spacing with subsoiling at the 30-cm depth in one tractor pass, then bed shaper and planting corn in another tractor pass. Herbicide (Dual) weed control after planting.
2. Bedding: similar to (1) without subsoiler.
3. Flat planted, subsoiling: subsoiling at 0.8 m spacing and the 30-cm depth in one tractor pass, then planting corn in another tractor pass. Herbicide (Dual) weed control after planting.
4. Flat planted: similar to (3) without subsoiler.
5. Bedding, subsoiling with banded P: similar to (1), and P was banded at planting time using a Soda Flo applicator.
6. Beds with banded P: similar to (2) and P was banded at planting time with a Soda Flo applicator.

In treatments 1, 2, 3 and 4, the P was broadcast before planting.

At the corn flowering stage, root biomass will be evaluated at three depths (0-15, 15-30, 30-60 cm)

between rows. Before the harvest of each crop, bulk density and soil water characteristics will be determined at the 0-10 and 10-20 cm depths. Penetrometer resistance and soil moisture will be measured at the 0-60 cm depth.

### Results

Corn grain and stover yield and plant height for the different treatments are shown in Table 1. There was no significant response to subsoiling for grain and stover. The only response was found for banded P, which, when it was bedded and subsoiled (TR5), gave higher grain yields and plant height than broadcast P (TR1). The lack of response to subsoiling was due to the high rainfall period during the corn-growing season, when most of the time the soil was wet. Soil moisture contents were greater than field capacity.

We expect a response to subsoiling in the drier periods. The next crop will again be corn.

### Implications

Suitable equipment is necessary for continuous cropping systems in this humid tropical area because, although soils are very similar to those in the southeastern United States, the annual rainfall is about double.

**Table 1. Corn grain and stover yield and corn height as affected by tillage treatments.**

| Treatment* | Grain | Stover | Plant height |
|---|---|---|---|
| | —— t/ha —— | | m |
| 1. Bedding-subsoiling | 3.54 | 5.00 | 2.50 |
| 2. Bedding | 3.44 | 4.80 | 2.64 |
| 3. Flat-subsoiling | 3.43 | 4.11 | 2.60 |
| 4. Flat | 3.40 | 4.53 | 2.64 |
| 5. Bedding-subsoiling-banded P | 4.06 | 4.52 | 2.77 |
| Flat-subsoiling-banded P | 3.82 | 4.14 | 2.72 |
| $LSD_{0.05}$ | 0.50 | 1.39 | 0.17 |

* P was broadcast in Treatments 1 to 4.

## Central Continuous Cropping Experiment

*Julio C. Alegre, N. C. State University*
*Pedro A. Sanchez, N. C. State University*

### Objective

The objective of this study is to maintain a demonstrative fertilizer-based continuous cropping system with sound physical and chemical soil management in acid soils of the humid tropics.

### Procedures

The long-term experiment in Chacra I, Yurimaguas, Peru, with seven fertility management treatments under the rotation rice-corn-soybean, originally occupied eight 10 x 28 m blocks with treatments in seven 4 x 10 m plots. In 1986 this experiment was reduced to four 10 x 28 m blocks, in which only the treatment without fertilizer or lime application (TR1) and the treatment with complete fertilization (TR3) were used to evaluate the 32nd and 33nd crops. These plots will also be used to evaluate successive crops, using the rotation corn-soybean. All other plots will be fertilized and limed at levels equal to treatment TR3 (complete, according to the soil test).

The 32nd crop was soybean (cv. Cristalino), planted at a spacing of 75 x 20 cm; 1 t lime/ha, 80 kg $P_2O_5$/ha, 20 kg N/ha (seeds were inoculated with *Rhizobium*) and 100 kg $K_2O$/ha were applied. Residues from the previous corn crop were chopped with a bush-hog, disked, chiseled at the 30-cm depth, and rototilled; the crop was planted with a row planter. The 33rd crop was corn (cv. Marginal 28), planted with new equipment for conventional

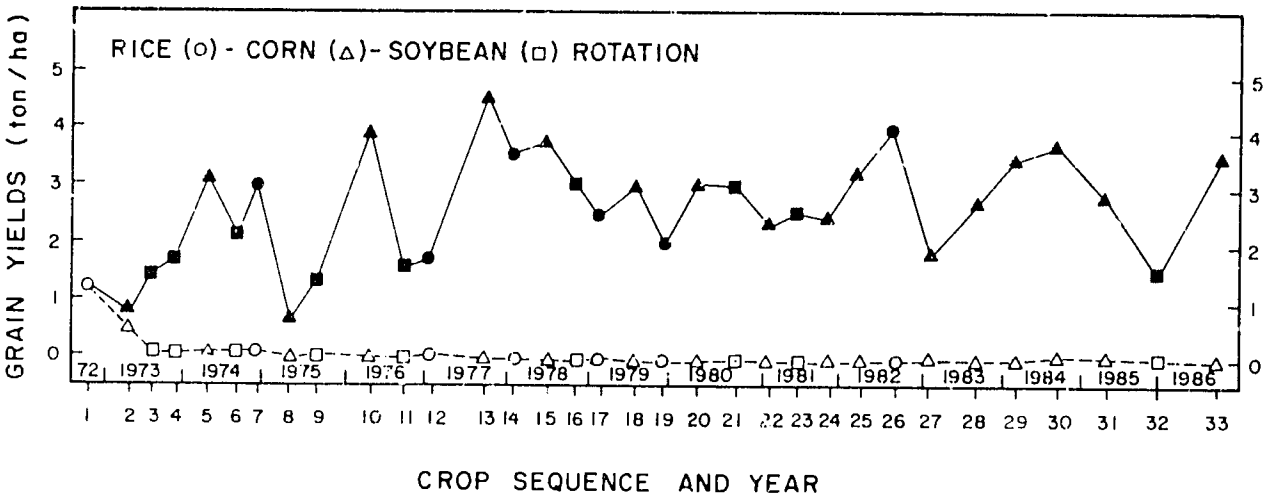


**Figure 1. Crop yields in the continuous cropping experiment.**

planting; 1 t of lime/ha, 4 kg Cu/ha and 4 kg Zn/ha were applied and incorporated with a disk plow. Field preparation proceeded with four more tractor passes, followed by an S-tyne field cultivator, a disk bedder at 90 cm between beds, and a disk shaper and planter simultaneously. The herbicide Dual was applied at the rate of 2 L/ha.

## Results

Yield for the 32nd crop was 1.5 t/ha of soybean for the complete treatment and no yield for the check plot (Figure 1). Average yield for the 33rd crop was 3.5 t/ha of corn. Some plots damaged by insects and herbicide were not evaluated. Long-term yield trends with time are shown in Figure 2 for individual crops.

## Implications

The continuous cropping system remains stable into its 13th year of operations.

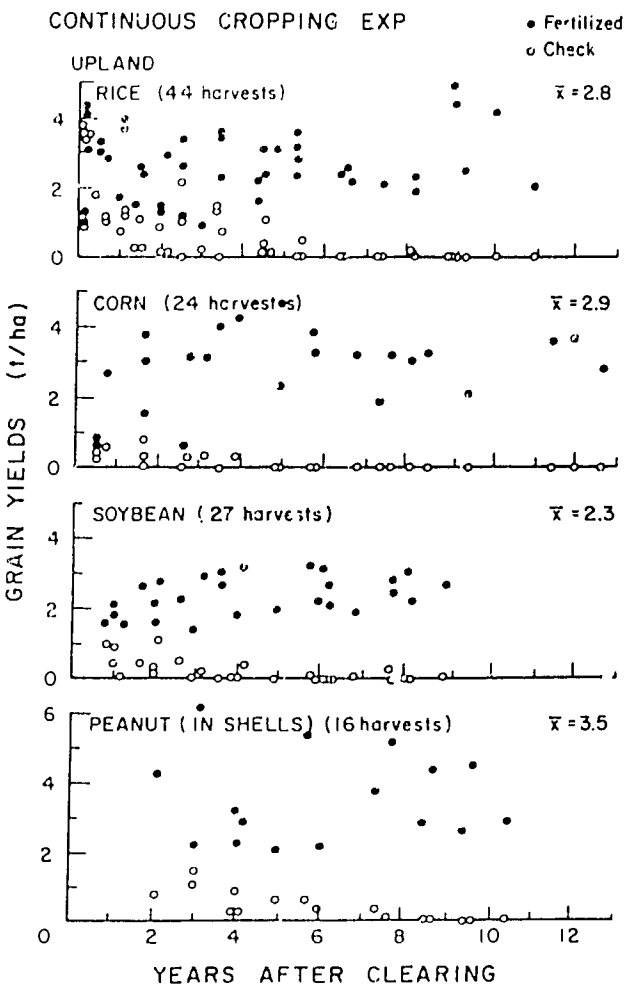


**Figure 2. Long-term yield patterns for individual crops, 1972-1985.**

# Nitrogen Carryover in Rotation And Strip-Intercropping Systems

*José R. Benites, N. C. State University*
*Robert E. McCollum, N. C. State University*
*Mary C. Scholes, N. C. State University*

Corn is one of the most important crops of the Amazon Basin; generally, however, it is intercropped under shifting cultivation and produces low yields. Usually corn is interplanted with rice, cassava and plantain in a seemingly random way. One of the soil management alternatives used to increase corn production is continuous cropping with crop rotation, judicious fertilizer and lime applications, and mechanizatio

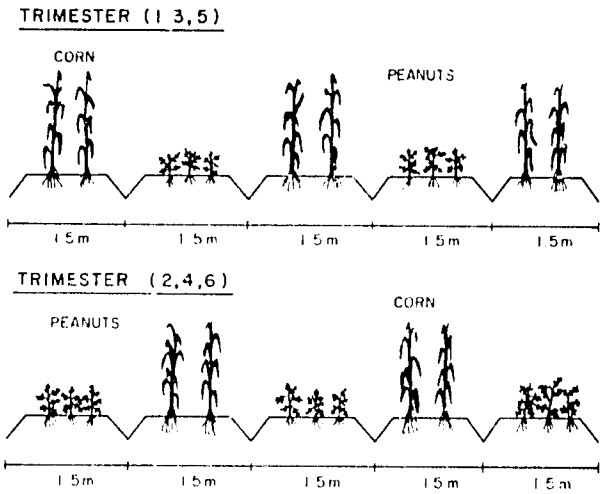


**Figure 1. Planting pattern of corn and peanuts in the strip-intercrop system, Yurimaguas, Peru.**

## Objectives

The objectives of this study are 1) to compare productivity efficiency of a corn/peanut strip-intercrop with monocultures of those intercrop components in rotation with continuous corn, and 2) to determine the effect of N fertilization on cropping system efficiency.

**Table 1. Cumulative crop grain yields during six biological cycles of corn grain and peanut as influenced by applied nitrogen and cropping system.**

| Cropping system (CRPGS) | Crop trimester | Crop syst. duration | N rates (kg N/ha) 0 | 100 | 200 |
|---|---|---|---|---|---|
| | | days | t/ha | | |
| **Strip Intercrop** | | | | | |
| C/P | Corn 1 to 6 | 690 | 7.33 | 13.42 | 14.42* |
| | Peanuts 1 to 6 | | 2.80 | 2.17 | 2.42** |
| **Sequential monocultures** | | | | | |
| C —> P | Corn 1, 3, 5 | 688 | 4.80 | 10.09 | 10.35 |
| | Peanuts 2, 4, 6 | | 2.68 | 2.74 | 2.73 |
| P --> C | Corn 2, 4, 6 | 683 | 7.45 | 12.76 | 14.01 |
| | Peanuts 1, 3, 5 | | 4.53 | 4.93 | 4.56 |
| C —> C | Corn 1 to 6 | 684 | 10.60 | 22.80 | 23.28 |

$LSD_{0.05}$ Corn: Systems = 0.98, N = 0.85, Systems x N = 1.69
Peanuts: Systems = 0.14, N = 0.14, Systems x N = 0.25

* Corn yield grain at 15.5% moisture.
** Peanut shelled grain yield air-dried.

## Procedures

A field experiment was planted in Yurimaguas in 1983 on a fine, loamy, silicious, isohyperthermic Typic Paleudult. The strip-intercrop system was planted by machine and consisted of two 75-cm rows of corn and three 38-cm rows of peanuts, then two rows of peanuts and three rows of corn (Figure 1). This alternating row arrangement permitted the intercrop to be grown as a corn-peanut-corn rotation. The idea of this arrangement was to maximize the N contribution from the residual N of peanut to the following corn crop.

The strip intercropping system was compared with a sequential cropping system also using a corn-peanut rotation. In this case, the entire plot was planted at 25 x 75 cm, and, in the following cycle, after corn was harvested, the peanut was planted at 25 x 38 cm. All the nutrients and lime except N were added at the recommended rate; N was the variable at the rates of 0, 100 and 200 kg/ha, applied only to corn and never to peanut.

## Results

*Grain yields*

Total yields during the six crop cycles are shown in Table 1. Duration of the cropping systems was approximately two years, and the cumulative yields of corn and peanut were measured at different rates of N application.

Continuous corn (Table 1) showed a sharp yield response from 0 to 100 kg N/ha and no response beyond that point on the total cumulative yield of six crops, with an average yield of 3.8 t/ha per crop. Strip-intercrop yields were much lower, mainly because the system was working at half the population. It is interesting to note, however, that the maximum response for N was at the same level. Even with no N, intercropped corn produced about 69% of its monoculture check (Table 2). Yield of interplanted peanut was severely reduced by the presence of corn. When averages over six cycles were taken, the intercropped peanut produced 33% of its monoculture check with 200 kg N applied to corn (Table 2).

Peanut plants were severely affected by *Cercospora* leaf spot during the second, fourth and sixth cycles, and the detrimental effect of this pathogen was more pronounced in strip-intercropping and less severe in the sequential cropping system.

The effectiveness of the strip-intercropped system using the area-time equivalent ratio (ATER) is shown in Table 3. Comparing means of the six crop cycles in terms of N applied to the corn, we see that the corn/peanut strip intercrop without N used area and time 7% more efficiently than monocultures. But it was less efficient (ATER less than 1.0) where N fertilizer was applied.

Yields expressed in terms of caloric yields (Mcal/ha/year) are shown in Table 4. Caloric production at the zero level of N was greater in the corn-peanut rotation and the corn/peanut intercrop than in continuous corn. However, as soon as fertilizer was added, the efficiency of the mixed systems was reduced, whereas the efficiency of the monoculture was greatly increased.

*Nitrogen contribution*

One way to estimate N contribution is simply to look at corn yields as a function of N, comparing when corn was preceded by peanut with when corn was preceded by corn.

In the second corn crop, which was preceded by a

**Table 2. Relative yield (as percentage of sole crop yield) of intercropped corn and peanut during six cycles (23 months).**

| Cropping system | Crop | N rates (kg/ha) 0 | 100 | 200 |
|---|---|---|---|---|
| | | % | | |
| Strip–intercrop | | | | |
| | Corn | 69 | 59 | 61 |
| | Peanut | 39 | 28 | 33 |

**Table 3. Effect of nitrogen fertilization on corn in a corn/peanut intercrop on area-time equivalency ratio (ATER) during six biological cycles.**

| N applied to corn | ATER |
|---|---|
| kg/ha | |
| 0 | 1.07 |
| 100 | 0.87 |
| 200 | 0.92 |
| $LSD_{0.05}$ | 0.12 |

**Table 4. Effects of nitrogen fertilization and cropping system on caloric yield.**

| Cropping system (CRPGS) | N fertilization (NR) (kg/ha) 0 | 100 | 200 | CS mean |
|---|---|---|---|---|
| | Mcal/ha/yr | | | |
| Cont. corn | 39.37 | 83.57 | 85.33 | 69.43 |
| Corn-peanut rotation | 43.74 | 64.63 | 66.23 | 58.20 |
| Corn/peanut intercrop | 43.22 | 61.61 | 65.62 | 56.82 |
| N Mean | 42.11 | 69.94 | 72.39 | |

$LSD_{0.05}$ NR = 3.69, CRPGS = 3.92, CRPGS x NR = 6.79

* Caloric conversions, as calories per kg of commercial product, were as follows: corn = 3432; peanuts = 5590.

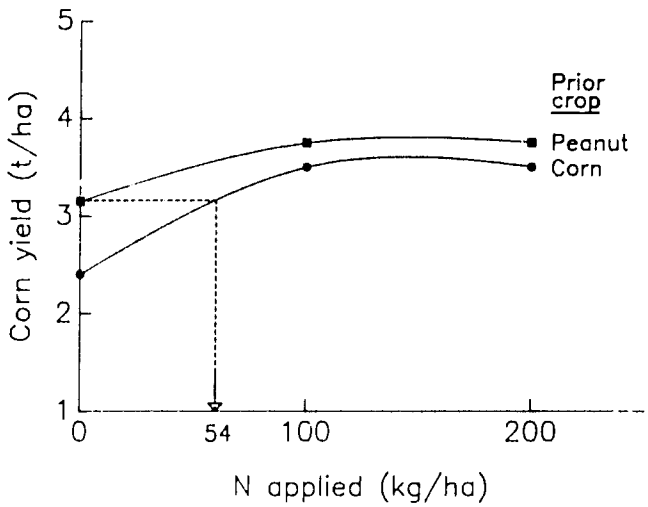


**Figure 2. Apparent N carryover from preceding peanut crop to subsequent corn crop. Second cycle, good peanut yield.**

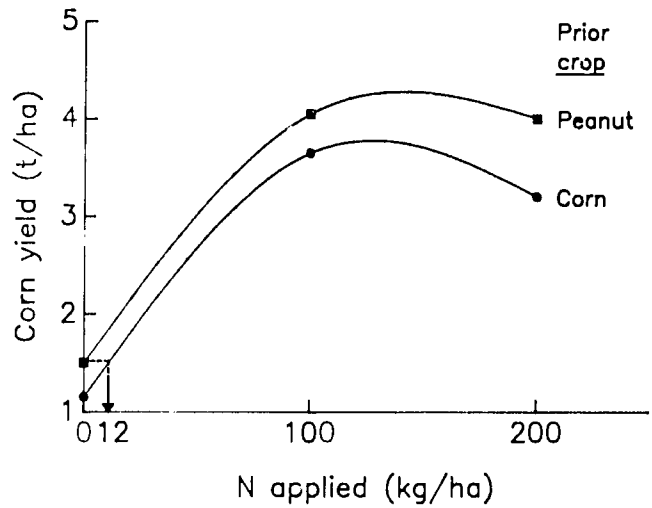


**Figure 3. Apparent N carryover from preceding peanut crop to subsequent corn crop. Fifth cycle, poor peanut yield.**

particularly good crop of peanut at zero level of N, corn yield when preceded by a peanut crop was higher than when preceded by continuous corn (Figure 2). Extrapolating that high yield to the continuous corn, we obtain an estimate of N contribution of 54 kg N/ha. In the fifth corn crop, in which the preceding peanut yield was very poor because of the *Cercospora* problem and perhaps bad weather, the contribution of N was very low (12 kg N/ha) (Figure 3). Over six crops, an average N contribution of 28 kg N/ha was obtained (Figure 4).

*N mineralization, uptake and recovery*

Residues of peanuts and corn were incorporated before planting the last corn crop in the corn-peanut rotation and the continuous corn systems; both systems had N rates of 0 and 200 kg/ha. The C/N ratio of the residues in peanuts was lower than the C/N ratio of corn (Table 5). It is interesting to note that residues of corn grown with 200 kg N/ha had a lower C/N than corn grown with zero N, simply because at 200 kg corn develops a higher N content in relation to its total biomass formed.

The double-tube method of Raison et al. is an experimental way to estimate *in situ* N mineralization used in this experiment on a trial basis. This measurement was taken at intervals of 14 days during the vegetative growth stage to the silking stage for a total of 56 days. Peanut residue at the zero level of N had a slight N mineralization of 3 µg N/g soil/14 days. When the same residue was used with 200 kg N/ha, some N was immobilized, expressed by a negative value of net N mineralization (Table 5). With corn residue, at the zero N level N was apparently immobilized. Adding 200 kg N/ha resulted in a net mineralization of 34 µg/g soil/14 days (Table 5).

Grain yield was definitely greater when peanut was the preceding crop at both fertilization levels (Table 5). These yields are reflected in higher N uptake, especially when peanut was the source of residues (Table 5). Nitrogen recovery was also higher when peanut was the preceding crop than when corn was (Table 5).

## Conclusions

The strip-intercropping system has some interesting conceptual and practical advantages, especially at low N rates. Conceptually it seems reasonable to alternate between the cereal and the legume crops for maximum N recovery. However, yields were not significantly better than those in the sequential cropping system.

The overall provision of peanut-crop residues to the following crop of corn was in the order of 28 kg N/ha. Preliminary values of *in situ* N mineralization must be validated by subsequent trials.

## Implications

This corn-peanut strip-intercrop is one of the few intercropping systems that can be fully mechanized. Perhaps higher yields could be obtained by having a better planting pattern, with corn and peanuts at the same population rates as the sequential monocultures.

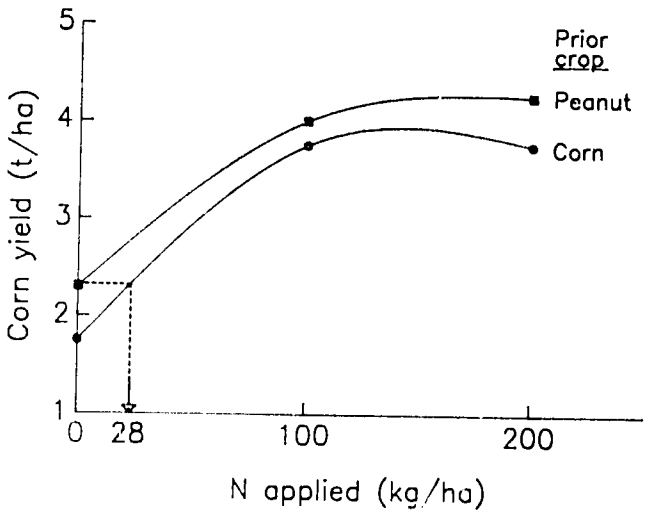


**Figure 4. Apparent N carryover from preceding peanut crop to subsequent corn crop. Pooled values over six cycles.**

**Table 5. Effects of fertilizer N and two incorporated residue sources on N mineralization, corn yield, N uptake and N recovery during the sixth corn crop.**

| Residue source | C/N | N applied | N min.* | Grain yield | N uptake | Apparent N recovery |
|---|---|---|---|---|---|---|
| | | kg/ha | µg/g soil/ 14 days | t/ha | kg/ha | % |
| Peanut | 19 | 0 | 2 | 2.01 | 42 | - |
| Peanut | 20 | 200 | -1 | 5.93 | 131 | 45 |
| Corn | 33 | 0 | -50 | 1.75 | 38 | - |
| Corn | 23 | 200 | 33 | 5.46 | 109 | 34 |
| $LSD_{0.05}$ | 1.56 | 49 | 24 | | | |

* Method by Raison et al. (1987): A negative value of net N mineralization means immobilization or denitrification. Preliminary estimates due to untested methodology.

# Maintenance of Phosphorus Fertility Under Continuous Cropping

*Luis A. Arévalo, INIPA*
*Fred R. Cox, N. C. State University*

The representative soils of a large portion of the Peruvian Amazon jungle basin are fine loamy, siliceous, isonyperthermic Typic Paleudults. They are well-drained and quite acid, with a high percentage of Al saturation, deficiency in exchangeable cations, and deficiency in P, although they are not high P fixers due to their coarse topsoil texture.

Because these soils are deficient in available P in their native state, they require P fertilizer for optimum crop yield. Knowledge of each crop's critical level of P is needed, which requires soil fertility evaluation for each crop grown.

## Objectives

The objectives of this study are 1) to determine the effect of P fertility and time on extractable soil P concentration; 2) to determine the critical soil P level for corn, soybean and peanut grown under mechanized soil management; 3) to determine the critical soil P level for rice and cowpea grown under unmechanized soil management; 4) to determine the rate of P that must be included in fertilization to maintain an adequate level of soil P; 5) to evaluate the effect of soil P concentration on Zn uptake and translocation; and 6) to test the model developed by determining the annual banded P rate necessary to maximize yields.

## Procedures

Three experiments for tilled soil and one for no-till soil were initiated in October 1985 in Chacra II, Yurimaguas, Peru. Soil samples were collected before establishing treatments.

In the first experiment, referred to here as Y-114A, the treatments were 0, 75, 150 and 300 kg P/ha; the source of P was triple superphosphate. These experiments had six replications on 6 x 12 m plots. The field received 3 t dolomitic lime per ha. Lime and P were applied in split applications—the first dose before plowing; the second dose after plowing and harrowing. Two more passes with the harrow will follow, after which corn will be planted. No further lime, P, Zn or Cu were applied to this study. Corn (cv. Marginal 28) was planted in October 1985 at 70 cm between rows and 20 cm within the row. Tissue and soil samples were taken at early flowering of corn. The corn was harvested in February 1986.

Experiment Y-114B was designed to evaluate the residual P status of the first three replications of the current plot in Chacra II. The old plots were located and cropped with the same restrictions as in the first experiment. This study received 3 t dolomitic lime per ha and no further lime, P, Zn or Cu will be applied.

Experiment Y-114C had the following P rate treatments: 0, 7, 14 and 21 kg P/ha as TSP banded 10 cm to the side and 10 cm below the seed as each crop was planted. General soil conditions, other fertiliza-

**Table 1. Variations in the quantity of available phosphorus and zinc in the soil (modified Olsen) due to the application of phosphorus.**

| | Avail. P | | Avail. Zn | |
|---|---|---|---|---|
| P applied | Before installation* | After treatment** | Before installation* | After treatment** |
| kg/ha | ppm | | | |
| | | Y-114A | | |
| 0 | 5.9 | 5.45 | 1.57 | 0.70 |
| 75 | 6.2 | 13.12 | 1.38 | 1.23 |
| 150 | 6.5 | 23.58 | 1.47 | 1.08 |
| 300 | 6.0 | 56.68 | 0.92 | 0.72 |
| | | Y-114C | | |
| 0 | 9.2 | 8.03 | 1.30 | 0.90 |
| 7 | 10.1 | 9.47 | 1.63 | 1.40 |
| 14 | 8.2 | 10.40 | 1.27 | 1.03 |
| 21 | 6.8 | 13.43 | 1.00 | 0.97 |
| | | Y-114D | | |
| 0 | 7.6 | 7.76 | 1.28 | 1.30 |
| 37.5 | 7.6 | 8.90 | 1.34 | 1.22 |
| 75 | 8.5 | 13.18 | 0.74 | 1.22 |
| 150 | 8.0 | 13.80 | 1.34 | 1.14 |

* Contents of P and Zn in the soil before installation of the experiment (10-1-85).
** Contents of P and Zn in the soil after treatment applications at early flowering of the crops (1-30-86).

tion, liming and crops were the same as for Y-114A and B in the same field. Corn planted in October 1985 was harvested in February 1986; soybean was planted in May 1986 and harvested in September 1986 with the same restrictions as for the corn.

Experiment Y-114D was a low-input study with rock phosphate to supply 0, 35.5, 75 and 150 kg P/ha. After P was applied, it was incorporated with a hand tractor (Ferrari, 9 HP); immediately rice (cv. Africano desconocido) was planted at 50 cm between rows and 25 cm within the row in October 1985. This experiment had five replications on 6 x 10 m plots. No lime, Zn, Cu or further P was applied. Tissue and soil samples were taken at early flowering of rice. Rice was harvested in February 1986; cowpea was planted in May 1986 and harvested in July 1986 with the same restrictions as for the rice.

## Results

*P and Zn contents*

Changes in the quantity of P and Zn in the soil due to the doses of P applied to the soil are shown in Table 1. Currently, we have results of soil sample analyses taken before establishment of the experiment and at early crop flowering.

As expected, P contents in the soil increased in experiment Y-114A and increased slightly in experiments Y- 114C and D. In Y-114C, this was due to the low doses of P applied. In Y-114D, the source of P applied to the soil was rock phosphate of slow solubility, compared to the source of triple superphosphate used for Y-114A and C. It is also possible that due to the low reactivity of the rock phosphate, differences in increase of P content between the treatments of 75 and 150 kg P/ha do not exist. When triple superphosphate was used as a P source, with only 21 kg P/ha, the same quantity of P in the soil was obtained as that obtained with the applications of 75 or 150 kg P/ha applied as rock phosphate.

A slight decrease in available Zn contents (Table 1) can be explained by the absorption of Zn by corn plants at the time of sampling (Table 2).

No differences existed in P concentration in the corn tissues in Y-114C, perhaps because of the low levels of P applied to the soil (Table 2). Phosphorus concentration increased in the rice tissues (Y-114D), according to the levels of P applied to the soil, but in lesser magnitude than the increase in Y-114A.

These data suggest that the antagonism between P and Zn results when the concentration of P in the tissues is high. In addition, it is suggested that rice absorbs less Zn than corn.

**Table 2. Leaf P and Zn concentration in corn (Y-114A and Y-114C) and the first rice (Y-114D) crop in relation to P added.**

| P applied | P | Zn |
|---|---|---|
| kg/ha | % | ppm |
| | **Y-114A** | |
| 0 | 0.25 | 40.05 |
| 75 | 0.39 | 35.45 |
| 150 | 0 42 | 34.41 |
| 300 | 0.46 | 33.67 |
| | **Y-114C** | |
| 0 | 0.25 | 35.96 |
| 7 | 0.25 | 44.20 |
| 14 | 0.26 | 40.94 |
| 21 | 0.26 | 53.10 |
| | **Y-114D** | |
| 0 | 0.08 | 35.96 |
| 37.5 | 0.10 | 31.33 |
| 75 | 0.12 | 33.29 |
| 150 | 0.11 | 35.60 |

*Grain yield*

There have been two harvests of corn and soybean for Y-114 A, B and C and of rice and cowpea for Y-114D (Table 3).

In the first harvest in Y-114A, the response was significant between treatments with highest yields from 150 kg P/ha; below and above that dosage, yields were lower, but between rates of 150 and 300 kg P/ha there were no significant differences. For Y-114C, there were no significant differences between treatments or between replications. Plots that received 21 kg P/ha showed lower yields, even lower than the check plots. In Y-114D, differences were not found between treatments or between replications. Rice yields were below 1 t/ha in 95% of the plots.

## Conclusions

Responses in the three experiments were not related to initial P content in the soil or to P applied as fertilizer. Rather, the low yields and lack of response to P seems related to water stress periods for corn and rice during the vegetation period. The very dry period between December 25, 1985, and January 20, 1986, affected and almost eliminated corn pollination and grain filling. The rice crop had two water stress periods: the first at maximum tillering, and the second at flowering and grain filling. The high variability of the three experiments confirm this idea (CV's ranged from 15 to 70%).

In the second harvest of soybean and cowpea, we did not find differences between treatments or between replications. The lack of response to P seems related to high P content in the soil (Table 1).

These results are only preliminary because the four experiments should be cultivated for many years. Recent budget cuts, however, forced the early termination of this experiment. Nevertheless, initial behavior of applied P in these soils under high- or low-input systems contributes to the scarce data base.

**Table 3. Grain yield related to fertilizer P applied to soil; two harvests.**

| P applied | First harvest | Second harvest |
|---|---|---|
| kg/ha | t/ha | |
| | **Y-114A** | |
| 0 | 0.82 | 1.85 |
| 75 | 0.95 | 2.16 |
| 150 | 2.00 | 2.59 |
| 300 | 1.88 | 2.32 |
| $LSD_{0.05}$ | 0.80 | 0.72 |
| | **Y-114C** | |
| 0 | 1.37 | 1.82 |
| 7 | 1.97 | 2.45 |
| 14 | 1.37 | 1.96 |
| 21 | 0.52 | 1.68 |
| $LSD_{0.05}$ | 1.06 | 1.67 |
| | **Y-114D** | |
| 0 | 0.45 | 1.43 |
| 37.5 | 0.56 | 1.40 |
| 75 | 0.61 | 1.41 |
| 150 | 0.63 | 1.53 |
| $LSD_{0.05}$ | 0.29 | 0.49 |

# Weed Population Shifts In Continuous Cropping

*Jane Mt. Pleasant, N. C. State University*
*Robert E. McCollum, N. C. State University*

In traditional slash-and-burn agriculture, fields are abandoned as weeds begin to dominate food crops, and a forest fallow is the primary agent in weed control. Stable continuous cropping systems require a comprehensive program of weed management, however, and are likely to involve herbicides.

## Objectives

The objectives of this study are 1) to determine which weed-control measures, when used over several cropping cycles, will cause a change in the spectrum of weed species. With intensive chemical control, a few species will become dominant and a different set of control measures will be needed, and 2) to devise effective weed-management programs for high-input, continuous cropping systems in the Amazon Basin.

## Procedures

A split-plot experimental design was used in a rice-corn-soybean-rice-corn-soybean rotation. Weed-control practices in rice were the main plot treatments; methods of weed control in corn and soybean represented subplots. In rice, the herbicides used were propanil and oxadiazon; in corn, metolachlor; and in soybean, metolachlor, sethoxydim and bentazon. In the second year of the experiment, a no-till treatment was introduced in which paraquat was used to kill existing vegetation. In all crops, hand-weeded and check treatments (no weed control) were also included.

## Results

There was a distinct change in the composition of the weed population over time. The average dry weight for several components of the weed population in each cycle of the experiment is shown in Figure 1. The Cyperaceae species, which were relatively important in Cycle 1, disappeared quickly. Grasses dominated throughout the course of the experiment, but the species comprising the grass population changed dramatically. *Digitaria sanguinalis* and *Elucine indica* were the major grasses early in the experiment, but *Rottboelia exaltata* emerged in Cycle 3 as a major weed. By Cycle 6, this single species represented 68% of the weed population.

This change in the weed population was a result of the herbicides applied. Using metolachlor in both

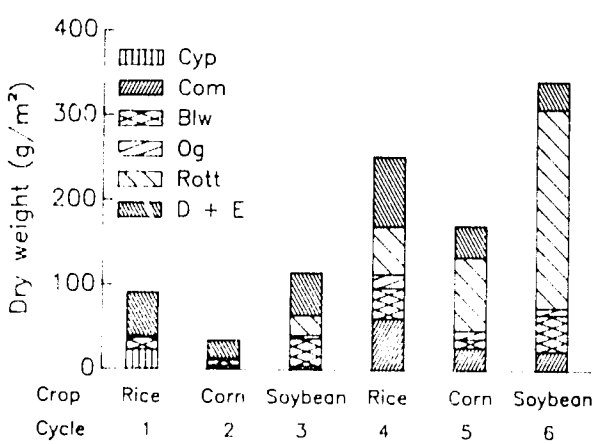


**Figure 1. Mean weed dry weights, averaged over all treatments in six consecutively planted short-season crops. Yurimaguas, 1983-1986. D + E = *D. sanguinalis* plus *E. indica*, Rott = *R. exaltata*, Og = all other grasses except D + E and Rott, Cyp = all Cyperaceae species, Com = all commelina species, Blw= all broadleaf weeds.**

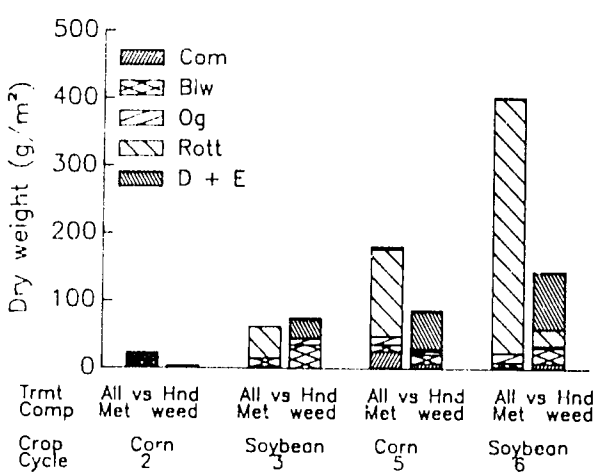


**Figure 2. Comparison of metolachlor-treated plots vs. hand-weeded plots on weed dry weights and population composition in corn and soybean. Yurimaguas, 1984-1986. Rott = *R. exaltata*, D + E = *D. sanguinalis* plus *E. indica*, Og= all other grasses except Rott and D + E, Blw = all broadleaf weeds, Com= all commelina species. All Met= all treatments that received metolachlor.**

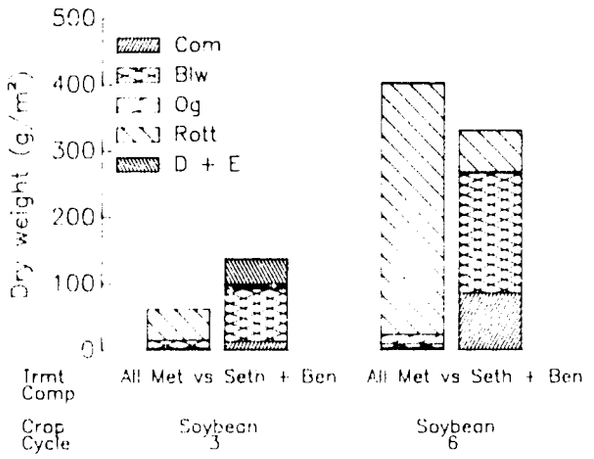


**Figure 3. Comparison of metolachlor vs. sethoxydim + bentazon on weed dry weights and population composition in soybean. Yurimaguas, 1984-1986. Rott = *R. exaltata*, D + E = *D. sanguinalis* plus *E. indica*, Og = all other grasses except Rott and D + E, Blw = all broadleaf weeds, Com = all commelina species. All Met = all treatments that received metolachlor, Seth + Ben = sethoxydim + bentazon.**

corn and soybean resulted in almost pure stands of *R. exaltata* by Cycle 6 (Figure 2). Metolachlor did an excellent job of controlling broadleaf weeds, cyperaceae, commelina, *D. sanguinalis* and *E. indica*; but *R. exaltata* was resistant to this herbicide. Sethoxydim + bentazon applied to soybean resulted in a completely different spectrum of weeds (Figure 3). Sethoxydim controlled all grasses, including *R. exaltata*, but bentazon did not provide sufficient control of broadleaf weeds or commelina.

The data also indicate that effective weed control is critical for attaining high crop yields, and that the three crops vary greatly in their ability to compete against weeds. For all crops except corn, product yields were lower when no weed-control measure was used (Table 1). Rice was especially vulnerable to weed pressure. In Cycle 4, for example, yields were reduced to essentially zero in the absence of weed control.

## Conclusions and Implications

Two years of research have shown that weed populations will change in response to chemical control practices. Species resistant to herbicides dominate with time, and their control becomes increasingly difficult and expensive. Weeds can be controlled in intensively managed, short-cycle food crops in this environment, but the cost is likely to be high. At present, chemical weed control represents an enormous economic input; it averaged $100/ha for upland crops in Yurimaguas. Hand-weeding is often much cheaper, but the labor for hand-weeding is frequently not available at any price.

Unless yields can be significantly increased to offset the high cost of weed control, data from this study suggest that upland rice should be removed from the high-input cropping system. Crops more competitive against weeds, such as corn and grain legumes, offer a broader range of economically attractive weed-control options, and may therefore be more practical than rice in continuous cropping.

**Table 1. Effect of weed control on total weed weight and crop yield in six consecutively planted short-season crops. Yurimaguas, 1983-1986.**

| | Total weed weight | Crop yield |
|---|---|---|
| | g/m² | kg/ha |
| Cycle 1 - Rice | | |
| All control[1] | 74 | 2009 |
| No control | 143 | 1411 |
| | * | *** |
| Cycle 2 - Corn | | |
| All control | 20 | 1286 |
| No control | 117 | 1226 |
| | *** | NS |
| Cycle 3 - Soybean | | |
| All control | 83 | 1746 |
| No control | 266 | 822 |
| | *** | *** |
| Cycle 4 - Rice | | |
| All control | 200 | 1645 |
| No control | 410 | 32 |
| | *** | *** |
| Cycle 5 - Corn | | |
| All control | 161 | 4840 |
| No control | 223 | 4932 |
| | *** | NS |
| Cycle 6 - Soybean | | |
| All control | 331 | 581 |
| No control | 397 | 311 |
| | *** | *** |

[1] "All control" refers to all treatments with some weed-control practice and includes both hand-weeded and herbicide treatments.
* Significant at P = 0.05.
*** Significant at P = 0.001.

# Potassium Buffering In Yurimaguas Ultisols

*Eduardo Uribe, N. C. State University*
*Fred R. Cox, N. C. State University*

Potassium is supposed to be rapidly lost in well-drained Ultisols of the humid tropics. Observations at Yurimaguas suggest that this is not necessarily the case. An in-depth study was initiated to elucidate this issue under continuous cropping.

## Objectives

The objectives of this study are 1) to estimate the size of the ecosystem K pools (biomass, exchangeable, nonexchangeable, leached) throughout the profile with time, as affected by fertilization and cropping; 2) to determine the relative contribution of the different K fractions to plant nutrient concentration and growth; 3) to determine the rate of K to be applied to bring a soil of a given K-buffering power from an existing to a given critical level, and to maintain that critical level; and 4) to relate the K-buffering power to the mineralogical composition of the soil.

## Procedures

Sites for two field experiments at the Yurimaguas station were selected for the contrasting textural classes of their soils: the first experiment, referred to here as Y-103C, is located in a sandy loam, and the second (Y-103D) is in a loamy sand.

Experiment Y-103C was planted in August 1986 after K levels had been lowered by a previous corn crop, which was removed from the field prior to maturation. A randomized complete block design was used. Five treatments consisting of 0, 30, 60, 90 and 120 kg $K^+$/ha were replicated five times. In 1987 the experimental design will be transformed into a split-plot design in which the subplot treatment will be either removal or reincorporation of the crop residue.

To establish experiment Y-103D, a three-year-old secondary forest was cut and the aboveground biomass was removed from the site to prevent K additions. A corn crop will be planted in January 1987 and removed from the field before maturation to bring the soil K to a lower level. The same experimental design and treatments used in Y-103C will be used in Y-103D.

### *K fixation*

A series of laboratory studies with the Yurimaguas soil was conducted during 1985-86. To determine the importance of K fixation and/or release to the dynamics of soil K in the Yurimaguas soils, we must know whether K fixation can occur. Thus, mineralogical analyses of the clay fraction of Y-103C and Y-103D were conducted. Analysis included samples at three depths (0-20, 20-40 and 40-60 cm). No differences among the samples were immediately apparent. The clay mineralogy is predominantly kaolinite, with low amounts of high-charged smectite and low-charged vermiculite, and small amounts of mica (weathered) and quartz. The smectite/vermiculite is slightly interlayered.

A complementary experiment was conducted to assess the capacity of the Yurimaguas clays and soils to fix K, and to develop a routine procedure to monitor changes in the size of the fixed pool. A rate of 50 mg $K^+$/kg was added to pure clay (Y-103B) and soil samples (Y-103C and Y-103D). The samples were incubated for ten days and subjected to drying and wetting cycles. At the end of the incubation period the samples were extracted twice with $NH_4OAc$ and then with $H_2SO_4$.

Given the mineralogy of these soils, it is reasonable to suspect that release of K from nonexchangeable sources can take place upon removal of K from the soil solution during a growing season. An extractant that truly reflects the availability of soil K should not only be able to extract what is immediately available but also what is potentially available during a growing season. The Olsen extractant, due to the nature of the exchanging cation, $Na^+$, can only recover exchangeable K and by doing so underestimates the real K status of soil K. On the other hand, the 1*N* $NH_4OAc$ extractant should recover the slowly available K in addition to the exchangeable K (readily available). This property of extracting K from interlayers of 2:1 clay minerals makes the 1*N* $NH_4OAc$ extraction a more realistic predictor of the availability of K in the soils.

If the mineralogy of the soil allows for release of nonexchangeable K during a growing season, fixation by the same minerals should also be

expected when the K concentration in the soil solution is increased above a certain point by K fertilizers. In previous research at the Yurimaguas station, leaching has been invoked to explain losses of K from the labile pool (Olsen-extractable K). However, the presence of small amounts of 2:1 clay minerals indicates that fixation or preferential adsorption can also take place. The vermiculite/montmorillonite content above which K fixation becomes important is difficult to predict. This is because the procedures used to study 2:1 clay minerals are somewhat qualitative: we work with a 5-10% error. Based on mineralogical studies to date on soils of the Yurimaguas station, it can be assessed that the concentration of 2:1 clay minerals on the clay fraction is somewhere between 4 and 10%.

*K buffering*

The K-buffering power is an important soil factor controlling availability of soil K. Since this soil property largely depends on the soil CEC, it was suspected that a range in K-buffering power should exist for the soils of the Yurimaguas station. The K-buffering power of samples from Y-103A (CEC = 4.6 cmol/L) and Y-103B (CEC = 2.8 cmol/L) was determined. Seventeen soils from various regions of North Carolina were also included.

**Results**

*K fixation*

The fixation study with pure clay samples of Y-103B indicated a greater capacity to fix K in the upper soil layers (Table 1). This was evidenced by the increasing recovery of K at the lower depths when the clays were first extracted with $NH_4OAc$. However, the greater K-fixing capacity of the clay fraction of the upper soil horizons may be oversnadowed by the lower clay contents of such horizons. Moreover, not all the K added was recovered, even after the two $NH_4OAc$ extractions and the $H_2SO_4$ extraction.

Whole soil samples from Y-103C and Y-103D were also subjected to the same treatments. For the soil samples, as with the clay samples, recovery of K with the first $NH_4OAc$ extraction was not complete. This again points out that K fixation or preferential sorption can take place in those soils. A second extraction with $NH_4OAc$ and a final extraction with $H_2SO_4$ were sufficient to recover in some cases nearly all the K added and in most cases more than what was added.

These results prove that K fixation and release can take place in these soils. The next step will be to assess the importance of this process under field conditions.

**Table 1. Potassium recovered by two successive extractions with $NH_4OAc$ and an extraction with $H_2SO_4$ after addition of 50 mg $K^+$/kg.**

| | | | % Recovered | | | |
|---|---|---|---|---|---|---|
| | | | 1st $NH_4OAc$ | 2nd $NH_4OAc$ | $H_2SO_4$ | |
| Sample | Depth | % Clay | 1*N* | 1*N* | 6*N* | Total |
| Y103B | 0-20 | 100 | 27.8 | 37.0 | 18.6 | 83.4 |
| Clay | 20-30 | 100 | 34.5 | 22.0 | 0.0 | 56.5 |
| (pure) | 30-45 | 100 | 53.0 | 23.0 | 0.0 | 76.0 |
| | 45-60 | 100 | 60.5 | 16.0 | 0.0 | 76.5 |
| Y103C | 0-20 | 16 | 71.8 | 24.6 | 19.6 | 116.0 |
| Soil | 20-40 | 19 | 72.5 | 14.4 | 5.9 | 92.8 |
| (sandy | 40-60 | 20 | 40.8 | 29.5 | 29.6 | 99.9 |
| loam) | | | | | | |
| Y103D | 0-20 | 10 | 75.0 | 18.0 | 19.2 | 112.2 |
| Soil | 20-40 | 14 | 63.0 | 22.8 | 22.2 | 108.0 |
| (loamy | 40-60 | 18 | 71.0 | 21.3 | 5.6 | 97.9 |
| sand) | 60-80 | 14 | 77.8 | 21.0 | 34.3 | 133.1 |
| | 80-95 | 26 | 63.8 | 22.4 | 24.6 | 110.8 |

*K buffering*

Results of the K-buffering analyses are shown in Figure 1. The K-buffering power is related to the inverse of the slope of the isotherms. The soils that underwent smaller changes in delta K at a given K addition have higher K-buffering power. The relatively important difference between the slopes of the isotherms of Y-103A and Y-103B indicates that factors other than the level of exchangeable K should be considered when the K status of these soils is evaluated.

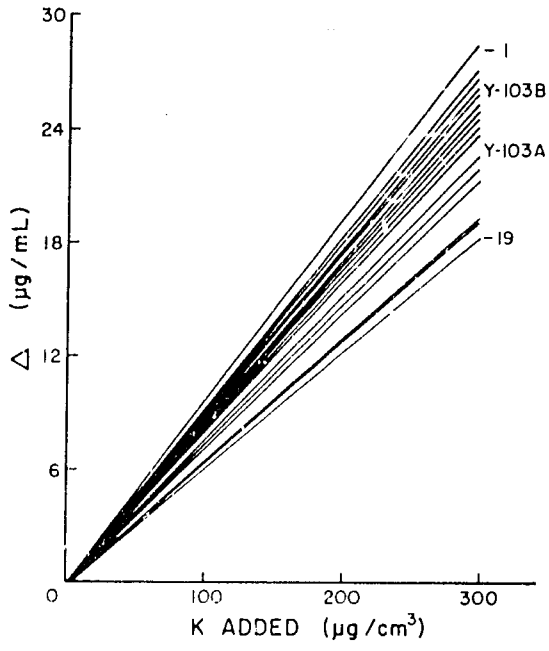


**Figure 1. Effect of K added to 19 soils on the K concentration in the soil solution.**

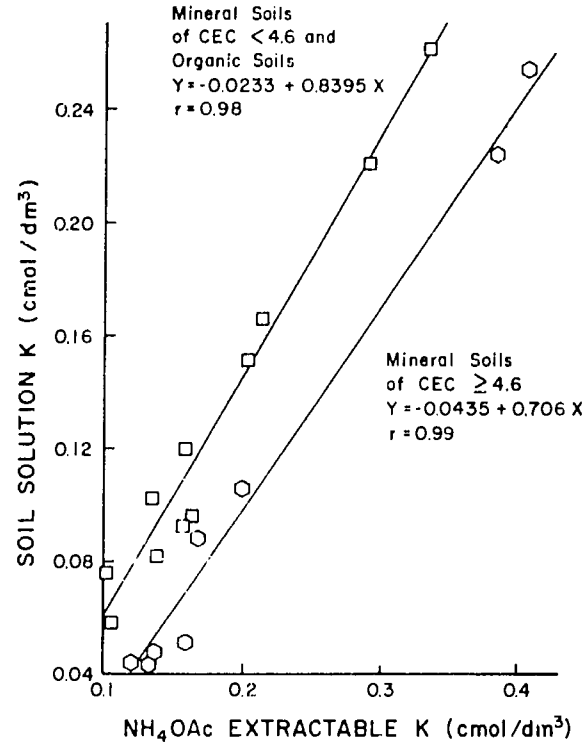


**Figure 2. Effect of $NH_4OAc$-extractable K on K concentration in the soil solution for two groups of soils.**

The relationship between the $NH_4OAc$-extractable K level and the K concentration of the soil solution is shown in Figure 2. The upper line corresponds to soils of low K-buffering power and the lower line to soils of higher K-buffering power. Each of the Yurimaguas soils falls into a different category. The figure indicates that any given level of $NH_4OAc$-extractable K level will be related to higher levels of K in the soil solution for soils of low K-buffering power. Therefore, the availability of exchangeable K will be greater in these soils (low CEC soils). Critical exchangeable K levels should then be different for soils of high and low K-buffering power.

The laboratory experiences described above are to be tested under field conditions at the Yurimaguas station on soils of high (Y-103C) and low (Y-103D) K-buffering power. The effect of "small" amounts of 2:1 clay minerals in the fixation/release reactions will also be evaluated under field conditions (Y-103C, Y-103D).

# Comparative Soil Dynamics

The potential effects of different farming systems on soil properties in rainforest regions are frequently mentioned in both the scientific and popular press. Such statements as "pastures degrade tropical soils," "trees improve soil properties," and "arable crops are erosive" allude to research questions that are fundamentally important for guiding the development of marginal lands in the humid tropics. To date, there are no studies in which the effects of different management systems on soil properties can be determined in a rigorous way. Thus, we are attempting to systematically compare the effect of what we have learned as promising options in 12 years of research at Yurimaguas.

During the first year of such research, we have found that differences in topsoil textural class (loamy sands with 12% clay vs. sandy loams with 20% clay) have pronounced effects on plant growth, both because water-holding capacity is higher in the sandy loams and because of the several chemical and biological properties. Higher clay content, for instance, provides not only higher organic matter and N but also higher microbial biomass. While microbial biomass decreases after clearing, there is no effect of management option on total organic-matter content in the profile. Pastures tend to distribute organic matter more deeply than do annual crops or forests.

We present our first estimates on root production, mycorrhizae, soil macrofauna and N mineralization as affected by high- and low-input cropping, pasture and agroforestry options in relation to primary or secondary forest fallow. Annual fine-root biomass production is similar in cropping systems and the forests, but well-managed pastures produce many more fine roots than do these two options. Vesicular-arbuscular mycorrhizal fungi infect trees more than annual crops and infect pastures the least. Mycorrhizal population decreases with time in high-input systems. Earthworms are the largest components of macrofaunal biomass. Earthworm biomass increases when pastures are grown but decreases with annual crop production. Nitrogen mineralization rate, measured by a preliminary method, is similar in forests and annual crop systems but much lower in pastures. A study of these soil dynamics with time of cultivation will help us better understand the positive and negative attributes of the different management options.

# Comparative Soil Dynamics Under Different Management Options

*Julio C. Alegre, N. C. State University*
*Pedro A. Sanchez, N. C. State University*
*Cheryl A. Palm, N. C. State University*
*Jorge M. Pérez, INIPA*

It is frequently stated that clearing tropical forest causes the soil to degrade and lose its productivity. While a loss in soil productivity may be observed under some types of land management, it is generally not known if this loss results from changes in soil chemical, physical or biological properties, or from a combination of these factors. Moreover, some land-management practices may result in sustained or even improved productivity, but again the reasons are unknown to date. Most studies attempting to compare soil properties under different management practices have been confounded by comparing plots of different ages or on different soil types. An experiment (referred to here as Y-412) was designed to allow comparisons of different management practices of the same age on similar soil types.

## Objective

The objective of this study is to monitor and compare changes in soil properties after a secondary forest has been cleared and the land subjected to different management practices.

This experiment is also being sampled according to the objective and methodologies of the Tropical Soil Biology and Fertility (TSBF) Program. The objectives of TSBF are to study biological processes in tropical soils with the eventual aim to manage and use biological processes to maintain and improve soil fertility. More specifically, the objectives are to quantify and obtain a predictive understanding of the factors controlling soil organic pools and fluxes and how these respond to disturbance. Yurimaguas, along with other sites throughout the tropics, serves as a Level 1 site. The task of Level 1 sites is to collect basic data on organic inputs, rates of decomposition, rates of mineralization, and the content and composition of soil organic matter under natural and managed systems. The data are collected using standardized methods to compare sites. The treatments encompass a broad range of intensity of disturbance and therefore serve as an excellent source for the TSBF data base.

In addition, other studies have compared biological and ecological processes and pools in different experiments on the Yurimaguas Experiment Station. The data for these studies are also presented in this chapter.

## Experimental Design Procedures

The experiment is located at the Yurimaguas Experiment Station on a Typic Paleudult with slopes of 0-5%. The vegetation was a ten-year-old secondary forest fallow. The experiment consists of six management options as treatments with three replications arranged in a randomized complete block design. Each plot is 1875 m$^2$ (75 x 25 m). The treatments are blocked according to soil texture, blocks 1 and 3 with loamy sand topsoil texture (12% clay), and block 2 with sandy loam topsoil texture (20% clay). In all cases clay content increases with depth (Table 1). All treatments were applied at the same time on similar soils. The loamy sand blocks are classified as "SLeak" in the Fertility Capability Classification System and the sandy loam blocks are

**Table 1. Texture distribution of the three blocks and FCC classification in Experiment Y-412. Samples taken before clearing. Topsoil values are means of 90 samples each; subsoil values are mean of six samples.**

| Block | Depth | Sand | Silt | Clay | Textural class | FCC class |
|---|---|---|---|---|---|---|
| | cm | % | | | | |
| 1 | 0-15 | 89 | 10 | 10 | Loamy sand | SLeak |
| | 15-30 | 73 | 16 | 11 | Sandy loam | |
| | 30-45 | 70 | 15 | 15 | Sandy loam | |
| 2 | 0-15 | 65 | 16 | 19 | Sandy loam | Leak |
| | 15-30 | 55 | 26 | 18 | Sandy clay loam | |
| | 30-45 | 57 | 22 | 21 | Sandy clay loam | |
| 3 | 0-15 | 80 | 8 | 8 | Loamy sand | SLeak |
| | 15-30 | 72 | 12 | 12 | Loamy sand | |
| | 30-45 | 72 | 15 | 15 | Sandy loam | |

classified as "Leak." In Soil Taxonomy all blocks belong to the same family (fine loamy, siliceous, isohyperthermic Typic Paleudults) because clay content exceeds 20% in the top 50 cm of the argillic horizon.

The area was cleared in August 1985. Land clearing was by slash-and-burn with the exception of the mechanized continuous cropping treatment. The treatment descriptions and work realized to date are:

1. Shifting cultivation. These plots were contracted out to a farmer. He planted upland rice (cv. Africano desconocido) September 23, 1985; two weeks later he planted half the plot with cassava and half with plantain. Rice was harvested January 16, 1986; cassava was harvested August 29, 1986. Now only the plantain remains and the forest fallow is regrowing.

2. High-input cropping. Land was cleared with a D6 bulldozer equipped with a straight blade. The vegetation was felled and left on the surface to dry, then was burned. Logs were pulled from the plots. The plots were limed (1 t/ha), fertilized with P (100 kg $P_2O_5$/ha), and disked. Applications of N (100 kg N/ha) and K (120 kg $K_2O$/ha) were split twice after planting corn. Corn (cv. Marginal 28) was planted October 7, 1985, and harvested February 21, 1986. Due to rainy weather conditions, corn was planted again on February 21, 1986, instead of soybean as had been planned. One t/ha of lime and 100, 80 and 100 kg/ha of N, $P_2O_5$ and $K_2O$, respectively, were applied. The second corn crop was harvested June 6, 1986. The next crop, soybean (cv. Jupiter), was planted June 28, 1986, and harvested October 28, 1986. Fertilizers were applied as 40, 80 and 100 kg/ha of N, $P_2O_5$ and $K_2O$. Seeds were inoculated with Nitragin but nodulation was not observed. The fourth crop, corn, was planted November 1986.

3. Low-input cropping. Upland rice (cv. Africano desconocido) was planted and harvested as in treatment 1. Next, the logs were removed from the plot. Rice was planted again January 31, 1986, without any fertilizer application and harvested June 2, 1986. The third crop, cowpea (cv. Vita 7), was planted June 11, 1986, and harvested August 20, 1986. The fourth crop, rice, was planted September 16, 1986. After two months, kudzu was interplanted. The kudzu fallow will stay for one or two years in an attempt to control weeds.

4. Multistrata tree crop production. Upland rice was planted and harvested as in treatment 3. Twenty-five days after the first rice crop was planted, *tornillo* (*Cedrelinga catenaeformis*) and peach palm (*Bactris gasipaes*), were interplanted; one month later *guaba* (*Inga edulis*) was planted; and three months later *arazá* (*Eugenia stipitata*) (Figure 1). Cropping of rice, cowpea and rice was as in treatment 3. A cover crop, *Centrosema macrocarpum*, was interplanted with the final rice crop in November 1986. The cover crop will serve as weed control and a source of N.

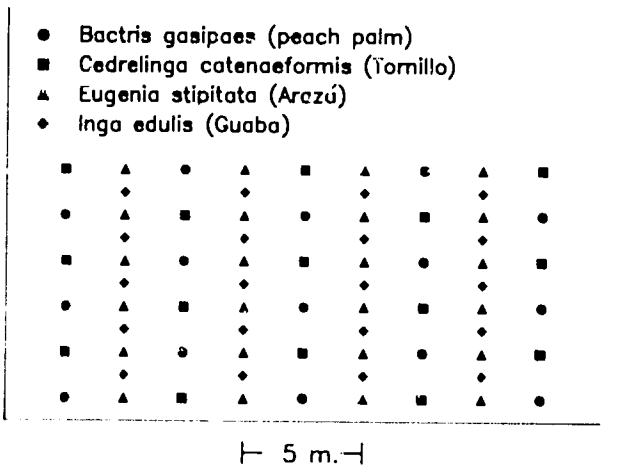


**Figure 1. Layout of multistrata tree production plots.**

5. Peach palm (*B. gasipaes*) production. Cropping in this treatment has been the same as in treatment 4, but this year peach palm was interplanted at 5 x 5 m 25 days after the first rice crop was planted. The fourth crop, rice, was planted September 16, 1986; 30 kg N/ha were applied 45 days later due to symptoms of N deficiency.

6. Forest fallow check. These plots were fenced and remain untouched. The fallow is now 11 years old.

Soil samples were taken for nutrient analysis (0-15, 15-30 and 30-45 cm), before and then one week, three months, six months and 12 months after clearing and burning. In addition, ash samples were collected after the burn and analyzed for nutrients. Physical properties such as bulk density, mechanical impedance, soil water characteristics and infiltration were taken before and after clearing at several dates. Microbial and ecological measurements of organic inputs (litterfall, crop residues), root production, decomposition, N mineralization, soil macrofaunal composition and soil microbial biomass began in June 1986. Crop yields and tree growth are also being measured.

## Results

*Soil physical properties*

Initial values were taken for particle-size distribution (Figure 2), soil water characteristics (Figure 3) and infiltration rate (Figure 4). Blocks 1 and 3 had similar particle-size distribution and were classified as loamy sands, the second block had a higher percentage of fine sand (106-0.05 mm), silt and clay content and was classified as a sandy loam. The sandy loam plots have higher water-holding capacity but lower infiltration than the loamy sand plots. The textural difference, and probably other factors, appears to have a significant effect on many of the soil and biological parameters; therefore, results will be presented according to soil texture.

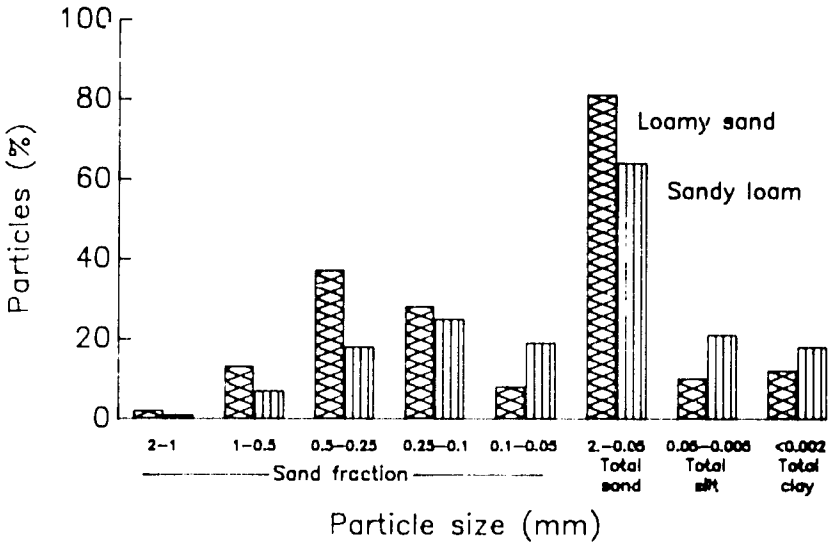


**Figure 2. Particle-size distribution of the two soil textures at the 0-10 cm depth (initial values before burning).**

*Soil chemical properties*

Total ash production from the burn was 5589 kg dry matter per ha. There was considerable variability within plots but no significant difference between plots.

Soil chemical data for 0-15 cm for the preburn, postburn, three-month and six-month samplings are presented in Tables 2 and 3. Table 2 compares replications (texture) and Table 3 compares treatments. Statistical analysis for changes with time is unfortunately not yet available, but it is possible to

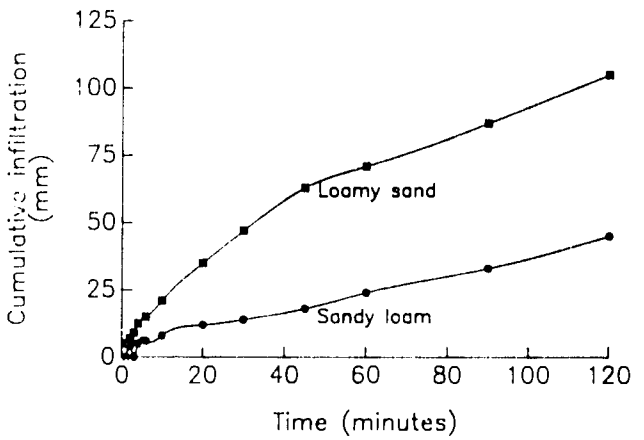


**Figure 4. Cumulative infiltration in two soil textures (initial values before burning).**

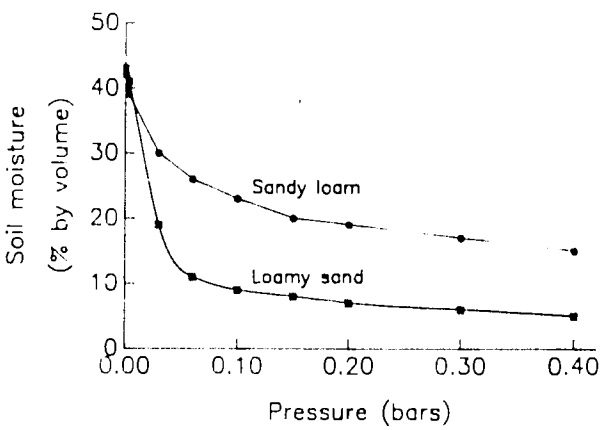


**Figure 3. Soil water characteristics of the two soil textures at the 0-10 cm depth (initial values before burning).**

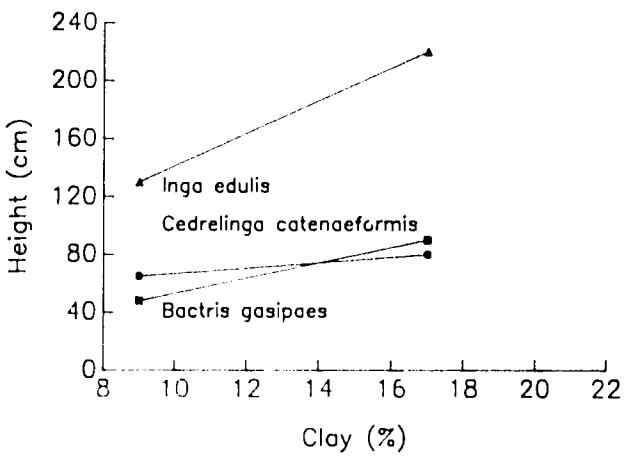


**Figure 5. Relationship between growth in height of trees and clay content in the multistrata treatment.**

**Table 2. Soil chemical analysis, for each block, at the 0-15 cm depth before and one week, three months and six months after clearing a ten-year-old secondary forest. (Date of burning: September 6, 1985.)*, ****

| Date | Block*** | pH | Al | Ca | Mg | K | P | O.M. | Total N | Al sat. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | cmol/L | | | | ppm | % | | |
| **Preburn** | | | | | | | | | | |
| Sept.3 | 1 | 4.7a | 1.08b | 1.22a | 0.17a | 0.11a | 13a | 1.56a | 0.062b | 41b |
| 1985 | 2 | 4.6a | 3.00a | 0.90b | 0.22a | 0.10ab | 9b | 1.42a | 0.075a | 70a |
| | 3 | 4.5a | 1.32b | 0.62c | 0.10b | 0.09b | 8b | 1.06b | 0.047c | 61a |
| **Postburn** | | | | | | | | | | |
| Sept.13 | 1 | 4.5a | 1.38b | 0.80a | 0.11b | 0.20a | 13a | 1.81a | 0.061ab | 55a |
| 1985 | 2 | 4.5a | 2.48a | 1.05a | 0.27a | 0.20a | 8a | 2.05ab | 0.073a | 61a |
| | 3 | 4.7a | 1.06b | 0.76a | 0.15b | 0.17a | 10a | 1.67b | 0.056b | 48a |
| **First crop: three-month sampling** | | | | | | | | | | |
| Dec. 5 | 1 | 5.1a | 1.10b | 1.04a | 0.24b | 0.25a | 15a | 1.53a | 0.057b | 42a |
| 1985 | 2 | 4.6b | 2.31a | 1.05a | 0.40a | 0.27ab | 8b | 1.79a | 0.087a | 55a |
| | 3 | 4.9ab | 0.99b | 0.74a | 0.23b | 0.17b | 9b | 1.50a | 0.060b | 46a |
| **Second crop: six-month sampling** | | | | | | | | | | |
| March 5 | 1 | 4.9ab | 0.60b | 1.28a | 0.25b | 0.16b | 11a | 1.17b | 0.032b | 27b |
| 1986 | 2 | 4.7b | 2.17a | 1.19a | 0.37a | 0.25a | 6b | 1.60a | 0.054a | 52a |
| | 3 | 5.1a | 0.52b | 1.00a | 0.24b | 0.15b | 7b | 1.06b | 0.036b | 28b |

*Each value is the mean of 30 measurements.
**Means followed by the same letter for each date are not significantly different at the 5% level using the Waller-Duncan multiple comparison test.
***Blocks 1 and 3 are loamy sands; block 2 is sandy loam.

make some conclusions. Preburn data show considerable variation between replications but not between treatments. Postburn data indicate changes between replications that continue at least for six months after the burn. The sandy loam had higher acidity, Al saturation, organic matter, total N and exchangeable cations. Differences between treatments began to appear at the three-month sampling. The most striking difference was in acidity and Al saturation, with the forest check plot being higher in both. The consequent rise in pH in the other treatments is attributed to the liming effect of the ash.

*Changes in organic matter*

Total soil C in itself gives little information about soil processes or fertility. Recently defined functional components of soil C, however, may provide a better understanding of the role and dynamics of soil organic matter, including the processes of decomposition and mineralization.

In addition to total soil C, light fraction C and soil microbial biomass C were measured in the top 10 cm of the shifting cultivation (TR 1), high-input cropping (TR 2), low-input cropping (TR 3), multistrata tree crop production (TR 4) and secondary forest fallow (TR 6) plots in September 1986, one year after the experiment was initiated.

Light fraction C is defined as the C that is not bound to the mineral soil and that falls in the 0.25 to 2 mm size category. It is separated from the soil by elutriation with water. This fraction could be considered litter in the soil and represents organic material as yet undecomposed. It is equivalent to the structural C in the Century Model although it may include some

**Table 3. Soil chemical analysis, for each treatment, at the 0-15 cm depth before and one week, three months and six months after clearing a ten-year-old secondary forest. (Date of burning: September 6, 1985.)*, ****

| Date | Treat-ment*** | pH | Al | Ca | Mg | K | P | O.M. | Total N | Al sat. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | cmol/L | | | | ppm | % | | |
| **Preburn** | | | | | | | | | | |
| Sept. 3 | 1 | 4.5a | 1.57ab | 1.01a | 0.18a | 0.11a | 10a | 1.32a | 0.056ab | 53ab |
| 1985 | 2 | 4.4a | 2.37a | 0.73a | 0.13a | 0.09a | 9a | 1.25a | 0.062ab | 66a |
| | 3 | 4.5a | 2.47a | 0.86a | 0.17a | 0.09a | 9a | 1.52a | 0.071a | 67a |
| | 4 | 4.7a | 1.16b | 0.92a | 0.17a | 0.10a | 10a | 1.21a | 0.059ab | 46b |
| | 5 | 4.5a | 1.36b | 0.93a | 0.15a | 0.10a | 11a | 1.35a | 0.051b | 52ab |
| | 6 | 4.8a | 1.87ab | 1.01a | 0.18a | 0.10a | 11a | 1.45a | 0.068ab | 58ab |
| **Postburn** | | | | | | | | | | |
| Sept. 13 | 1 | 4.5a | 1.56a | 0.77a | 0.15a | 0.20ab | 11a | 1.75a | 0.067a | 54a |
| 1985 | 2 | 4.6a | 1.96a | 0.77a | 0.17a | 0.23a | 11a | 1.87a | 0.067a | 57a |
| | 3 | 4.5a | 1.84a | 1.12a | 0.22a | 0.19ab | 11a | 2.02a | 0.066a | 56a |
| | 4 | 4.7a | 1.45a | 0.87a | 0.18a | 0.17b | 8a | 1.82a | 0.060a | 50a |
| | 5 | 4.5a | 1.39a | 0.83a | 0.16a | 0.16b | 10a | 1.77a | 0.057a | 55a |
| | 6 | — | — | — | — | — | — | — | — | — |
| **First crop: three-mo. sampling** | | | | | | | | | | |
| Dec. 5 | 1 | 5.0ab | 1.09b | 0.89ab | 0.32ab | 0.23ab | 12a | 1.54a | 0.068a | 42b |
| 1985 | 2 | 4.7ab | 1.85ab | 0.89ab | 0.31ab | 0.27a | 13a | 1.63a | 0.063a | 54ab |
| | 3 | 4.8ab | 1.79ab | 0.92ab | 0.30ab | 0.28a | 9a | 1.74a | 0.063a | 50ab |
| | 4 | 5.1a | 0.94b | 1.23a | 0.34a | 0.21ab | 11a | 1.49a | 0.057a | 31b |
| | 5 | 5.1a | 0.87b | 1.09ab | 0.31ab | 0.26a | 12a | 1.54a | 0.073a | 36b |
| | 6 | 4.6b | 2.25a | 0.63b | 0.15b | 0.11b | 7a | 1.71a | 0.083a | 73a |
| **Second crop: six-mo. sampling** | | | | | | | | | | |
| March 5 | 1 | 5.0a | 0.76b | 1.19ab | 0.28b | 0.18b | 8ab | 1.21a | 0.040a | 29b |
| 1986 | 2 | 4.9a | 0.97b | 1.54a | 0.50a | 0.24a | 11a | 1.30a | 0.048a | 23b |
| | 3 | 4.9a | 1.35ab | 1.11bc | 0.28b | 0.20ab | 7ab | 1.43a | 0.053a | 39b |
| | 4 | 5.0a | 0.75b | 1.09bc | 0.26b | 0.17b | 7ab | 1.07a | 0.035a | 26b |
| | 5 | 4.9a | 0.68b | 1.26ab | 0.25b | 0.21ab | 9ab | 1.52a | 0.044a | 28b |
| | 6 | 4.4b | 2.07a | 0.72c | 0.14c | 0.11c | 5b | 1.13a | 0.042a | 67a |

*Each value is the mean of 15 measurements.

**Means followed by the same letter for each date are not significantly different at the 5% level using the Waller-Duncan multiple comparison test.

***Treatment 1 = shifting cultivation; TR 2 = high-input cropping; TR 3 = low-input cropping; TR 4 = multistrata tree crop production; TR 5 = peach palm production; TR 6 = forest fallow check.

**Table 4. Total soil carbon, microbial biomass carbon and light fraction carbon in the top 10 cm one year after clearing in five different land management systems. All numbers are means.***

| Treatment | Total C | Soil microbial C** | Light fraction C |
|---|---|---|---|
| | % | µg C/g | mg C/g |
| Shifting cultivation | 0.65a | 357a | 0.38a |
| High-input cropping | 0.86a | 423a | 0.87a |
| Low-input cropping | 0.77a | 450a | 0.78a |
| Multistrata tree crop production | 0.74a | 367a | 0.74a |
| Forest fallow check | 0.86a | 578b | 0.68a |

* Numbers within columns followed by the same letter are not significantly different at the 5% level using the Waller-Duncan multiple comparison test.
** Experimental procedure still being tested for acid soils, not yet recommended as a standard method.

soluble carbon compounds and microbes. The reactivity of the light fraction will depend on the quality of the organic inputs.

Soil microbial C represents an active fraction of the soil C, which can perhaps serve as an index for comparing biological processes such as decomposition and mineralization. Microbial biomass C was estimated by measuring ninhydrin-N resulting from autolysis of microbial cells that had been subjected to chloroform fumigation for ten days, according to procedures proposed by J. N. Ladd. Microbial biomass C may estimate the active C pool in the Century Model.

Results for total C, microbial C and light fraction C are presented in Table 4. After one year in different management systems, there is no significant difference in the total C or light fraction C among the treatments in the top 10 cm. Microbial C, however, is significantly higher in the secondary forest plots than in the other treatments. This difference could be due to differences in the amount and type of organic inputs according to the treatments or to differences in soil physical and chemical properties (temperature, moisture, aeration, etc.) resulting from removal of the secondary forest. Corroborating data are not yet available. One would expect to find more differences among the treatments with time as the soil properties change according to the land-use practice, as is shown in the accompanying study of soil organic matter.

In addition to the difference in microbial C between the forest check plot and the other treatments, there is also a difference in the total C and microbial C according to soil texture: the clayier plots had higher values. This is consistent with results reported from other studies.

*Crop yields and tree growth*

Crop yields for each treatment are shown in Table 5. There was no significant difference in yield for the first rice crop in treatments 1, 3, 4 or 5 or for the cowpea crop. This was expected, because these treatments were all essentially low-input systems at this stage. There was a 20% reduction in yield for the second rice crop, but again no difference between treatments. Corn yields increased 30% for the second crop in the high-input treatments.

The two agroforestry treatments, multistrata crop production and peach palm production, presented a very clear pattern of tree growth according to soil texture. After ten months, the peach palm (*B. gasipaes*) and the *tornillo* (*C. catenaeformis*) showed a strong correlation between growth and clay content in the top 0-15 cm. Average peach palm height was 50 cm in the loamy sand blocks and 94 cm in the sandy loam blocks (Figure 5). Average height of *tornillo* was 70 cm in the loamy sand block and 88

**Table 5. Crop yields for different treatments.*, ****

| Treatment | 1st crop | | 2nd crop | | 3rd crop | | Cassava (fresh weight) |
|---|---|---|---|---|---|---|---|
| | Rice | Corn | Rice | Corn | Cowpea | Soybean | |
| | t/ha | | | | | | |
| 1. Shifting cultivation | 1.68a | — | — | — | — | — | 8.7 |
| 2. High-input cropping | — | 2.72 | — | 3.81 | — | 2.36 | — |
| 3. Low-input cropping | 1.33a | — | 1.20a | — | 1.04a | — | — |
| 4. Multistrata tree crop | 1.56a | — | 1.20a | — | 0.90a | — | — |
| 5. Peach palm production | 1.65a | — | 1.33a | — | 1.10a | — | — |

* Each value is the mean of 15 samples.
** Means followed by the same letter for rice and cowpea are not significantly different at the 5% level using the Waller-Duncan multiple comparison test.

cm in the sandy loam blocks. *Inga edulis*, a fast-growing legume, attained 1.40 m in the loamy sand plots and 2.15 m in the sandy loam plots in ten months. *Arazá* (*E. stipitata*) had no significant correlation of height with soil texture.

The faster growth in the finer textured blocks could be due to the higher water-holding capacity during the drier periods and to less leaching of nutrients during the wetter periods. Nutrient losses in the leachate water are being monitored, but results are not yet available. Also the organic-matter content is higher in the sandy loam than in the loamy sand (Table 2).

## Implications

The first year of this study vividly shows the striking effect of topsoil texture on tree growth and related chemical properties. The textural difference is recognized in the FCC system but not by Soil Taxonomy at the family level. Although the different management options caused no change in total soil organic matter (SOM), there was a significant decrease in microbial biomass C upon clearing and cultivation. This fraction is hypothesized to represent the active organic matter pool. Continuation of this experiment will let us determine whether these differences are transient or sustained.

# Soil Organic Matter Pools As Affected by Management Options

*Robert J. Scholes, N. C. State University*

Soil organic matter (SOM) has many potential impacts on soil physical and chemical characteristics. It is generally believed that SOM declines rapidly when primary or secondary tropical rainforest is converted to agriculture. The current view of SOM dynamics is that several pools with different turnover rates are involved. This study is a preliminary attempt to quantify these pools and estimate the degree to which they are influenced by the management treatment imposed on them.

## Objective

The objective of this study is to characterize the SOM content of the same soils of the Yurimaguas series with different management histories and relate the differences between pedons to their management histories.

## Procedures

Soil samples were taken with a Giddings probe to a depth of 0.7 m in a primary (50-year) forest (*bosque virgen*) on sandy loam; a long-term (14-year) continuous cultivation field (Chacra I) on sandy loam; pasture (two-year) grazing of *Brachiaria humidicola/Desmodium ovalifolium* on sandy loam (p. 31); a 12-year secondary forest on loamy sand (p. 102), and a high-input continuous (six-year) cultivation field on loamy sand (p. 97). All soils were of the Yurimaguas series, an Ultisol with mineralogy dominated by kaolinite.

The cores were divided into 0-5, 5-10, 10-20, 20-30, 30-50 and 50-70 cm subsamples. Total organic C, light fraction C by flotation in water, fine roots and macroorganics (by hand sorting) were determined. In addition, measurements of microbial biomass in the

**Table 1. Soil organic matter fractions under different management options at Yurimaguas.**

| Management option and site | Depth | Macro-organics* | Fine roots | Light fraction | Heavy fraction | Total | Clay |
|---|---|---|---|---|---|---|---|
| | cm | t/ha | | | | | % |
| 50-year forest (*bosque virgen*) (sandy loam) | 0-20 | 0.34 | 2.48 | 5.95 | 23.22 | 32.00 | 19.0 |
| | 20-70 | 0.00 | 0.77 | 2.38 | 37.80 | 40.95 | 26.0 |
| 14-year continuous cultivation (Chacra I) (sandy loam) | 0-20 | 0.63 | 0.20 | 6.25 | 13.83 | 20.91 | 17.3 |
| | 20-70 | 0.76 | 0.10 | 1.92 | 45.98 | 48.77 | 21.6 |
| Two-year pasture (Y-307) (sandy loam) | 0-20 | 0.61 | 6.41 | 6.16 | 20.81 | 34.00 | 20.2 |
| | 20-70 | 0.00 | 3.73 | 6.19 | 27.39 | 37.31 | 24.9 |
| 12-year secondary forest (Y-412) (loamy sand) | 0-20 | 0.90 | 3.49 | 6.31 | 27.40 | 38.11 | 10.0 |
| | 20-70 | 0.02 | 0.29 | 0.68 | 43.13 | 44.12 | 15.0 |
| Six-year high inputs, continuous cultivation (Y-103B) (loamy sand) | 0-20 | 0.43 | 0.06 | 2.62 | 17.87 | 20.98 | 15.4 |
| | 20-70 | 1.00 | 0.01 | 3.38 | 35.46 | 39.87 | 17.7 |

* Litter and roots > 2 mm.

surface 10 cm were made using a modified ten-day incubation with chloroform described in the previous section. Although this technique had not been applied previously to acid soils, no problems were experienced and extremely reproducible estimates of microbial biomass were obtained.

"Macroorganics" include all biomass and necromass greater than 2 mm in size (other than live fine roots, which were enumerated separately). This is an important fraction, because although it is technically not soil organic matter, since it is as yet not modified by microbial activity, it is included in the percentage of organic C determination because it is crushed during the milling process and therefore passes through a 2-mm sieve.

"Fine-roots" include root biomass smaller than 2 mm in diameter. "Light fraction" is here defined as being less than 2 mm and having a density less than 1 g/cm$^3$. It is assumed to represent the structural C pool in the Century Model. "Heavy fraction" is less than 2 mm in diameter, but, due to its association with mineral particles, it has a bulk density greater than 1 g/cm$^3$. It represents the sum of the slow and passive C pools in the Century Model. It is obtained from the difference between the total C contributed by the light fraction, assuming that total C is 0.57 OM. The active pool of the Century Model is represented by the microbial biomass data, which were collected for the same sample locations.

## Results

The data presented (Table 1 and 2) are from a preliminary unreplicated pilot study. Since it is unreplicated, statistical analysis is not possible. However, a visual comparison of the data show that, between treatments, there is no marked difference in total C in the top 70 cm. Differences do appear if one looks at the distribution of C in the different fractions and profile. For example, both sites under forest have high content of root C in the surface layers, higher microbial biomass C and higher heavy fraction C than the cultivated plots. The cultivated plots have higher light fraction but less heavy fraction and microbial C in the plow layer and very little structural C. The pasture has a considerable portion of the soil C in the roots and the roots are found at considerable depth in the profile.

**Table 2. Estimates of microbial biomass from different management practices.**

| Management practice | Nitrogen* | Carbon** |
|---|---|---|
| | —mg/g dmass soil— | |
| 50-year-old forest (sandy loam) | 56 | 1142 |
| Chacra I (sandy loam) | 20 | 410 |
| Six-year-old pasture (sandy loam) | 49 | 1002 |
| 12-year-old forest (loamy sand) | 59 | 1213 |
| Six-year-old high-input cultivation system (loamy sand) | 16 | 321 |

* Calculated by multiplying microbial N x 20.4.
** Experimental procedure being tested for acid soils, not yet recommended.

# Root Production and Turnover In Different Management Options

*Robert J. Scholes, N. C. State University*
*Angel Salazar, INIPA*

Since the equilibrium level of soil organic matter (SOM) is a balance between inputs and losses, a logical place to look for the cause of the SOM changes that occur when management practices are changed is in the type and magnitude of inputs. The focus of this study was on fine-root (less than 2 mm diameter) turnover as an input to the soil organic matter pool. Increasing evidence from temperate systems shows that below ground production (which is mostly fine-root production) constitutes the major part of total primary production. There is virtually no comparable data for tropical systems.

### Objective

The objective of this study is to estimate root production under major land-use options (including secondary forest, pastures, high- and low-input cropping) at Yurimaguas.

### Procedures

Estimating fine-root production in short-duration crops requires only one total root biomass estimate near anthesis, when the root biomass is at a maximum. This approach assumes that 1) all roots in short-duration crops are functionally fine roots, and 2) there is little root turnover during the growth period of the crop. Care must be taken when applying this approach that dead roots from the previous crop are excluded from the estimate.

Root production estimates in perennial vegetation are much more difficult. The most widely accepted approach is that of sequential coring, in which the fluctuations in live and dead fine-root biomass (or total fine-root biomass) over an annual period are summed to give total production. The assumptions inherent in this method are 1) root production shows seasonal fluctuations; 2) growth and mortality are sufficiently out of phase to allow them to be independently assessed; and 3) there is no significant turnover of roots at a scale shorter than the sequential sampling interval.

Only significant differences between sequential samples must be used in the calculation lest spurious statistical variation be counted as root production.

Root biomass was estimated in both perennial and annual crops by taking 18 cores, 40 mm in diameter, to a depth of 30 cm (in 10-cm increments) per treatment. A pilot study had indicated that 18 samples gave 90% confidence intervals within 5% of the mean on a stratified random basis (one random sample per 2-m interval on a 36-m long transect laid diagonally across the treatment). The roots were separated from the sample within hours with the aid of a hydropneumatic elutriator and were sorted by hand into live fine, dead fine and live coarse root categories, rejecting organic debris and dead coarse roots. Live and dead fine roots were distinguished on the basis of color, flexibility, strength and condition of cortex. The root samples were dried for 24 hours at 70° C and weighed to 0.0001 g. Bulked samples for each treatment were combusted in a muffle furnace at 600° C for three hours to determine the ash content at the roots. Results were expressed as ash-free, live-root fine mass in t/ha.

For short-duration crops, biomass sampling was done soon after anthesis. Root production effectively ceases at anthesis, and root die-off begins. Peak root biomass was therefore determined by summing the live and recently dead roots, excluding old dead roots from the previous crop, which were easily identifiable and constituted a small fraction of the root mass. All roots were classified as fine roots.

In the case of perennial crops, biomass samples were repeated monthly. Sampling will continue until July 1987 in order to obtain annual production estimates. The Wilcoxon-Mann-Witney rank sum test was applied to detect differences between samples.

### Results

The ash-free root biomasses in the 0-30 cm zone for four crops, the 11-year-old secondary forest and the *B. humidicola/D. ovalifolium* pasture are given in Table 1. The root biomass under all crops was considerably less than the fine-root (less than 2 mm diameter) biomass under the secondary forest and the root biomass under improved pasture. Among the crops, the two legumes produced the highest root biomass and had the highest root:shoot ratios, with soybean producing both the highest root biomass and the highest total residue mass. Cowpea was exceeded

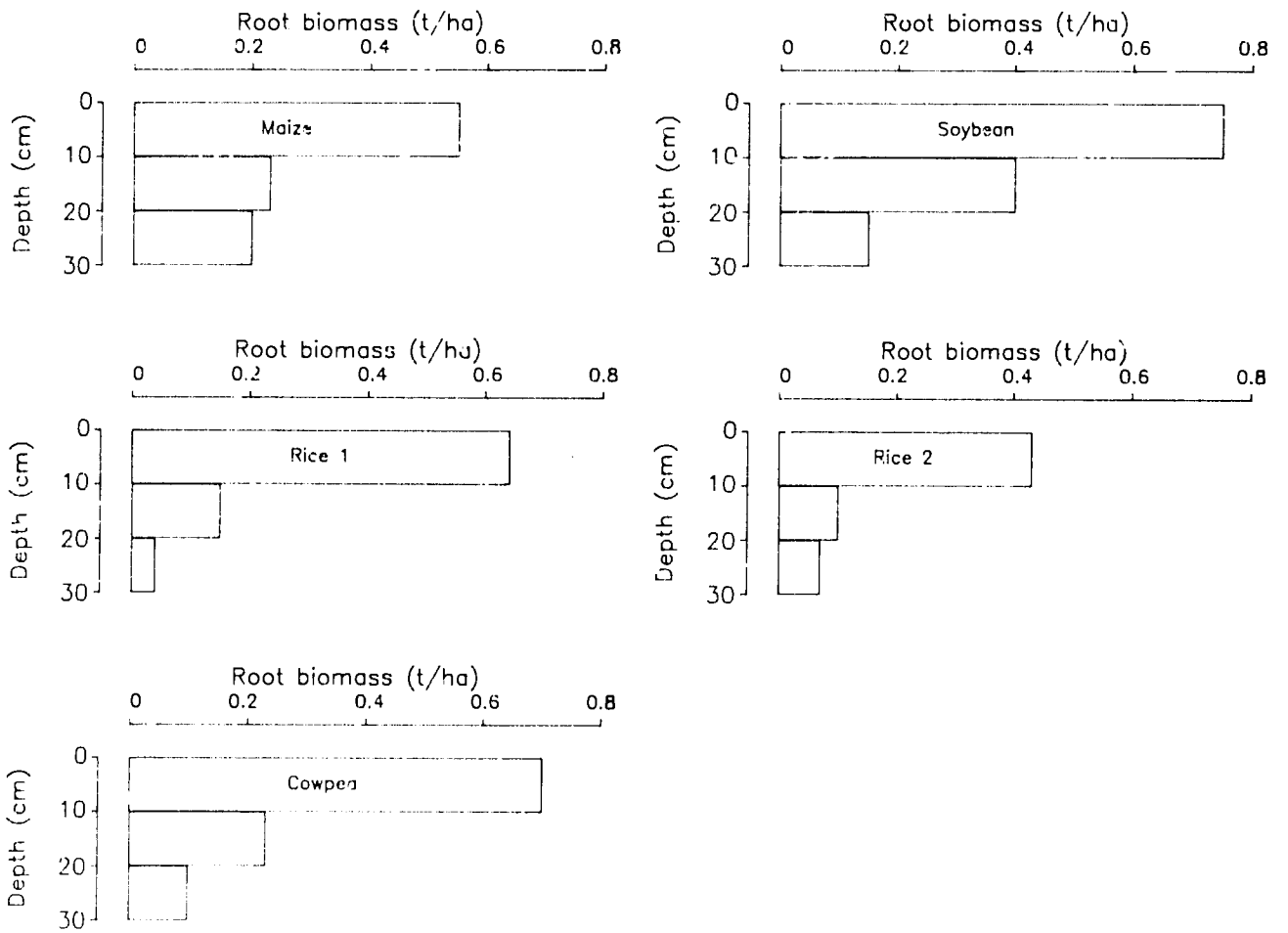


**Figure 1. Root biomass at anthesis of several crops in an Ultisol, except for rice 1, which was on an alluvial Alfisol in Yurimaguas.**

in total residue by corn. Upland rice showed the lowest root production, with the treatment growing on the more fertile, clayier Alfisols slightly outperforming the treatment on the loamy sand Ultisol both in root biomass and aboveground residue.

Roots were concentrated in the top 10 cm of the soil in all the crops, although less so in corn and soybean, which had been limed and tilled (Figure 1). The upland rice, although an acid-tolerant variety, was relatively shallow-rooted in the acid Ultisol.

Root biomass of perennial vegetation is shown in Table 2. Total root biomass ranged from 4.6 to 8.2 t/ha, with a tendency for higher biomass in the heavier-textured soils and a strong negative response to increasing grazing pressure on pasture biomass.

The predicted annual organic-matter inputs to the topsoil in the two annual crop production systems are shown in Table 3. The total organic input to the soil is more than double in the low-input system than in

**Table 1. Fine-root biomass (ash-free) to a depth of 30 cm, aboveground residues, and grain yields of various crops at Yurimaguas. Bracketed quantities are the standard errors for 18 samples. All soils are Ultisols unless otherwise specified.**

| Plant | Fine-root biomass | Aboveground residues | Grain yield |
|---|---|---|---|
| | t/ha | | |
| Soybean | 1.39 (0.42) | 2.76 | 1.80 |
| Cowpea | 1.03 (0.09) | 1.70 | 0.86 |
| Corn | 0.97 (0.12) | 3.03 | 3.00 |
| Upland rice (1) (Alfisol) | 0.80 (0.14) | 2.59 | 2.29 |
| Upland rice (2) | 0.62 (0.12) | 1.60 | 1.41 |
| Forest fallow | 2.45 (0.19) | | |
| Improved pasture | 4.22 (0.45) | | |

**Table 2. Root biomass of perennial vegetation at Yurimaguas (0-30 cm depth).**

| Vegetation | Root biomass | | | |
|---|---|---|---|---|
| | Fine live | Fine dead | Coarse | Total |
| | t/ha | | | |
| 12-year forest (loamy sand) | 2.51 | 0.33 | 3.41 | 6.25 |
| 12-year forest (sandy loam) | 3.01 | 0.43 | 3.88 | 7.32 |
| Pasture (light grazing) | 4.72 | 0.51 | 2.91 | 8.14 |
| Pasture (heavy grazing) | 3.06 | 0.31 | 1.23 | 4.60 |

**Table 3. Predicted annual organic inputs to the soil under different management systems (both with residue returns).**

| Management system | Crop rotation | Root input | Aboveground residues | Total input |
|---|---|---|---|---|
| | | t/ha/yr | | |
| High-input | Corn-corn-soybean | 3.33 | 8.82 | 12.15 |
| Low-input | Rice-rice-cowpea | 2.27 | 4.90 | 7.17 |

the high-input system, with crop residues removed. When the high-input system is practiced with residue return, it exceeds the low-input system by 69% in organic inputs. A similar proportion of the total residue returns is due to roots in both returned-residue cases (28% high-input, 32% low-input).

The total annual organic-matter input to the soil in tropical forests is not precisely known at this stage, due mainly to difficulties in determining the turnover of fine roots, but it would seem to be considerably higher than under crop systems. The one available estimate of root production in a tropical forest, by Jordan and Escalante, generally thought to be an underestimate, is at 2.13 t/ha of the same order as production in three successive crops at Yurimaguas.

## Conclusions

1. Approximately one-third of the organic inputs to the soil in a variety of tropical cropping systems originates from dead roots. Total organic inputs in a no-till, no-fertilizer cropping system were only three-quarters of the inputs from the high-input system when residues were returned.

2. There are statistically significant fluctuations in fine-root production in perennial vegetation despite the udic isohyperthermic soil climate (data not shown). These fluctuations will allow at least a minimum estimate of root production to be made.

# Root Distribution in Pastures And Alley-Cropping Options

*Robert J. Scholes, N. C. State University*
*Angel Salazar, N. C. State University*

Root biomass is most efficiently estimated by taking multiple samples with a small diameter cover. When the roots are sparse, such as they are at depths exceeding 30 cm in most situations, the efficiency of this method decreases due to increasing statistical variability and decreasing root yield per core. One solution to this problem is to modify an absolute sample obtained by coring the portion of the profile with the densest root network with relative root distribution data obtained from a non-absolute but rapid and efficient method such as the profile wall counting method.

Relative root-distribution data can also be useful as a rough measure of the distribution of root activity (for input into crop production models such as CERES, for instance), for assessing the relative importance of surface and subsoil roots in nutrient-uptake studies, and for revealing soil conditions that inhibit root penetration.

One of the most fundamental questions in alley-cropping systems is the degree to which the alley-cropping species competes with the crop species. Such competition is reduced by selecting the appropriate inter-alley spacing. Data on the lateral extent of rooting by species would be useful in this regard.

## Objectives

The objectives of this study are 1) to determine the vertical distribution of root biomass under various management options as an aid to the estimations of total root biomass, and 2) to determine the vertical and horizontal overlap of roots of the tree and crop species in alley-cropping systems.

## Procedures

*Profile count method:* Pits were dug to the maximum rooting depth and one face was cut vertical and planar with a machete. After washing out a thin soil layer with a gentle water spray from a backpack sprayer, the number of roots exposed in contiguous 100 x 100 mm squares was counted. This provides a two-dimensional map of root distributions, which can be reduced to a one-dimensional distribution by summing vertically or horizontally. To remove the effects of observer and depth of washing variations, the counts were normalized by expressing them as percentages of the total number of roots counted.

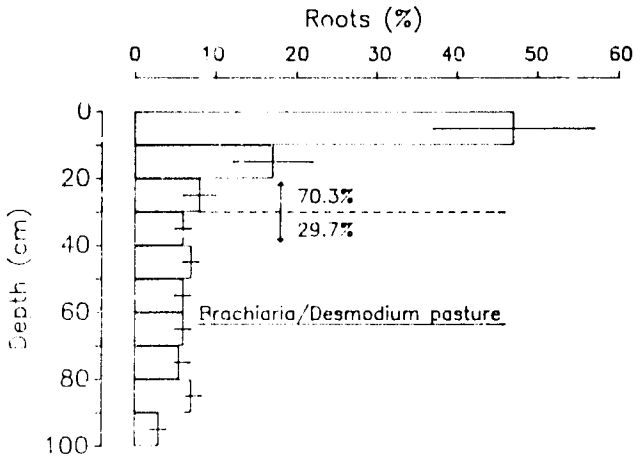


**Figure 1. Root distribution under a *Brachiaria humidicola/Desmodium ovalifolium* pasture.**

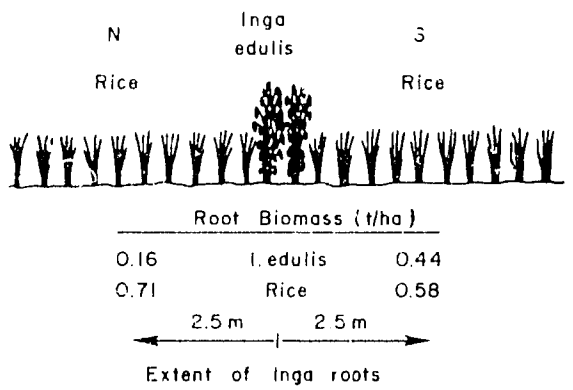


**Figure 2. *Inga edulis* and rice root biomass at increasing distances from an *Inga*/rice interface.**

*Coring methods:* A Giddings probe of 40-mm diameter was used to sample cores in 100-mm increments to a depth of 300 mm. Roots were extracted in a hydropneumatic elutriator, sorted by species and separated from extraneous material, dried and weighed. The ash content on a bulked sample was determined by combusting in a muffle furnace at 600 for three hours.

## Results

In *Brachiaria/Desmodium* pasture systems at Yurimaguas, about 70% of the roots are in the top 30 cm of the profile (Figure 1). Maximum rooting depth in *Brachiaria/Desmodium* pastures is 1 m. *Brachiaria* roots are deeper than *Desmodium* roots.

There is a marked asymmetry in alley root distribution. There are more roots on the south side of an east-west oriented alley than on the north, and their influence extends farther from the alley.

# Occurrence of Mycorrhizae in Crops, Pastures and Tree Species

*Pedro O. Ruiz, International Potato Center*
*Mary C. Scholes, N. C. State University*
*Theodore St. John, New York Botanical Garden*

Most acid tropical soils are low in P content, and in many cases P deficiency limits the productivity of the area. Plants showing VAM associations may be better adapted to growing in these soils. Improved facilities now available at Yurimaguas will make many new studies of mycorrhizae possible.

## Objective

The objective of this study is to survey the crop species and certain of the native species for mycorrhizal association to determine the degree of infection and the organisms involved.

## Procedures

Root samples of nine species were collected from a number of trials at the station. They were carefully washed, cleaned in boiling 10% KOH, and stained with Acid Fuchsin. Forty 1-cm root sections, from each species, were placed in groups of 10 on microscope slides and observed. Mycorrhizal infection was scored as either present or absent in each of the sections. A positive score was constituted by the presence of both hyphal structures and arbuscules. Relative infection levels were determined.

## Results

Tree species had the highest percentage of infection followed by the crop species and finally the pasture species (Table 1). The values obtained are only relative because a fairly crude method of estimation was used. Better techniques (e.g., a modified Newman approach) are available, but they require a dissecting microscope with a minimum magnification of 40+. A new microscope has been ordered, which will allow more accurate estimates to be obtained. This study has given some indication as to the extent of VAM infection; using these data, further manipulative experiments with VAM can be designed. *Inga edulis* has been chosen as the species to be used for establishing spore cultures.

Soil samples were collected from the same areas as the root samples. Spores were obtained by wet-sieving. Representatives from the generae *Glomus*, *Gigaspora* and *Acaulaspora* were identified, with specimens from *Glomus* most numerous. Identification to the species level was not possible due to lack of expertise, but permanent mounts of the spores were made and will be identified by Dr. Theodore St. John of the New York Botanical Garden.

The initial work on VAM was done using an Acid Fuchsin staining procedure: Dr. St. John recommended, however, that trypan-blue lactophenol should be used for better resolution.

Dr. St. John also showed the professionals a rapid way of assessing whether mycorrhizal infection had taken place. This technique can only be used on white-colored roots, e.g., corn. After removal from the soil, roots are washed rapidly under a stream of running water. When all the soil has been removed, the roots are examined for a yellow coloration, which occurs in isolated spots along the surface of the root where infection has taken place. This yellow pigment is photosensitive and only lasts for a few minutes. It allows one to rapidly assess a large number of samples for mycorrhizal infection; however, it must be backed up by traditional cleaning and staining.

**Table 1. Degree of VAM infection, selected species.**

| Species | Infection |
|---|---|
| | % |
| *inga edulis* | 100 |
| *Erythrina* sp. | 90 |
| *Desmodium gyroides* | 85 |
| Peanut | 83 |
| Sweet potato | 69 |
| Corn | 40 |
| Upland rice | 32 |
| *Desmodium ovalfolium* | 30 |
| *Brachiaria humidicola* | 30 |

In order for any manipulative experiments to be carried out with mycorrhizae, a facility must be available to produce large quantities of sterile soil. One method is to sterilize the soil by autoclaving; however, this is laborious and the possibility of Mn toxicity does exist. The use of "Basamid," a commonly used, commercially available soil fumigant, was also tried but it is not suitable for mycorrhizal work because of its long-term residual effect. Methyl bromide was located, and an experiment is under way to test its efficiency.

## Conclusions

All species tested were mycorrhizal, but degree of infection ranged from 30 to 100%. The pasture species seem to be least infected; the annual crops occupy a middle position, and native tree legumes used in agroforestry show the greatest infection.

# Effect of Different Management Options On Mycorrhizal Infection

*Pedro O. Ruíz, International Potato Center*
*Mary C. Scholes, N. C. State University*

In the humid tropics most wild and cultivated plant species are associated with mycorrhizae, especially of the vesicular-arbuscular (VAM) type. These associations are formed by fungi of the order Endogonaceae that colonize the cortical cells of roots. The main agronomic significance lies in their ability to supply the plant with nutrients, particularly P and Zn, that diffuse slowly in the soil, thus developing depletion zones in the immediate vicinity of the root. Other beneficial effects attributed to mycorrhizae include improved N fixation by leguminous species; greater tolerance to root pathogens, drought, high soil temperatures and other factors that enhance growth rate; good recovery from transplanting, and good plant survival. Many plant species in the tropics greatly depend on mycorrhizae for their P nutrition. These fungi can be lost from soils gradually as a consequence of land use, especially when management practices incompatible with fungal survival are adopted.

### Objective

The object of this study is to determine the degree of occurrence of VAM fungi in tropical soils under different management practices.

### Procedures

A pot experiment was conducted at the Yurimaguas Experiment Station, using soils collected from the following systems: 1) 11-year-old secondary forest; 2) one year of shifting cultivation; 3) one year of continuous cropping with low inputs; 4) one year of continuous cropping with high inputs; 5) 14 years of a high-input system. Sites 1 to 4 were from the experiment reported on p. 102 (referred to here as Y-412), while site 5 was from an experiment reported on page 86.

Soils under shifting cultivation and for the low-input system were cleared by the traditional method (slash-and-burn) and no inputs were applied. Soil of the one-year-old high-input system was cleared by bulldozer and prepared mechanically before it received lime and fertilizer applications. Soil 14 years old in the high-input system was cleared by slash-and-burn and received continuous mechanization, lime, fertilizer and pesticide applications. The chemical characteristics of the soils are given in Table 1.

The experiment had a complete randomized design with ten replications. One and one-half kg of soil were placed in plastic bags, and corn was used as an indicator plant. Shoots from five replications were harvested after 15 and 30 days, when plant height, dry weight and P content were determined. Roots were cut into 1-cm sections, cleared in hot 10% KOH, and stained in trypan-blue lactophenol. The stained sections were mounted in glycerin and examined at 100x and 400x for the presence or absence of mycorrhizal infection. The degree of occurrence was measured in terms of percentage of mycorrhizal infection. Ten grams of soil were wet-sieved for spores.

### Results

Significant differences in percentage of infection with management type were detected (Table 2), especially between the short- and long-term high-input systems—100 vs. 10%, respectively—at 30 days after sowing. Shoot P levels differed greatly, too (0.64 vs. 0.19 g %, respectively) in contrast with their available soil P contents (8.48 vs. 14.14 ppm P, respectively). This relationship was less evident in soils from the secondary forest, the shifting cultivation system and the low-input system, where infection levels were similar. Shoot P levels in all treatments in the study were high at 15 days after sowing; at 30 days these levels dropped except in the soil under the short-term high-input system where this value was maintained. Plant height and dry-matter production were higher in soils under both high-input systems. Spores were present in all soils in small quantities; three different size species of the genus *Glomus* were recognized.

### Discussion

Results obtained indicate that mycorrhizal infection is affected by high levels of P in the soil, which may inhibit mycorrhizae formation, as noted in the long-term high-input system with a high soil P level. This could have been due to continuous P

**Table 1. Chemical characteristics of Ultisol sites of sandy loam topsoil texture in the mycorrhizal study.**

| Management type | pH | P | Al | Ca | Mg | K | N | Al sat. |
|---|---|---|---|---|---|---|---|---|
| | | ppm | cmol/L | | | | % | |
| Secondary forest (11 yr) | 5.0 | 6.0 | 0.9 | 1.83 | 0.25 | 0.09 | 0.060 | 29 |
| Shifting cultivation (1 yr) | 6.0 | 4.0 | 0.0 | 3.50 | 0.88 | 0.14 | 0.040 | 0 |
| Low-input (1 yr) | 5.0 | 4.0 | 2.4 | 1.67 | 0.48 | 0.18 | 0.078 | 50 |
| High-input (1 yr) | 5.0 | 6.4 | 1.1 | 2.44 | 1.01 | 0.63 | 0.072 | 21 |
| High-input (14 yr) | 4.3 | 14.1 | 1.0 | 4.11 | 1.70 | 0.87 | 0.052 | 13 |

**Table 2. Plant height, dry weight, shoot phosphorus content and percentage of infection of corn plants grown under different management practices.***

| Management type | 14 days after sowing | | | | 30 days after sowing | | | |
|---|---|---|---|---|---|---|---|---|
| | Plant height | Dry weight | Shoot P cont. | Infect. | Plant height | Dry weight | Shoot P cont. | Infect. |
| | cm | g | g % | % | cm | g | g % | % |
| Secondary forest (11 yr) | 38.2b | 20.8b | 0.43b | 32cd | 55.2b | 39.6b | 0.21b | 74b |
| Shifting cultivation (1 yr) | 34.9b | 17.9b | 0.53ab | 46bc | 45.8c | 34.0b | 0.21b | 92a |
| Low-input (1 yr) | 37.3b | 18.8b | 0.55ab | 62b | 43.3c | 33.8b | 0.19b | 94a |
| High-input (1 yr) | 49.1a | 33.6a | 0.66a | 98a | 62.3a | 74.8a | 0.64a | 100a |
| High-input (1 yr) | 50.6a | 38.9a | 0.38b | 4d | 60.1ab | 68.7a | 0.19b | 10c |

* Means with the same letter are not significantly different at P = 0.05, using the Duncan multiple range test.

applications, although the soil test level is at about the critical level for corn growth (15 ppm). The low infection level could have also been due to the lack of VAM inoculum in this system.

A positive relationship between mycorrhizal infection and the amount of P absorbed by plants is particularly evident in the soils under the high-input systems. This difference is attributable to the efficiency of VAM fungi to absorb P from the soil and translocate it to the plant, and their ability to explore more area in the soil. Mycorrhizal infection in soils from secondary forest, shifting cultivation and the low-input system were high; however, these values did not coincide with high shoot P content, probably due to the low levels of this nutrient in the soil or by effects of Al toxicity (see subsequent experiments). These observations may explain the drop in shoot P levels at 30 days after sowing. The presence of spores in all soils in small quantities indicates that such spore counts do not determine mycorrhizal infection levels.

### Conclusions

1. The degree of occurrence of VAM fungi in Yurimaguas Ultisols differs with management option.

2. Low percentages of mycorrhizal infection in high-input systems over the long term could result from high levels of P in the soil or the disappearance of VAM fungi from the system.

3. Further research is needed to investigate optimum P requirements for mycorrhizae formation in tropical soils

## *Rhizobium* Nodulation In Grain Legumes

*Mary C. Scholes, N. C. State University*
*Rafael Román, INIPA*

The objective of this work was to isolate and characterize *Rhizobium* sp. from legume crop species grown in acid tropical soils of Yurimaguas.

Bacterial colonies were isolated on yeast extract mannitol agar from a number of cultivated and naturally occurring species. The species investigated included cowpea, peanut, soybean, *Desmodium ovalifolium*, *Inga edulis*, *Erythrina* sp., *Desmodium gyroides* and others. Some of the colonies resembled *Rhizobium*. None of the *Rhizobium* species was identified due to the lack of facilities and expertise. Because plants were not reinoculated with the isolated species, we cannot be absolutely certain that *Rhizobium* sp. were isolated. Since conditions were not sterile, maintenance of the isolated species was extremely difficult and, as a result, this line of research was not pursued.

The principle of including legumes in a continuous cropping system assumes that the legume is fixing N efficiently and will result in some N carry-over to the subsequent crop. However, estimates of N fixation by legumes under acid tropical conditions are scarce. This study focused on trying to obtain estimates of N fixation by native and introduced *Rhizobium* species.

### Procedures

Three plant species were used: cowpea, peanut and soybean. Soil collected from the field where the crops were growing was sterilized by autoclaving.

Four treatments and five replications were used: 1) sterile soil; 2) sterile soil and inoculum from the field; 3) sterile soil and inoculum from a known

strain; and 4) sterile soil and urea (equivalent to 150 kg N/ha).

Inocula from the field were prepared by crushing nodules removed from the plant roots. Five seeds of each species were placed in each 1 kg plot; each seed was inoculated with a 0, 1 ml aliquot of the prepared inocula. The plants were placed in a greenhouse and watered daily with deionized water; a nutrient solution minus N was applied twice weekly. After an eight-week period the plants were removed and divided into above- and belowground parts.

### Results

Most plants developed nodules, implying that a great deal of contamination had taken place; therefore, no conclusions about the amount of N fixed can be drawn. Nevertheless, the mean number of nodules per plant (Table 1) indicates that nodulation occurs readily in peanut and cowpea, but not in soybean in Yurimaguas.

Cowpea and peanut nodulated prolifically under field conditions without any additional inocula; however, soybean (p. 102) did not nodulate very extensively even after being inoculated with *Rhizobium japonicum*.

The "greenhouse" facilities are not adequate for controlled experiments due to excessively high temperatures, the leaking roof and the presence of insects. The station does need a facility for growing plants under controlled conditions if the program continues to include work in soil microbiology.

**Table 1. Mean number of nodules per plant with and without *Rhizobium* inoculation in pot conditions.**

| Species | Inoculated | Non-Inoculated |
|---|---|---|
| Soybean | 0 | 1.1 |
| Cowpea | 22.2 | 16 5 |
| Peanut | 40.1 | 53.5 |

## Soil Macrofauna as Affected By Management Practices

*Beto Pashanasi, INIPA*
*Patrick Lavelle, University of Paris*

Invertebrate participation in the chemical processes of decomposition of soil organic matter is decisive, with the ingestion and digestion of hundreds or thousands of tons of soil per year; the invertebrates mix and aerate the soil. The invertebrates are subdivided into mesofauna and macrofauna. The mesofauna consist of organisms less than 2 mm; the macrofauna include organisms greater than 2 mm.

### Objectives

The objectives of this study are 1) to determine the existence of the different components of the soil macrofauna under different land management alternatives; 2) to evaluate weight and number of individuals in the different components of the macrofauna; and 3) to associate the diverse macrofauna components with the different systems of soil use.

### Procedures

To study variation of macrofauna under different forms of management, the following production systems were sampled: 1) primary forest; 2) secondary forest with ten years of natural regeneration; 3) a peach palm plantation with a kudzu (*Pueraria phaseoloides*) cover; 4) a four-year-old pasture in association with *Brachiaria humidicola* + *Desmodium ovalifolium*; 5) a high-input system, one year old (p. 102); 6) a low-input system, one year old (p. 102); 7) a traditional shifting agriculture system, one year old (p. 102); 8) a humid *torourco* degraded pasture (five-year-old traditional system), and 9) dry degraded *torourco* pasture (five-year-old traditional system).

Samples were taken by a transect whose departure and direction were randomly selected. Every 5 m a sample was taken along the length of the transect.

The samples had the following dimensions: 25 x 25 cm and 30 cm depth divided into four successive layers: litter layer, 0-10, 10-20 and 20-30 cm. The litter and soil samples were placed in plastic bags and then hand-picked for macrofauna.

The animals were put in a 4% formol solution to conserve them for identification. For each sample the density and biomass of the different taxonomic units were determined.

**Table 1. Macrofauna present in Yurimaguas soils, under different management systems.**

| Type of management | No. of samples | Average density | Biomass | No. of units recorded |
|---|---|---|---|---|
| | | individuals/m² | g/m² | |
| Primary forest | 10 | 4256 | 41.3 | 41 |
| Secondary forest | 10 | 3755 | 18.9 | 27 |
| Peach palm + kudzu | 10 | 1794 | 54.1 | 32 |
| *Brachiaria* + *Desmodium* | 10 | 915 | 127.9 | 27 |
| High-input cropping | 10 | 709 | 2.4 | 20 |
| Low-input cropping | 4 | 3612 | 8.1 | 13 |
| Shifting cultivation | 3 | 1397 | 3.7 | 8 |
| Humid degraded pasture | 3 | 1008 | 128.6 | 13 |
| Dry degraded pasture | 3 | 3296 | 25.0 | 17 |

## Results

When separated by soil-management system, a great variation existed in the density and biomass of the macrofauna (Table 1). This density apparently is due to the floristic composition of each system; for example, the primary forest is the richest in number of individuals/m² while the high-input system is the poorest. The macrofauna biomass in the improved and humid degraded pastures was greater than that in the traditional system or in the high- and low-input systems. This difference is due to the fact that in pastures a greater quantity of endogenous organisms such as earthworms was found. This endogenous group has a greater biomass than the consumer groups of leaves, wood and crop residues that predominate in the other systems (Table 2).

## Conclusions

1. The greatest percentage of density and biomass is found in the 0-10 cm layer, as this presents the best conditions for aeration and the greatest amount of nourishment.

2. The animal communities' composition is determined by the forest nature of the medium and by the texture of the soil.

3. Clearing and substitution of the forest for other management systems profoundly transforms the structure of the biological communities of the soil. Macrofauna biomass increases with pastures and decreases with annual cropping.

4. The dominant units are termites in density (54%) and earthworms in biomass (73%).

Table 2. Density and biomass (%) of different soil macrofauna in the various management systems.

| | Type of management | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Macrofauna | Prim. forest | Second. forest | Peach palm +kudzu | High-input system | Low-input system | Shift. cult. | *Brach. +Desm.* pasture | Humid degraded pasture | Dry degraded pasture |
| **Termites** | | | | | | | | | |
| Density | 76.1 | 86.4 | 63.9 | 43.6 | 90.1 | 81.3 | 1.7 | 24.9 | 21.2 |
| Biomass | 16.5 | 26.1 | 6.4 | 21.1 | 70.5 | 81.9 | 0.02 | 0.9 | 12.2 |
| **Earthworms** | | | | | | | | | |
| Density | 2.9 | 2.6 | 8.2 | 2.0 | - | - | 81.1 | 53.4 | 7.0 |
| Biomass | 58.9 | 49.1 | 91.0 | 48.8 | - | - | 96.2 | 96.4 | 71.1 |
| **Ants** | | | | | | | | | |
| Density | 13.0 | 7.2 | 20.1 | 37.8 | 6.2 | 12.6 | 5.8 | 13.2 | 66.2 |
| Biomass | 1.3 | 3.0 | 0.3 | 2.7 | 2.4 | 3.8 | 0.1 | 0.2 | 3.4 |
| **Coleoptera** | | | | | | | | | |
| Density | 1.6 | 0.8 | 2.1 | 11.5 | 1.8 | 1.1 | 2.8 | 3.7 | 1.5 |
| Biomass | 2.6 | 2.5 | 0.6 | 15.3 | 2.9 | 12.8 | 0.1 | 1.8 | 7.9 |
| **Spiders** | | | | | | | | | |
| Density | 1.6 | 1.2 | 1.2 | 1.4 | - | 0.8 | 2.4 | 2.6 | 0.6 |
| Biomass | 6.0 | 8.3 | 0.7 | 0.6 | - | 1.1 | 0.02 | 0.02 | 0.1 |
| **Miriapods** | | | | | | | | | |
| Density | 0.7 | 0.7 | 1.7 | - | 0.6 | - | 1.0 | 0.5 | 0.2 |
| Biomass | 6.0 | 8.3 | 0.7 | - | 5.6 | - | 0.2 | 0.5 | 0.02 |
| **Miscellaneous** | | | | | | | | | |
| Density | 4.1 | 1.1 | 2.8 | 4.5 | 1.8 | 4.2 | 5.2 | 1.7 | 3.3 |
| Biomass | 8.7 | 2.7 | 0.3 | 11.4 | 18.6 | 0.4 | 3.3 | 0.2 | 5.3 |

# Nitrogen Mineralization and Leaching as Affected By Crop-Management Practices

*Mary C. Scholes, N. C. State University*
*Pedro A. Sanchez, N. C. State University*

Few comparisons of mineralization processes have been made between agricultural systems and the natural systems from which they are derived. This is especially true for tropical systems. The process of natural selection on nutrient-poor systems is believed to have resulted in organisms that show efficient nutrient utilization; agricultural practice, on the other hand, tends to disrupt this. By comparing the two systems it should be possible to more readily identify management practices which, when included in the derived agricultural system, act to stabilize and optimize the transfer of nutrients.

This study, involving soils of two textures, was undertaken to determine changes in some soil biological properties of an Ultisol upon clearing and being subjected to different crop management systems. Nitrification and mineralization were analyzed over the course of a growing season in a conventional and no-tillage agroecosystem and these results compared to the values obtained in the indigenous vegetation. Differences in nitrification and mineralization activity over 0-30 cm were analyzed as well as differences in the distribution of activity within 0-30 cm depth segments.

This work focused on determining the changes that take place in the dynamics of soil N when one converts an 11-year-old tropical forest fallow to cultivated systems managed in different ways. The various N conversions in the soil can be seen in Figure 1. Mineralization, nitrification and leaching were followed in this study.

## Procedures

An *in situ* methodology for studying fluxes of mineral-N described by Raison and coworkers was used. PVC tubes 5 cm in diameter and 33 cm in length were used for the field incubations. Tubes were hammered into the soil to 30 cm. This was easy in the sandier soils but difficult in clayier soils or where coarse roots are present. The tubes were placed in groups of three; one tube was immediately removed and returned to the laboratory for time zero measurements of $NO_3^-$ and $NH_4^+$. The remaining tubes were incubated for two weeks, one tube covered with a plastic drinking cup to keep out moisture and the other left open. After two weeks the tubes were returned to the laboratory. The period of incubation was chosen arbitrarily, relying on the information that mineralization would occur rapidly due to suitable climatic conditions. The core was pushed out of the tube and divided into two sections, 0-15 cm and 15-30 cm, and the samples were extracted with 0.5*M* $K_2SO_4$. After 30 minutes of shaking, followed by filtration, the filtrate was analyzed for $NO_3^-$ and $NH_4^+$ using standard techniques.

The following estimates were made, expressed

$NO_3$ extractable nitrate
$NH_4$ extractable ammonia
Superscripts:
- o Time zero, bulk soil
- c Time one, covered tube
- u Time one, uncovered tube
- 1 Time one, bulk soil

Net mineralization = $(NH_4^c + NO_3^c) - (NH_4^o + NO_3^o)$
Net ammonification = $NH_4^c - NH_4^o$
Net nitrification = $NO_3^c - NO_3^o$
"Leaching"= $(NH_4^c + NO_3^c) - (NH_4^u + NO_3^u)$
Uptake = $(NH_4^1 + NO_3^1) - (NH_4^o + NO_3^o)$ + leaching + net mineralization

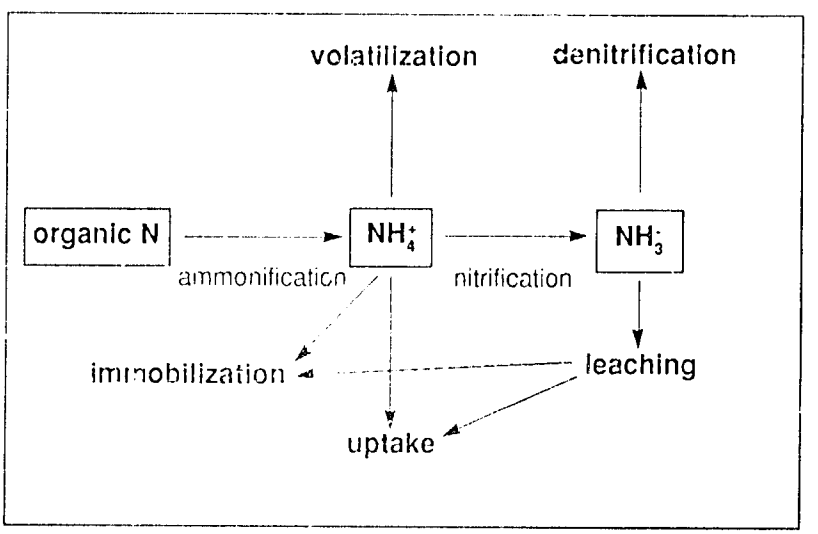


Figure 1. Nitrogen processes in soils.

**Table 1. Net N mineralization rates as affected by management systems and soil texture on Yurimaguas Ultisols (June-September, 1986).**

| Topsoil texture | Depth | High-input | Low-input | Forest | Pasture | Chacra I |
|---|---|---|---|---|---|---|
| | cm | µg N/g dmass soil | | | | |
| Sandy loam | 0-15 | 25.12 | 37.22 | 27.78 | 4.07 | 17.16 |
| | 15-30 | -0.06 | -7.98 | -0.23 | -1.04 | -8.30 |
| | 0-30 | 25.06 | 29.24 | 25.55 | 3.03 | 8.86 |
| Loamy sand | 0-15 | 6.13 | 19.69 | 34.04 | | |
| | 15-30 | 14.98 | 9.97 | 13.98 | | |
| | 0-30 | 21.11 | 29.66 | 48.02 | | |

**Table 2. Nitrification rates as affected by management systems and soil texture in Yurimaguas Ultisols (June-September, 1986).**

| Topsoil texture | Depth | High-input | Low-input | Forest | Pasture | Chacra I |
|---|---|---|---|---|---|---|
| | cm | µg N/g dmass soil | | | | |
| Sandy loam | 0-15 | 28.34 | 40.49 | 25.93 | 1.78 | 31.61 |
| | 15-30 | 0.86 | 0.83 | 3.62 | -1.52 | -2.86 |
| | 0-30 | 29.20 | 41.32 | 29.55 | 0.26 | 28.77 |
| Loamy sand | 0-15 | 17.68 | 18.84 | 31.51 | | |
| | 15-30 | 12.90 | 9.95 | 16.36 | | |
| | 0-30 | 30.58 | 28.79 | 47.87 | | |

In the study reported on page 102 (referred to here as Y-412), leaching was also estimated by taking samples weekly from suction cup lysimeters over the period April-August 1986. The lysimeters were at 100 cm in all of the management practices except in the shifting cultivation treatment where the lysimeter was at 50 cm, due to a shortage of 100-cm lysimeters. Samples were taken from the sandy loam and loamy sand replicates 2 and 3. Samples were analyzed for $NO_3$-N and $NH_4$-N.

Several management systems were sampled at two-week intervals from June to September 1986. This included the high-input cropping, low-input cropping and forest fallow plots of experiment Y-412, using a loamy sand and a sandy loam block. The high-input cropping was finishing its second (corn) and third (soybean) consecutive crops during its first year of operation, with tillage, liming and full fertilization. During the same time period, the low-input system was into its second (upland rice) and third (cowpea) crops with no tillage, lime, or fertilization. The forest fallow was ending its eleventh year of growth.

The pasture management option was sampled for the central grazing experiment (p. 21) under *Brachiaria humidicola/Desmodium ovalifolium* in its fourth year of continuous grazing. To estimate the long-term effects of high-input continuous cultivation,

**Table 3. Maximum N leaching measured in 14-day intervals as affected by topsoil texture and management practice (Experiment Y-412).**

| Sampling period (14 days) | Rainfall | Loamy sand | | | Sandy loam | | |
|---|---|---|---|---|---|---|---|
| | | High-input | Low-input | Forest fallow | High-input | Low-input | Forest fallow |
| | mm | µg N/g dmass soil/14 days | | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 3.4 | 0 |
| 2 | 86 | 2.9 | 1.9 | 0 | 4.2 | 0.2 | 5.2 |
| 3 | 104 | 0 | 5.8 | 2.8 | 0 | 10.6 | 0 |
| 4 | 163 | 25.7 | 6.9 | 14.5 | 0.6 | 0 | 0 |
| 5 | 95 | 2.2 | 2.9 | 5.0 | 10.5 | 4.1 | 2.3 |

Chacra I (experiment Y-101) was sampled at the same time during the course of a corn crop. The pasture and Chacra I location had only one topsoil texture: sandy loam.

## Results

Mineralization and nitrification rates were found to vary throughout the period studied. In the Y-412 comparisons (high-input, low-input and forest) on the sandy loam, cropping cultivation has had no effect on the rates of mineralization, whereas on the loamy sand, the mineralization rate in the forest was substantially higher than in the two cropping systems. No differences can be seen between the two high- and low-input cropping systems in Y-412 in spite of differences in tillage, liming and fertilization. It will be interesting to follow mineralization patterns between management treatments as the experiment ages, since these are only first-year data.

In most cases, mineralization and nitrification rates were substantially higher in the 0-15 cm zone than in the 15-30 cm zone (Tables 1 and 2).

If one compares the mineralization rates in the pasture and in Chacra I, it can be seen that the values are extremely low, compared with the Y-412 values (Table 1). This is perhaps due to denitrification caused by more frequently observed saturated moisture conditions and somewhat higher clay contents encountered. This is an area that should be followed up in the future.

Values obtained for maximum leaching were obtained by comparing the values obtained for $NO_3^-$ and $NH_4^+$ in the covered and the uncovered tubes (Table 3). It must be borne in mind that they are maximum leaching values because of the absence of roots, and only to a depth of 30 cm.

**Table 4. Total soil nitrogen measured to 30 cm in different management practices.**

| | Management practice | Total N 0-15 cm | Total N 15-30 cm |
|---|---|---|---|
| | | % | |
| Y-412 | Sandy loam: | | |
| | High-input cropping | 0.05 | 0.06 |
| | Low-input cropping | 0.08 | 0.04 |
| | Forest fallow | 0.08 | 0.06 |
| Y-412 | Loamy sand: | | |
| | High-input cropping | 0.05 | 0.02 |
| | Low-input cropping | 0.05 | 0.04 |
| | Forest fallow | 0.05 | 0.03 |
| Y-302 | Pasture: | | |
| | Legume | 0.09 | 0.04 |
| | Grass | 0.10 | 0.05 |
| Chacra I | | 0.04 | 0.05 |

A word of caution must be given about the method used here to estimate mineralization and leaching. Compaction may occur, particularly in the clayier soils as the tube is inserted. This does not allow water to flow freely through the open tubes and therefore may not serve as a good estimate of leaching. In addition, if the soil is above field

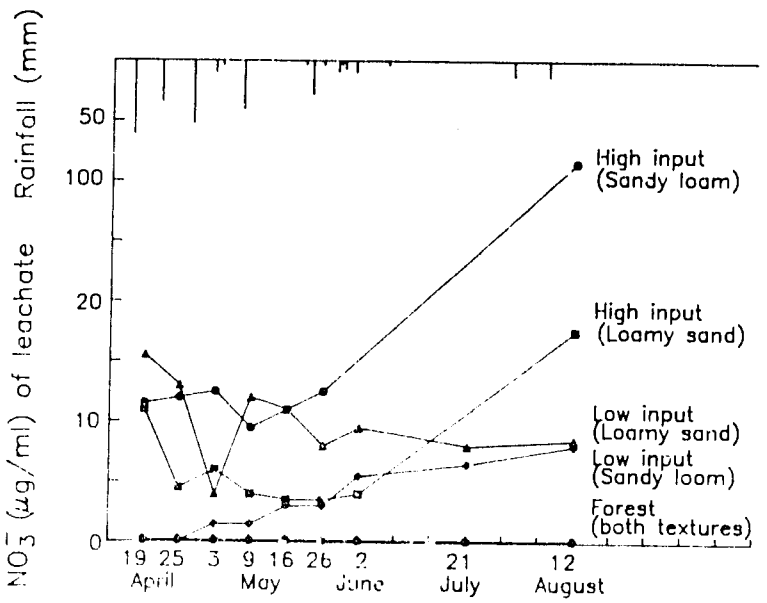


**Figure 2. Nitrate concentration in leachates at 100-cm depths from three management options in two Ultisols with different textures.**

capacity when the tubes are located, anaerobic conditions may form in the tube, leading the denitrification. Thus, care must be taken when applying this method and when interpreting these particular results.

Data from the porous cup lysimeters (Figure 2) indicate that ammonium N did not leach into the lower profile. However, the amounts of nitrate N at the 100-cm depth were substantial, especially during periods when ground cover was minimal. It is assumed that nitrate measured at 100 cm is from leaching and not from mineralization and nitrification, which would be extremely low at that depth. The nitrate measured should only be used for comparative proposes and not as absolute measures of leaching obtained from the data. It appears that more nitrate is present at 100 cm in the sandy loam soil, but this might be misleading because the throughflow of water on the loamy sand is much higher, which probably results in more nitrate being lost from this system.

Management practices appear to have an influence on the loss of nitrate. Nitrate levels are high in the high-input system where inorganic fertilizer was applied. In all management systems, nitrate losses were high following harvest and during seedling establishment when rooting systems were not extensively developed. Nitrate was never detected in the forest fallow check. This study, therefore, provides evidence that asynchrony can take place, resulting in losses from the system.

Total soil N was determined once during the sampling period by Kjedahl analysis, and the results are presented in Table 4. Total N was higher in most cases in the first 15 cm than between 15-30 cm. Most management systems were similar except for the pasture systems, which showed higher levels of total N.

## Implications

Incubation of undisturbed soil *in situ* appears to be a promising technique for studying N mineralization in plant communities, but significant problems were encountered: (a) difficulty in driving the cores into the soil in the forest sites due to the presence of large roots; (b) compaction of sandy loam soils in the tubes with adverse effects on mineralization and nitrification; (c) in some areas, especially after periods of heavy rains, free drainage did not occur in the tubes (probably due to compaction), resulting in standing water on the surface of the tubes and thus leading to anaerobic conditions; (d) the precision of the estimates could be improved if many more replications are measured. In practice this is difficult because of the time required to analyze each sample.

It is difficult to compare the rates of N mineralization and nitrification found in this study with rates found for other systems because of differences in incubation conditions. Most of the research on mineralization and nitrification is based on laboratory or field incubations using disturbed samples, rather than the *in situ* incubations used in this study. Because both soil disturbance (e.g., sieving, drying and rewetting) and environmental conditions markedly affect soil N mineralization rates, rates measured in disturbed soils in the laboratory are unlikely to be quantitatively similar to those measured in the field. Most temperate forest soil incubations produce mineral N at rates of around 1-2 µg N/g dry soil/day; typical rates for tropical forest soils range from 0.1 to 5 µg N/g dry soil/day. Rates measured in this study are toward the lower end of the range, being 0.3-0.7 µg N/g dry soil/day.

# Nitrogen Mineralization And Soil Moisture Content

*Mary C. Scholes, N. C. State University*
*Pedro A. Sanchez, N. C. State University*

Extremely low N mineralization rates were measured in pastures in a study reported on page 21 (referred to here as Y-302), and mentioned in the previous report. This might be related to the constantly moist conditions encountered, usually in the range of 20-24% moisture, which is close to field capacity.

### Objective

The objective of this study is to determine the effect of soil moisture content and wetting and drying on mineralization.

### Procedures

Soil samples were collected in triplicate from different *Brachiaria humidicola/Desmodium ovalifolium* pastures: (1) Y-302, replication 1; (2) Y-302, replication 2; (3) experiment reported on page 31. These soils were subjected to the following laboratory incubation treatments:

1. Soil was placed in plastic bags directly (24% moisture);
2. Soil was air-dried for five days to reduce the moisture content from 24 to 19%;
3. Soil was subjected to a series of wetting and drying cycles for five days and incubated at 22% moisture.

All treatments were incubated in plastic bags in the dark for two weeks, then analyzed for $NO_3^-$ and $NH_4^+$; net mineralization and nitrification were determined.

Lowering the moisture content and the imposition of wetting/drying cycles markedly increased mineralization and nitrification rates (Table 1). These data may be interpreted in at least two ways: 1) under field conditions, mineralization is taking place extremely slowly due to the unfavorable climatic conditions (saturated sites), and only upon drying of the soils does the mineralization rate increase, or 2) mineralization and nitrification are proceeding at normal rates, but denitrification is occurring quickly so that one cannot measure nitrification by the accumulation of nitrate.

**Table 1. Nitrification and N mineralization measured by various procedures in pasture treatments.***

| | Field | | | Laboratory |
|---|---|---|---|---|
| Process | Tube Incubation | Bag Incubation** | Dry*** | Dry/ Wetting**** |
| | μN/g dmass/14 days | | | |
| Nitrification | 0.05 | 0.80 | 4.89 | 9.55 |
| Mineralization | 0.61 | 0.89 | 3.68 | 8.05 |

* Mean of all pasture treatments.
** 24% moisture (near field capacity).
*** Drying from 24 to 19% moisture.
**** Three wetting and drying cycles and then incubated at 24%

# Soil Characterization and Interpretation

Knowledge about properties of humid tropical soils, their variability in relation to the landscape, and their interpretation to users continues to be an essential component of this program. An informal survey revealed that the Fertility Capability Classification (FCC) system is being used in 37 countries throughout the world. A software interactive program for FCC classification and interpretation is being developed. A study on the variability on alluvial soils of the Amazon was completed and shows that some are quite fertile while others are of very low native fertility. Parameters for predicting fertility of alluvial soils have been indicated. Transects along West Sumatra, from the volcanic highlands to transmigration areas, show that volcanic influence does not extend to the central part of Sumatra, despite close proximity. Phosphorus fixation in Oxisols and Ultisols in Sitiung and nearby areas is less than if allophane were present due to volcanic influence.

# Utilization of the Fertility Capability Classification System

*Christopher W. Smith, N. C. State University*
*Stanley W. Buol, N. C. State University*
*Pedro A. Sanchez, N. C. State University*

The Fertility Capability Classification (FCC) system developed at North Carolina State University is used increasingly throughout the world, primarily in the tropics. This report summarizes the use of FCC to date and the direction of future work to document and expand the system.

To date, 34 countries and eight international organizations and agencies are using FCC in research or in the development of interpretative maps (Table 1). Many of these activities are discussed below.

As a result of the development of the ASIALAND Network, established and coordinated through IBSRAM, six Malaysian research agencies are developing a crop-specific classification system based on soil characteristics defined in the FCC. Activities planned include compilation and inventory of all existing soil data into a centralized data base. Yield data previously obtained on Malaysian soils will also be catalogued. The soil-management response for rubber, oil palm, cocoa, fruits and other food crops will be compared with FCC groups via cluster analysis; based on the results, the system may be amended or revised for Malaysia. The resulting FCC recommendations will be tested for acceptability by extension personnel and practicality of the system. Expected benefits include 1) achievement of maximum benefits from fertilizer-associated soil amendment practices by identifying the soil conditions where each technology has the greatest potential for success; 2) achievement of the maximum potential return on expenditures for soil survey and soil fertility research by improving communication between members of these two subdisciplines; 3) inputs toward an internationally accepted soil fertility classification system; and 4) exchange of information on soil fertility between tropical countries.

Several countries involved in the IBSRAM network agreed to classify their research sites in FCC as an integral part of their program. These countries include Burundi, Congo, Nigeria, Rwanda, Zambia; China, Malaysia, Thailand, Vietnam; Bolivia, Brazil,

**Table 1: Summary of countries and institutions using and testing FCC.**

**A: Countries that have requested information and are in initial stages of testing**

| | | |
|---|---|---|
| Argentina | Ecuador | Philippines |
| Australia | France | Rwanda |
| Bolivia | Guatemala | Sierra Leone |
| Brazil | Honduras | Spain |
| Burundi | India | Sri Lanka |
| Cameroon | Indonesia | Thailand |
| China | Ivory Coast | United States |
| Colombia | Madagascar | Venezuela |
| Congo | Nepal | Vietnam |
| Costa Rica | Nigeria | Western Samoa |
| Cuba | Panama | Zambia |
| Dominican Republic | Peru | |

Total: 37 countries

**B: Countries intensively testing and in an advanced stage of utilization**

| | | |
|---|---|---|
| Brazil | Peru | United States |
| Indonesia | Taiwan | Venezuela |
| Malaysia | Thailand | Zambia |

**C: Organizations using or testing FCC**

Food and Agriculture Organization (FAO) World Soil Map of Africa

International Board for Soil Research and Management (IBSRAM), Bangkok, Thailand

Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia

International Rice Research Institute (IRRI)

International Network for Fertility and Fertilizer Research (INSFFER), Los Baños, Philippines

USDA-Agriculture Research Service, Temple, Texas

USDA-Forest Service, Corvallis, Oregon

USDA-Soil Conservation Service, Lincoln, Nebraska

Canada-Manitoba Soil Survey

Costa Rica, Dominican Republic, Ecuador, Guatemala, Panama, Peru and Venezuela.

A Belgian university translated the FCC system into French, evaluated portions of the system, and offered recommendations for modifications and amendments pertaining to the depth criteria for the type, substrata type, and k and i modifiers. Alternative criteria are suggested for the i modifier in terms of the amount of P fertilizers required per ha or amount of soil test P in solution. It was also suggested that a new modifier for flooding hazard be added.

In the Philippines, IRRI has begun characterizing and classifying their fertilizer network (INSFFER) sites according to Soil Taxonomy and FCC with the intent of correlating the INSFFER results to the FCC system. IRRI also uses FCC to categorize ecosystems used in rainfed rice cultivation in South and Southeast Asia and to determine percentages of these lands with various fertility constraints.

FCC was used in Indonesia in conjunction with their Land Suitability Classification to provide interpretations for specific crops such as paddy rice, cassava, fruit trees, rubber and other horticultural crops. In addition, FCC was used to evaluate the extent of soil constraints in the Sitiung area. Trop-Soils staff used FCC to successfully predict that a Typic Dystropept in the uplands of Indonesia (Ceak by FCC) will not fix large quantities of P in spite of high levels of added P required to attain a critical level of solution P via P sorption isotherms.

Work in Thailand was conducted to relate Soil Taxonomy to FCC for some problem soils on the southeastern coast. The study showed the value of including FCC with Soil Taxonomy to include surface soil properties. The FCC system was modified to meet local requirements. The type, substrata type and modifiers were assigned numerical ranks, and FCC groups were scored and placed into one of five classes.

The FCC was extensively evaluated for applicability in managing P and K fertilizers on lowland rice in Taiwan. These workers concluded that (1) nonexchangeable K and CEC in the surface soil are proportional to the clay content, (2) large differences in rice yields are found among FCC type and substrata type (i.e., LC greater than C greater than LS greater than L"), and (3) yield response to PK-fertilizer on C-textured soils is insignificant but is highly significant in LS and L" soils. LC and L soils also showed a significant response. Based on these findings, it is predicted from FCC maps that P and K use in Taiwan for lowland rice can be significantly decreased. Char Fer Lin also used FCC as a guide for making N fertilizer recommendations for lowland rice.

At the request of UN-FAO in Rome, Buol helped translate the FAO world soil map of Africa into FCC units. These interpretative maps are now available. In addition, the FAO soil map of South America was translated into FCC units. CIAT has compiled a general FCC map of tropical South America using data from general soil maps and other studies. Several studies used FCC to group soils of Campinas, Brazil, and portions of Venezuela and Peru as the basis for further technology transfer and research.

In a USAID project to study the growth and site relationships of Caribbean pine in Jamaica, Costa Rica, Trinidad and Venezuela, FCC is being used to explore the growth and yield as it relates to FCC criteria. To date, it does not appear that low soil K (k modifier) and high soil acidity (a modifier) limit tree growth.

The Canada Soil Survey recently requested a copy of FCC and plans to evaluate the system for use in Manitoba and possibly nationwide.

In the United States, fertilizer response and management practices have been compared with FCC groups, where it was found that high soybean level yields can be obtained under a variety of different soil conditions. It was also noted that not all soil properties influence yield in the same way every year, and, in this study, prediction of suitable and unsuitable soils for soybean production cannot be made because researchers preselect sites that are suitable for the intended use. Denton and coworkers determined the usefulness of FCC in predicting relative rates of K required for tobacco production: the FCC system was found useful in evaluating tobacco leaf yield response to fertilization and could be used to improve fertilizer recommendations.

The USDA Soil Conservation Service placed all the soil series in the United States into FCC, noting dominant soil series by the major FCC groupings within major land resource areas. Application of FCC by the SCS is currently being tested. The SCS also classified phases of soil series mapped in Greenville, Virginia, in the FCC system and provided manage-

ment interpretations for each FCC grouping. Fertility specialists were impressed by the interpretations and groupings, and it was felt that the exercise would help foster a better working relationship among pedologists and soil fertility specialists. Sharpley, working with USDA-ARS to develop a model for predicting the K-supplying power of soils, used FCC as a basis for grouping soils in the study. He determined that the prediction of exchangeable K based on clay content is significantly improved if soils are separated by FCC groupings (Sharpley and Buol 1986).

Lastly, requests for reprints of the FCC system were received from a variety of locations and institutions, among them the following: the University of Western Australia, Perth; the University of Cordoba, Spain; the University of Santiago, Spain; Ecological Systems Analysis Group, Bariloche Foundation, Rio Negro, Argentina; the AID Mission to Honduras; North-Eastern Hill University, Shellong, India; Soil Testing Laboratory, Thanjavur District, Tamil Nadu, India; the Institute for Investigation in Agrochemistry and Improvement of Soils, Havana, Cuba, and the National University, Medellin, Colombia. A summary of the countries and institutions involved at some level in the use and testing of FCC is shown in Table 1. Documentation on the use is shown in Table 2.

### Software Development

Currently, the FCC computer software delivery system includes a number of interpretations for FCC groups under the different management system headings of "Upland Agronomic Recommendations" and "Paddy Rice Recommendations." Work is being undertaken to further document existing criteria and recommendations, to amend criteria and add alternative criteria to define modifiers, and to expand and document the interpretations of FCC groupings for low- and high-input upland agronomic systems and paddy-rice cultivation. Another proposed expansion of the system includes interpretations for agroforestry systems.

**Table 2. Documentation of FCC use by countries or international organizations.**


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**Table 2. (continued)**

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## Alluvial Soils of the Amazon Basin

*Robert E. Hoag, N. C. State University*
*Stanley W. Buol, N. C. State University*

Diversity among soils in the tropics is not confined to regions with sharply contrasting elevation, precipitation, temperature or vegetation. Diversity may be observed even in alluvial systems where the principal source of variation is attributable to differences in parent, or initial, materials.

### Objective

The objective of this study is to assess the variability of alluvial soils of the Peruvian Amazon in relation to their production potential.

### Procedures

Floodplains of tributaries flowing into the Marañón and Amazon rivers were selected as sampling sites (Figure 1). Three geographic units were defined from which the tributaries originate and acquire their sediment loads:

*Group I*—the northern Peruvian Andes, composed predominantly of Paleozoic and Mesozoic sandstones, slates and limestones containing batholiths of acid igneous and metamorphic rocks;

*Group II*—areas in which the tributaries dissect or are in close proximity to calcareous-bearing sandstones and limestone. This includes a portion of the southern Ecuadorian Andes, which are predominantly Mesozoic and Paleozoic metamorphosed sedimentary rocks, basalt and igneous rocks overlain in some areas by volcanic ash of recent origin but flanked on the eastern edge by Tertiary calcareous-bearing sandstones and limestone. It also includes tributaries that originate within the western edge of the Peruvian basin and which dissect or are in close proximity to calcareous-bearing sandstone and limestone outcroppings;

*Group III*—areas of polycycled, within-basin, unconsolidated Quaternary sediments with no inputs of calcareous sediments or solutes. This also includes the Rio Putumayo, which originates in the Northern Ecuadorian Andes where the lithology is comprised of acid igneous and volcanic formations.

At the time of sampling 20 sites were selected, which either were being used for agriculture or at some time in the past two to five years had been in production. When possible, fields were chosen along straight stretches of the tributaries and upstream from, or well below, tributaries flowing into the primary channel. The soils were sampled at a distance of approximately 20 to 50 m from the river embankment.

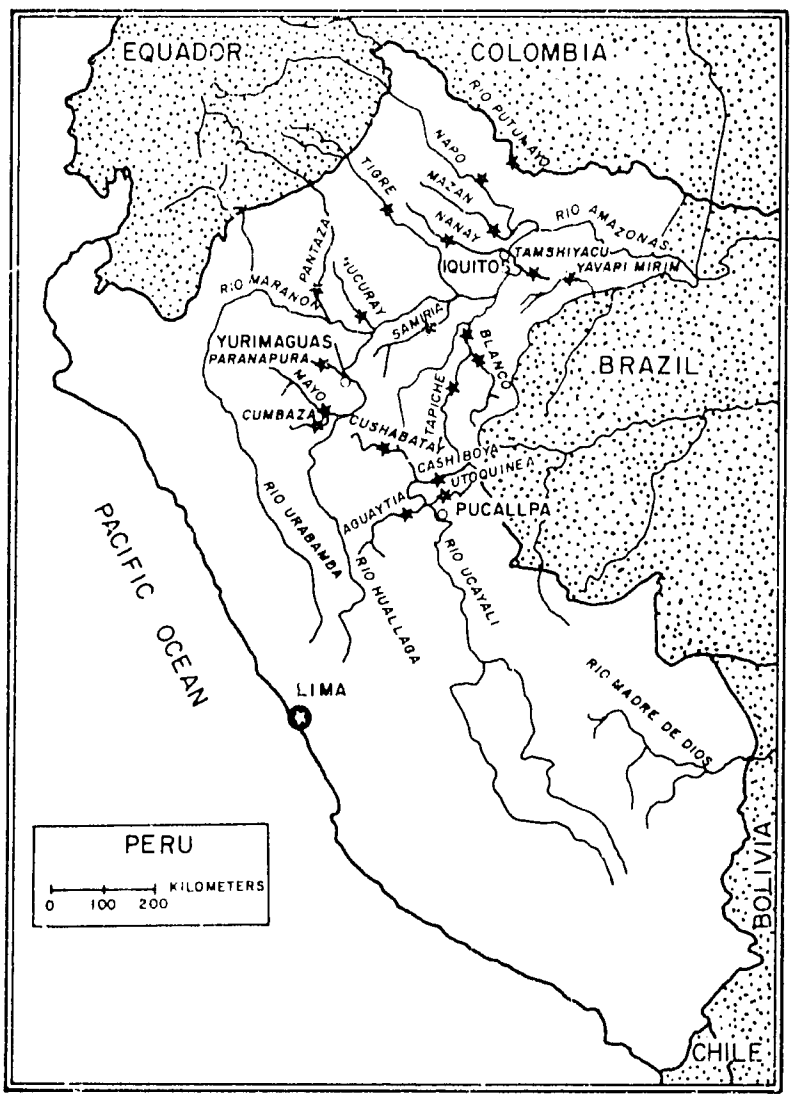


**Figure 1. Sampling sites in Peru, indicated by stars.**

**Table 1. Taxonomic and Fertility Capability Classification of sampled alluvial soils of the Amazon.**

| Location | Soil Taxonomy | FCC classification |
|---|---|---|
| **Group I** | | |
| Aguaytia | (Typic)* Tropofluvent; clayey over loamy, montmorillonitic (nonacid), isohyperthermic | Cbg |
| Cumbaza | (Typic) Tropofluvent; coarse-loamy, siliceous (nonacid), isohyperthermic | Lgk |
| Cushabatay | Aeric Tropic Fluvaquent; coarse-loamy, mixed (nonacid), isohyperthermic | Lbgk |
| Mayo | Aquic Hapludult; very-fine, montmorillonitic (calcareous), isohyperthermic | Cbgv |
| **Group II** | | |
| Cashiboya | Aeric Tropic Fluvaquent; very-fine; montmorillonitic (acid), isohyperthermic | Cg |
| Napo | (Aquic) Tropofluvent; coarse-silty over clayey, mixed (nonacid), isohyperthermic | Lgk |
| Nucuray | Typic Eutropept; fine silty, mixed, isohyperthermic | Lgk |
| Paranapura | (Typic) Tropofluvent; coarse-loamy, mixed (nonacid), isohyperthermic | Lg |
| Pastaza | Tropic Fluvaquent; coarse-loamy, mixed, (nonacid), isohyperthermic | Lgk |
| Samiria | (Aquic) Tropofluvent; fine-silty, mixed (nonacid), isohyperthermic | Lgk |
| Tapiche (upper) | (Aquic) Tropofluvent; fine, montmorillonitic (acid), isohyperthermic | Lghk |
| Tapiche (lower) | (Aquic) Tropofluvent; fine-silty, mixed, isohyperthermic | Cg |
| Utoquinea | Aeric Tropic Fluvaquent; fine-silty, mixed (acid), isohyperthermic | Lg |
| **Group III** | | |
| Blanco | Aeric Tropaquept; fine, mixed (acid), isohyperthermic | Lag |
| Mazan | Aeric Tropic Fluvaquent; fine, mixed (acid), isohyperthermic | Cagk |
| Nanay | Aeric Tropic Fluvaquent; fine-loamy, siliceous (acid), isohyperthermic | Lagk |
| Putumayo | Aeric Tropaquept; very-fine, mixed (acid), isohyperthermic | Cgh |
| Tamshiyacu | Tropic Fluvaquent; fine, mixed (acid), isohyperthermic | Cag |
| Tigre | Aeric Tropic Fluvaquent; fine loamy, mixed (acid), isohyperthermic | Seghk |
| Yavari Mirim | Tropic Fluvaquent; very-fine, mixed (acid), isohyperthermic | Cag |

* Subgroups for the Tropofluvents are not defined in Soil Taxonomy. The Typic and Aquic subgroup designations appear in parentheses and were based upon criteria for Udifluvents.

## Results

### *Soil Taxonomy*

Taxonomic classification of the soil profiles is presented in Table 1. Except for the profile along the Rio Mayo, which was classified into the Mollisol order, all soils are either Inceptisols or Entisols. Surface horizons of the profile by the Rio Mayo meet criteria for a mollic epipedon, and base saturation was near 100% at a depth of 2 m. Free calcium carbonates were present as finely divided lime. An argillic horizon was not present, as there was less than an 8% increase in clay content below the A horizon.

### *Organic carbon*

Surprisingly, most of the profiles had a regular decrease of organic C with depth; C content fell

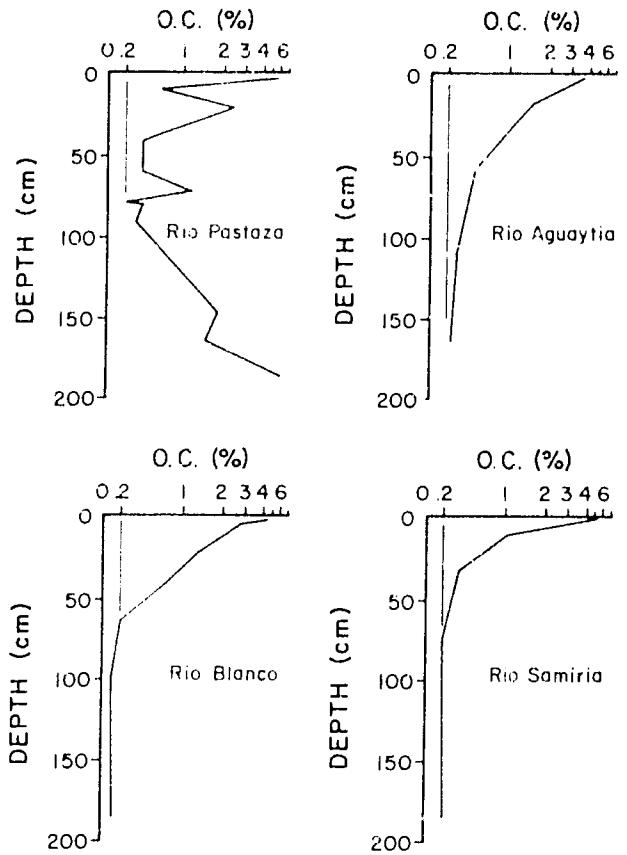


**Figure 2. Comparison of organic carbon content distribution with depth in selected soils.**

below 0.2%, however, only in sites along the Blanco, Nucuray and Putumayo rivers. In an alluvial setting with recently deposited sediments, one would expect to find an irregular decrease in organic C with depth (as in the case of the sampling site near Rio Pastaza) rather than a regular decrease (as illustrated by data for sites near the Aguaytía, Blanco and Samiria rivers) (Figure 2). Organic C content of the surface horizons was generally in the range of 4 to 7%, but was recorded in some sites as less than 1% and at another at slightly over 17%. The C content dropped dramatically and uniformly with depth in most soils.

At sampling sites that had recently been cleared for agricultural use, a thin (< 2 mm) but dense mat of fine roots covered the soil surface. During the following year this root mat would presumably decompose and provide a source of nutrients to the crop, while at the same time provide a protective cover against erosion during the next flooding sequence.

*Green rust*

Most of the sampling sites flood annually and remain submerged for several weeks during January-April. More highly elevated sites flood periodically every three to five years. Most of the profiles have gray matrix colors with more brightly colored mottles indicating a fluctuating water table. The phenomenon known as "green rust" was observed in the profile along the Pastaza River. As subsoil samples were removed by augering, the colors appeared greenish-blue, but within minutes a brownish rind had formed on the surface of the sample. Colors of the wet samples had to be identified quickly due to the rapid partial oxidation of $Fe^{2+}$.

*Mineralogy*

Mineralogy designation at the family level for soils in loamy and silty particle-size classes were determined by grain counts made of the fine sand fraction (Table 2). While the taxonomic classification of soils is useful in that the names communicate specific information, it may be observed that it is not possible to make a distinction between Group II and III soils based solely on taxonomy (Table 1). Thus, to make agricultural management interpretations, one must look beyond the taxonomic classification and consider the laboratory data. The taxonomic classification has served its purpose of communicating information with respect to specific soil properties and within a defined range.

*Fertility Capability Classification*

The soil Fertility Capability Classification system (FCC) is used to indicate the status of fertility-related properties in the topsoil and upper portions of the subsoil. Quantitative physical and chemical measurements are made to evaluate soils for their agronomic management potential.

The primary symbol of the FCC classification indicates the textural grouping of the 0-20 cm zone as sandy, loamy or clayey. Within any given tributary system, the surface texture may range from sand to clay and is a function of sediment source, sediment load and stream morphology rather than a function only of the geological source of sediments. Except for the site along the Rio Tigre, which has a sandy topsoil, all sites have loamy or clayey textures. The Rio Tigre site was sampled on a point bar where one would expect coarser textures, whereas 15 of the

remaining sites were sampled along straight portions of the tributaries.

The secondary symbols or modifiers indicate potential nutrient or physical limitations for agronomic crops. Across the range of soils sampled, vertic properties, low K reserves, Al toxicity, free Ca carbonates, low CEC or impeded internal drainage is acknowledged by a modifier symbol.

Symbols indicating the FCC classification were assigned on the basis of weighted values from laboratory data appearing in Table 3.

The FCC classifications of several soils contain the symbol k, indicating low K reserves in the 0-50 cm zone. Laboratory analysis indicates that for some soils there are high levels of K in the surface horizons, decreasing substantially in the upper subsoil horizons. For instance, at the site along the Rio Mazan, the K level within the 0-20 cm zone is 0.23 cmol/L soil. However, within the A horizon (0-1 cm), 0.53 cmol/L of K was measured; within the 1-8 cm zone, 0.24 cmol/L, and within the 8-70 cm zone, 0.14 cmol/L were measured. The weighted average of K for the 0-50 cm zone was calculated to be 0.19 cmol/L; therefore, the symbol applies. Concentration of K in the surface horizons at this site is likely the result of nutrient cycling or recent alluvial deposition rather than ash accumulation as the slash had been gathered and burned in piles and not eliminated by broadcast burning.

The k symbol was intended to be applied to soils low in weatherable minerals in which K deficiencies could occur. Test results indicate levels of K < 0.20 cmol/L within the 0-50 cm zone for some of the soils; however, most of the soils sampled have > 10% weatherable minerals within the fine sand fraction.

Soils at five of the sampling sites have a relatively high potential for K deficiency and are in the eastern half of the sampling region: the Blanco and Tamshiyacu sites, whose soils are classified as fine, montmorillonitic; those along the Pastaza and Tigre rivers, which are loamy with mixed mineralogy, and the soil along the Rio Nanay, which is fine-loamy, siliceous.

Sites along three tributaries (Aguaytía, Cushabatay and Mayo) fed by watersheds in the Andes contain free Ca carbonates. In contrast, the very acid alluvial soils in the eastern portion of the Peruvian basin may have 60-90% Al saturation.

**Table 2. Summary of grain counts used to determine mineralogy at the family level in loamy and silty particle-size classes.**

| Location | Mineralogy | | | |
|---|---|---|---|---|
| | Quartz | Feldspar | Mica | Opaque |
| | % | | | |
| **Group I** | | | | |
| Aquaytía | 57 | 14 | 4 | 25 |
| Cumbaza | 92 | 4 | 2 | 2 |
| Cushabatay | 78 | 9 | 4 | 9 |
| Mayo | Montmorillonitic (very-fine particle-size class) | | | |
| **Group II** | | | | |
| Cashiboya | 55 | 6 | 2 | 37 |
| Napo | 38 | 13 | 15 | 34 |
| Nucuray | 66 | 7 | 7 | 20 |
| Paranapura | 63 | 22 | 4 | 11 |
| Pastaza | 17 | 6 | 15 | 62 |
| Samiria | 56 | 12 | 15 | 17 |
| Tapiche (upper) | Montmorillonitic (fine particle-size class) | | | |
| Tapiche (lower) | 59 | 8 | 18 | 15 |
| Utoquinea | 73 | 7 | 7 | 13 |
| **Group III** | | | | |
| Blanco | 80 | 3 | 5 | 12 |
| Mazan | Mixed (fine particle-size class) | | | |
| Nanay | 94 | 0 | 1 | 5 |
| Putumayo | Mixed (very-fine particle-size cl.) | | | |
| Tamshiyacu | Mixed (fine particle-size class) | | | |
| Tigre | 64 | 8 | 19 | 9 |
| Yavari Mirím | Mixed (very-fine particle-size cl.) | | | |

*Particle-size distribution*

In the soils sampled, particle-size distribution was related to stream morphology rather than to position within the Basin. When possible, sampling sites were selected along a straight portion of the tributary channel. Circumstances precluded this effort in the cases of the Cushabatay, Tigre and Utoquinea rivers, which were sampled on point bars. They tended to have a higher percentage of sand and greater variability throughout the profile than sites sampled along straight stretches or cutbanks.

The profile along the Rio Pastaza is an exception. That sampling site was just upstream from a cut bank, but the profile had many depositional layers of

**Table 3. Nutrient data used to determine weighted values for the 0-20 cm layer.**

| Location | Depth | Ca | Mg | K | Na | Mn | Cu | Zn | P |
|---|---|---|---|---|---|---|---|---|---|
| | cm | cmol/L soil | | | | mg/L soil | | | |
| **Group I** | | | | | | | | | |
| Aguaytía | 0-5 | 33.5 | 2.9 | 0.55 | 0.14 | 134.6 | 5.41 | 5.19 | 30.7 |
| | 5-30 | 25.2 | 3.2 | 0.44 | 0.12 | 188.8 | 4.26 | 2.26 | 9.6 |
| Cumbaza | 0-10 | 6.7 | 1.17 | 0.22 | 0.06 | 85.8 | 1.40 | 1.01 | 6.2 |
| | 10-20 | 6.5 | 0.95 | 0.19 | 0.05 | 87.3 | 1.63 | 0.52 | 3.0 |
| Cushabatay | 0-2.5 | 37.6 | 2.5 | 0.44 | 0.14 | 150.5 | 5.64 | 3.37 | 26.7 |
| | 2.5-30 | 47.4 | 2.6 | 0.47 | 0.15 | 172.0 | 6.53 | 3.86 | 11.0 |
| Mayo | 0-8 | 41.2 | 10.0 | 2.43 | 0.67 | 94.9 | 5.92 | 5.53 | 202.8 |
| | 8-30 | 38.7 | 9.5 | 1.76 | 2.14 | 86.4 | 6.30 | 3.87 | 99.9 |
| **Group II** | | | | | | | | | |
| Cashiboya | 0-1.5 | 33.4 | 6.5 | 0.76 | 0.21 | 126.9 | 5.73 | 5.64 | 30.1 |
| | 1.5-7 | 30.5 | 6.6 | 0.72 | 0.19 | 142.0 | 5.37 | 3.91 | 18.2 |
| | 7-75 | 29.1 | 7.2 | 0.66 | 0.47 | 125.6 | 4.64 | 2.55 | 33.7 |
| Napo | 0-3 | 7.4 | 2.9 | 0.99 | 0.16 | 26.2 | 6.42 | 4.67 | 46.7 |
| | 3-10 | 5.1 | 1.7 | 0.19 | 0.15 | 15.5 | 6.77 | 2.18 | 19.4 |
| | 10-27 | 5.3 | 2.0 | 0.11 | 0.19 | 19.8 | 3.66 | 0.89 | 12.2 |
| Nucuray | 0-9 | 15.9 | 2.5 | 0.28 | 0.04 | 98.8 | 4.55 | 6.44 | 12.2 |
| | 9-20 | 9.7 | 1.7 | 0.19 | 0.04 | 51.9 | 4.65 | 2.23 | 24.2 |
| Paranapura | 0-2 | 7.0 | 0.8 | 0.24 | 0.01 | 60.0 | 2.24 | 2.32 | 27.2 |
| | 2-6 | 3.7 | 0.8 | 0.16 | 0.00 | 30.1 | 1.25 | 1.87 | 25.0 |
| | 6-15 | 4.9 | 1.0 | 0.21 | 0.01 | 25.1 | 1.86 | 1.78 | 25.9 |
| | 15-25 | 5.8 | 1.0 | 0.21 | 0.02 | 33.3 | 2.84 | 2.13 | 31.2 |
| Pastaza | 0-5 | 4.4 | 7.6 | 0.57 | 0.07 | 32.7 | 7.59 | 4.23 | 36.5 |
| | 5-13 | 2.3 | 4.4 | 0.11 | 0.04 | 32.7 | 6.57 | 1.37 | 8.8 |
| | 13-24 | 5.0 | 6.8 | 0.18 | 0.12 | 31.4 | 21.36 | 1.65 | 11.8 |
| Samiria | 0-2.5 | 13.9 | 3.3 | 0.44 | 0.05 | 77.7 | 0.92 | 5.75 | 50.6 |
| | 2.5-8 | 8.5 | 2.3 | 0.25 | 0.04 | 91.2 | 0.74 | 3.39 | 24.4 |
| | 8-15 | 9.4 | 2.9 | 0.19 | 0.05 | 73.5 | 2.65 | 1.86 | 16.7 |
| | 15-50 | 11.6 | 3.2 | 0.20 | 0.07 | 33.2 | 2.78 | 0.77 | 23.0 |
| Tapiche (upper) | 0-2.5 | 21.6 | 4.7 | 0.70 | 0.10 | 32.7 | 7.59 | 4.23 | 29.4 |
| | 2.5-8 | 21.2 | 5.3 | 0.71 | 0.08 | 32.7 | 6.57 | 1.37 | 23.7 |
| | 8-30 | 8.6 | 2.3 | 0.32 | 0.09 | 31.3 | 21.36 | 1.65 | 27.8 |
| Tapiche (lower) | 0-1 | 10.4 | 1.1 | 0.48 | 0.18 | 76.3 | 10.20 | 6.09 | 48.3 |
| | 1-7 | 13.9 | 2.1 | 0.40 | 0.13 | 36.0 | [illegible] | 2.11 | 30.0 |
| | 7-22 | 7.4 | 1.9 | 0.19 | 0.20 | 21.0 | 1.27 | 0.78 | 2.0 |
| Utoquinea | 0-10 | 18.9 | 4.1 | 0.41 | 0.14 | 168.2 | 2.19 | 2.42 | 33.3 |
| | 10-45 | 12.5 | 2.4 | 0.28 | 0.12 | 159.3 | 1.69 | 1.78 | 26.7 |

**Table 3. (continued)**

| Location | Depth | Ca | Mg | K | Na | Mn | Cu | Zn | P |
|---|---|---|---|---|---|---|---|---|---|
| | cm | cmol/L soil | | | | mg/L soil | | | |
| **Group III—** | | | | | | | | | |
| Blanco | 0-3 | 17.0 | 4.3 | 0.49 | 0.08 | 46.2 | 2.30 | 1.96 | 8.5 |
| | 3-7 | 5.1 | 1.7 | 0.24 | 0.07 | 14.1 | 0.91 | 1.82 | 16.2 |
| Mazan | 0-1 | 2.1 | 0.9 | 0.50 | 0.08 | 28.3 | 2.38 | 3.13 | 40.0 |
| | 1-8 | 0.9 | 0.3 | 0.24 | 0.04 | 9.5 | 1.98 | 1.54 | 6.6 |
| | 8-70 | 0.7 | 0.4 | 0.19 | 0.05 | 5.1 | 2.53 | 0.71 | 2.0 |
| Nanay | 0-2 | 0.6 | 0.5 | 0.27 | 0.03 | 14.6 | 0.76 | 2.62 | 20.7 |
| | 2-10 | 0.4 | 0.3 | 0.14 | 0.02 | 5.9 | 0.53 | 1.68 | 15.8 |
| | 10-22 | 0.6 | 0.2 | 0.11 | 0.02 | 3.5 | 0.82 | 1.24 | 12.4 |
| Putumayo | 0-4 | 3.1 | 0.9 | 0.53 | 0.44 | 13.9 | 2.66 | 4.14 | 28.1 |
| | 4-14 | 3.1 | 0.8 | 0.18 | 0.29 | 16.5 | 2.57 | 1.50 | 8.6 |
| | 14-23 | 2.3 | 1.1 | 0.30 | 0.28 | 20.3 | 2.48 | 0.97 | 9.7 |
| Tamshiyacu | 0-2 | 6.1 | 1.0 | 0.52 | 0.05 | 67.1 | 3.26 | 5.71 | 42.2 |
| | 2-8 | 2.0 | 0.3 | 0.25 | 0.01 | 42.9 | 2.09 | 2.85 | 4.8 |
| | 8-52 | 0.5 | 0.1 | 0.30 | 0.01 | 16.6 | 2.97 | 1.26 | 0.9 |
| Tigre | 0-2 | 2.8 | 0.9 | 0.11 | 0.02 | 35.9 | 0.75 | 2.40 | 20.3 |
| | 2-6 | 3.1 | 1.2 | 0.11 | 0.01 | 34.8 | 1.30 | 2.27 | 10.5 |
| | 6-8 | 7.4 | 2.4 | 0.13 | 0.13 | 62.0 | 3.43 | 5.76 | 9.1 |
| | 8-18 | 3.0 | 1.1 | 0.06 | 0.04 | 46.9 | 2.47 | 3.23 | 8.5 |
| | 18-30 | 4.8 | 1.7 | 0.09 | 0.04 | 41.4 | 3.80 | 5.50 | 11.0 |
| Yavarí Mirím | 0-2 | 6.7 | 1.5 | 0.48 | 0.01 | 114.8 | 2.58 | 7.22 | 24.5 |
| | 2-10 | 1.8 | 0.4 | 0.32 | 0.02 | 34.5 | 2.04 | 2.91 | 3.9 |
| | 10-30 | 0.8 | 0.3 | 0.37 | 0.02 | 19.0 | 2.30 | 2.80 | 4.0 |

sandy loam and silt loam materials. This was one of the larger rivers adjacent to a sampling site, and the sedimentation environment was apparently more varied and in more rapidly flowing waters than along other tributaries.

*Soil reaction*

Soil pH values (1:1 $H_2O$) are related to the geologic formation from which tributaries originate and their relative position within the Basin. In Table 1 the sampling sites were grouped according to their geological source of sediments. In Table 4 the range of pH values within horizons of the upper 1 m are also listed. Soil reaction within the major portion of the rooting zone (taken arbitrarily to be 1 m in depth) is related to the sediment source and distance from the Andes, the Andes being the primary source of calcareous sediments in the tributary systems.

The Aguaytía, Cumbaza, Cushabatay and Mayo rivers comprise Group I and originate within the Eastern Peruvian cordillera. Those soils are alkaline, with pH values ranging from 6.3 to 8.5. Soils within Group I may exhibit phosphate and minor element deficiencies, although extractable levels of these elements are high. It is important to recognize that elements extracted with a weak acid from soils with high pH values may not be strongly correlated to plant availability.

The Cashiboya, Paranapura, Samiria, Tapiche and Utoquinea rivers of Group II originate within the foothills of the Peruvian Andes on uplifted marine sediments containing carbonaceous sandstones. The Napo and Pastaza rivers originate in the Ecuadorian cordillera, which, at upper elevations, is composed

**Table 4. Sampling sites grouped according to their geologic source of sediments and reaction class.***

| Location | pH value range within the profile |
|---|---|
| **Group I (pH 8.0-6.5)** | |
| Aguaytia | 8.5 - 7.5 |
| Cumbaza | 8.2 - 7.8 |
| Cushabatay | 7.7 - 6.3 |
| Mayo | 8.0 - 7.2 |
| **Group II (pH 6.5-5.0)** | |
| Cashiboya | 5.9 - 5.1 |
| Napo | 5.9 - 5.2 |
| Nucuray | 5.7 - 5.0 |
| Paranapura | 7.3 - 5.2 |
| Pastaza | 6.9 - 5.4 |
| Samiria | 6.0 - 5.4 |
| Tapiche (upper) | 5.5 - 4.7 |
| Tapiche (lower) | 5.7 - 4.8 |
| Utoquinea | 5.9 - 5.1 |
| **Group III (pH 5.0-3.5)** | |
| Blanco | 5.0 - 4.7 |
| Mazan | 5.0 - 4.0 |
| Nanay | 4.5 - 4.0 |
| Putumayo | 5.0 - 4.5 |
| Tamshiyacu | 4.7 - 4.5 |
| Tigre | 6.9 - 4.3 |
| Yavarí Mirím | 4.3 - 3.8 |

* Groupings for reaction class were made on the basis of pH values measured within the upper 1 m of the soil profile. The classification indicates the predominate reaction class througnout the profile, although the range of pH values within a profile may exceed or fall below class limits.

predominantly of acid igneous and volcanic rock strata. The tributaries dissect limestone-bearing marine deposits along the eastern flank of the mountains. Rio Nucuray originates from within-basin sediments, yet pH values within the profile are only slightly to moderately acidic. Soils within this group appear to be chemically the most conducive for agriculture.

Group III contains soil samples along the Blanco, Mazan, Nanay, Tigre, Tamshiyacu and Yavarí Mirím tributaries originating from within-basin sediments.

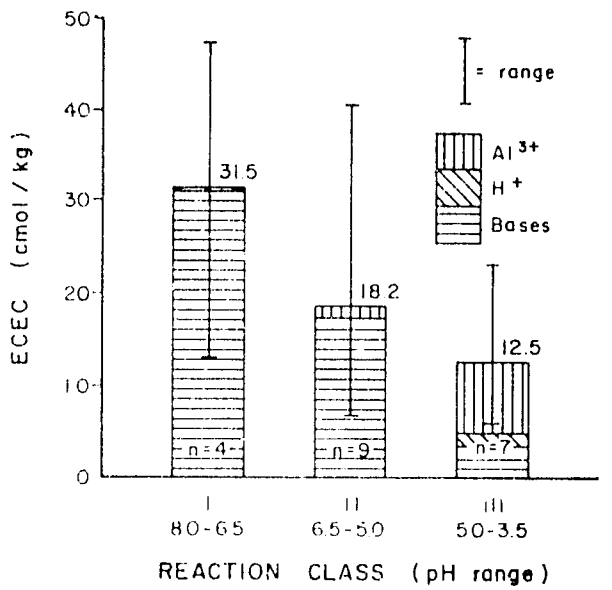


**Figure 3. Average ECEC values for the 0-20 cm zone by reaction class.**

The Putumayo river originates in the northern portions of Ecuador dominated by acid igneous and volcanic lithology. Soils along tributaries in Group III do not receive inputs of calcareous sediments or solutes and are extremely acid.

Within a soil profile there may be differences in pH values of the various horizons. Abrupt changes may be observed in the profiles sampled near the Blanco, Paranapura and Tigre rivers where the maximum and minimum pH values differ by as much as 2.7 units. Other soils also lack uniform pH values, but to a lesser degree. Differences in pH values among the horizons may be related to burning of slash, which reduces acidity of the surface horizons, or to past events in the sedimentation process.

Mountains and hills are the primary watersheds for some tributaries, and erosional events may account for differences in pH values within a profile downstream. Additions of calcareous material to the sediment load of a tributary may occur during a single erosive event rather than as a gradual and progressive erosion process. Stream piracy or the joining of stream channels with different sources of sediment caused by the high degree of meandering may also result in the chemistry of one river system to become altered.

Although there may be variability of pH values within a profile, variability within the basin among profiles is even greater. The fact that it is possible to

predict the reaction class based upon position within the Basin and origin of the tributary is important.

*Exchange properties*

The degree of diversity of alluvial soils within the Amazon Basin of Peru is more fully expressed in the chemistry of the soils than it is in the physical properties. Soil acidity, percentage of base saturation, and percentage of Al saturation are the most apparent soil characteristics for making comparisons.

Soils within Group I tributaries have base saturation values near 100% at both the natural soil acidity and at pH 8.2 (data not shown). Sampling sites along tributaries in Group II have base saturation values predominantly in the range of 90 to 100% at the soil's actual pH value, and over 50% at pH 8.2. Aluminum saturation within the group is generally less than 10%. Some soils, like those along the Rio Napo and lower Rio Tapiche, have layers that are more acid and more highly Al saturated than the rest of the profile. It is unlikely that pedogenetic processes are the cause of these acidic horizons; it is more likely that they are a result of erosional and depositional events.

The sum of bases in Group III soils is substantially lower than those in Groups I and II at the field soil pH values, since much of the exchange complex is occupied by $Al^{3+}$ ions. The CEC values nearly double at pH 8.2, demonstrating the large amount of variable charge present in these extremely acid soils.

The 0-2 cm zone of the Rio Yavari Mirim site contains considerably more bases than the rest of the profile. This is likely due to the effect of ash that accumulated on the surface after a burn the previous year. Although the pH value of the soil has likely not increased, the Al saturation is only one-half that for the 2-10 cm zone.

A comparison of the average ECEC values for the 0-20 cm zone is made for each of the three soil groups (Figure 3). Within Group I soils, the exchange complex is fully saturated with bases, and the average ECEC value is 31.5 cmol/L soil. The bars in Figure 3 representing Group II and III soils have been partitioned to show exchangeable bases and exchangeable acidity as well. On the average (n = 9), there is only a negligible amount of exchangeable Al in Group II soils with pH values ranging from 5.0 to 6.5.

In sharp contrast to soils in Groups I and II, soils in Group III with an extreme acid reaction may have up to 90% Al saturation, with a mean value (n = 7) around 60%. To neutralize the exchangeable acidity in these strongly buffered soils with high activity clays is impractical given the current economic and technological constraints. It may be possible, however, to increase yields by planting Al-tolerant varieties. Currently there is little incentive to do so, as many farmers are unable to market their excess yields.

Apparent CEC of the clay was calculated to determine if CEC values were consistent with the mineralogy of the clay fraction. Except for soils that contain free carbonates, CEC values were consistent with clay mineralogy, as determined by X-ray analysis.

Most clay fractions of the soils sampled are dominated by montmorillonite, which may have a charge of 80-120 cmol/L. Kaolinite CEC values range from approximately 1-10 cmol/L, and CEC values for mica may range from 20-40 cmol/L. Organic matter may contribute significantly to the variable charge in the surface layers of acid soils as CEC values have been reported to range from 100 to 300 cmol/L.

Values reported for apparent CEC of the clay and percentage of variable charge appear to be consistent with the clay mineralogy and distribution of organic matter throughout the profiles.

*White-, black- and clear-water rivers*

Before this study was initiated, there appeared to be some basis on which to group the tributaries feeding the Amazon as determined by sediment load—i.e., white-, black- or clear-water rivers. It was already recognized, however, that river color was not a justifiable parameter upon which to differentiate drainage systems and alluvial soils. Factors such as stream morphology, gradient, elevation of the watershed, and sediment source determine whether a river is allochthonous or autochthonous.

The Rio Negro flowing out of Brazil acquired its name from the appearance of the water: darkened by leachates from organic matter, but free of suspended clay, the water of this river appears black.

Some rivers within the study area flowed white, brown or black. The Rio Tapiche appears to be a black-water river near Requena; however, nearing its intersection with the Blanco River, the river is

considerably narrower and the water is chalky with sediment. Apparently, as small, sediment-free tertiary drainages flow into the Tapiche, the sediment load acquired farther upstream is substantially diluted. The Tapiche appears to be a drowning river channel in which the gradient near the intersection of the Amazon is not great, and the primary channel strongly meanders and appears braided. It is not known to what extent acids flowing into the system via tertiary drainages have encouraged flocculation of suspended clay, thereby clearing the water.

It appears that while tributaries originating within the mountains gain much of their sediment load during the rainy season, tributaries at lower elevations gain their load as the waters recede. River banks, once kept buoyant by high water as abrasive sediments undercut the bank, collapse into the river as the waters recede and the weight of the saturated soil overcomes cohesive forces. The sediment load along a tributary does not continue to increase with distance, however, due to the unloading process that takes place along the many point bars.

*Socioecological relationships*

It is the point bars and sand bars that become exposed with the receding waters that the natives cherish for rice production. Warm, moist soil free of weeds and jungle litter provides rice farmers with a beach for a system requiring almost no inputs.

The tributaries are used by natives for transportation, fishing, waste disposal and bathing, and as a source of drinking water. Frequently, people in boats appeared to be involved in routine daily activities, although no homes were present along the riverbanks. Along rivers with broad floodplains (2 km or more wide), the people did not live directly along the main river channel but on the secondary, elevated terrace not subject to annual flooding. Almost any secondary terrace along the primary channels of continuously navigable tributaries may be inhabited.

Secondary residences, many of them still partially submerged at the time of sampling, were constructed along some tributaries and the Amazon floodplain. The people evacuate these residences during the seasonal flood stage and re-inhabit them as receding waters expose the floodplains, point bars and river banks for cultivation.

A much greater difference may exist between the low- and high-water marks along the tributaries than exists along the primary channel of the Amazon. Where the tributaries tend to be channelized with a relatively narrow floodplain, the water level may fluctuate 5 m or more over a period of one year. The Amazon River, however, may fluctuate by only 1-3 m. Even with the vast amount of water flowing into the Amazon via tributaries, the water level does not appear to fluctuate as much as along the tributaries. This observation is based upon physical evidence of flooding and the height of pilings supporting permanent dwellings along the Amazon. Apparently, though, the floodplain of the Amazon is much larger in proportion to its volume of peak flow than along some tributaries. It appears that expansive areas of the jungle are inundated by water flowing more or less along the general course of the Amazon.

**Conclusions**

Soils of floodplains of tributaries flowing into the Amazon River in Peru may be chemically very diverse, with potentially significant agronomic ramifications. This diversity in soil properties, however, is predictable knowing the geologic source of sediments and the distance from the Andes.

Soils on floodplains of tributaries originating within the limestone and calcareous-bearing sandstone regions of the Peruvian Andes are moderately alkaline and 100% base-saturated, and they have clay fractions dominated by montmorillonite.

Soils on floodplains of tributaries that dissect or are in close proximity to calcareous outcroppings are near neutral to moderately acid, may have < 10% Al saturation, and may have montmorillonitic or mixed clay mineralogy in the control section. Sampling sites within this group lie in the central portion of the Peruvian Amazon.

Soils whose sediment source is the acid-igneous/volcanic formations of northern Ecuador or within-basin sediments distant to the Andes are extremely acid, may be 60-90% Al saturated, and may have either montmorillonitic or mixed clay mineral suites. The abundance of relatively unweathered 2:1 clays, even in the most acid soils along tributaries with headwaters only within basin sediments, suggests that most sediment is derived from stream bank cutting rather than upland erosion.

Except for the soil sampled along the Rio Mayo, which has vertic properties, there was no clear observable pattern of occurrence across the study

area with respect to physical properties. Soil texture, color, structure, internal drainage and organic-matter form and content appear independent of sediment source and seem to be more a function of stream and regional morphology.

Of the 20 sampling sites, one soil was classified as a Mollisol and three as Inceptisols; the remaining 16 were classified as Entisols. Most of the profiles had a regular decrease in organic C content with depth; organic C was greater than 0.2% at 1.25 m, however, thus exempting them from the Inceptisol order.

Separation of the sampling sites by geologic source of sediments and their respective reaction class is not manifested in Soil Taxonomy. For example, the Cashiboya and Yavarí Mirín sites were classified as Tropic Fluvaquents, very fine, montmorillonitic (acid), isohyperthermic. Yet there was a considerable difference in soil reaction (5.9-5.1 vs. 4.3-3.8) within the profiles and in the amount of exchangeable Al throughout the profiles (1% vs. 80-90%). This does not imply a flaw in Soil Taxonomy but serves to illustrate the point that diversity of soil properties at the family level may influence soil-management recommendations and point to the need for a supplementary technical classification such as the FCC system.

No clear relationship was observed between the chemical and mineralogical properties of the soils and the presence of forest tree species, although it is possible that one exists. It appears that differences in soil drainage override the effects of inherent fertility. In this region of highly diverse forest species, an indicator-species association would be very difficult to elucidate.

Areas of interest in which additional research could be carried out on the alluvial soils include: implementing a similar study in the lower two-thirds of the Basin, i.e., Brazil; sampling soils along selected tributaries to determine the within-tributary system variability; making a more in-depth analysis of mineral transformations within profiles; and studying the source and fate of reduced Fe and Mn.

# Volcanic Ash Influence In Transmigration Areas Of Sumatra

*H. Subagjo, Centre for Soils Research*
*Stanley W. Buol, N. C. State University*

Amorphous material weathered from volcanic material in udic soil moisture regimes has significant influence on P reactions in soils. The volcanic areas in Sumatra are on the southern coast of the island, but ash deposits extend over other geologic areas to the north of the source area. Although the mantle of ash may no longer be recognized because of weathering and pedoturbation processes, it may be detectable and spatially predictable in the surface horizons of otherwise contrasting soils. Landscape evolution may have produced microvariability with more amorphous material on the stable landscape positions than on the hillslopes.

Correction of P deficiencies through fertilization is a major concern to other projects in this program. From results in other areas of the world, it is known that P fixation by amorphous Al cannot be managed the same as P fixation by Fe. Soils in some of the transmigration areas are classified as Oxisols, and, consequently, the initial hypothesis is that the technology previously developed in Brasilia by our earlier project will transfer. However, Brasilia has no known potential amorphous material source such as volcanic ash. Also, if the natural geomorphic activity has unevenly eroded the surface layers, local variability related to landscape position may significantly influence results from fertilization application.

## Objectives

The objectives of this study are 1) to determine the amount, thickness and present composition of amorphous material in the major soil and geographic areas surrounding Sitiung, West Sumatra; 2) to characterize and classify the soils according to Soil Taxonomy as the basis for soil management and for the purposes of interpretation and transfer of

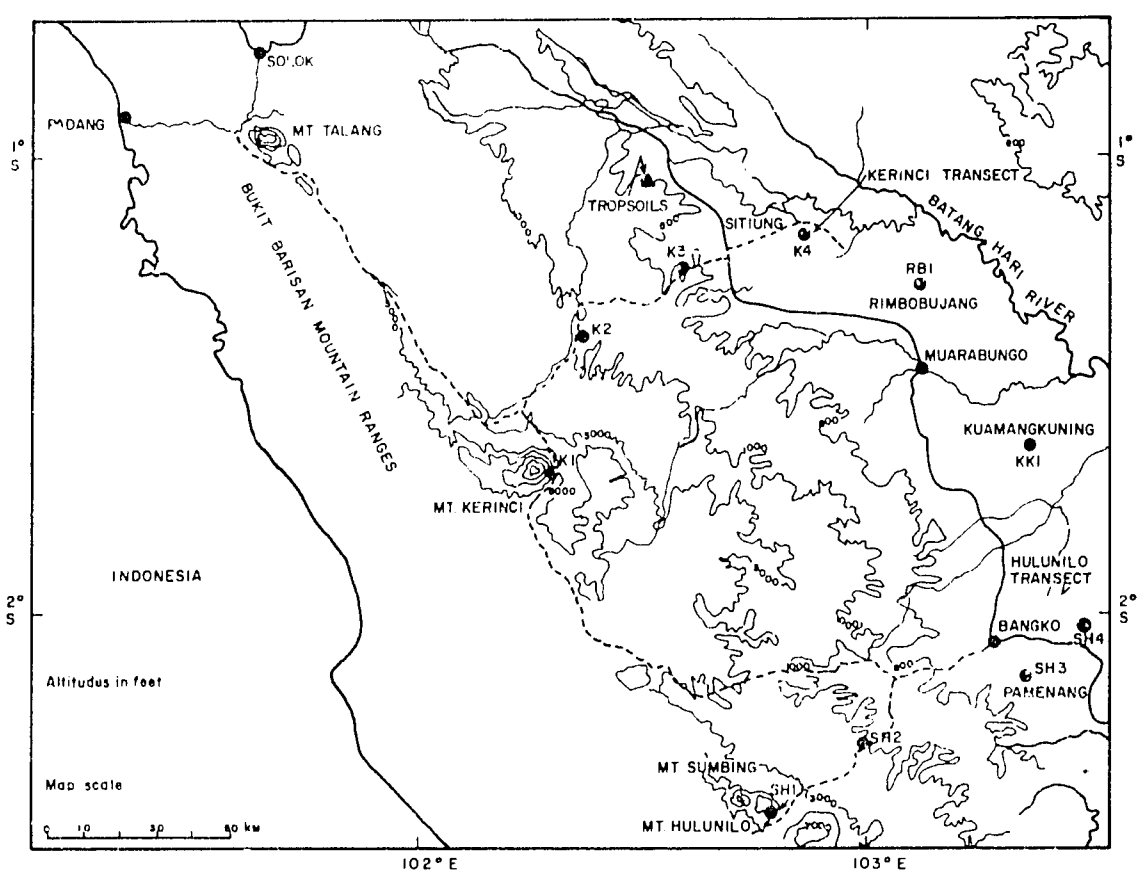


**Figure 1. Location of the pedons studied.**

**Table 1. Tentative placements in soil family for pedons described in two transects and the transmigration areas between Sitiung and Bangko. See Figure 1 for location of transects.**

| Pedon* | Altitude | Soil family |
|---|---|---|
| | m | |
| **Kerinci soil transect** | | |
| K 1A | 1350 | Oxic Dystrandept; medial, isothermic |
| K 1B | | Oxic Dystrandept; medial, isothermic |
| K 1C | | Oxic Dystrandept, medial, isothermic |
| K 2A | 300 | Typic Haplorthox; clayey, kaolinitic, isohyperthermic |
| K 2B | | Tropeptic Haplorthox; clayey, kaolinitic, isohyperthermic |
| K 2C | | Orthoxic Palehumult; clayey, kaolinitic, isohyperthermic |
| K 3A | 150 | Typic Haplorthox; clayey, kaolinitic, isohyperthermic |
| K 3B | | Typic Haplorthox; clayey, kaolinitic, isohyperthermic |
| K 4A | 90 | Typic Haplorthox; clayey, kaolinitic, isohyperthermic |
| K 4B | | Orthoxic Palehumult; clayey, kaolinitic, isohyperthermic |
| K 4C | | Orthoxic Tropudult; clayey, kaolinitic, isohyperthermic |
| **Sumbing-Hulunilo soil transect** | | |
| SH 1B | 1200 | Oxic Dystrandept; medial, isothermic |
| SH 1C | | Oxic Dystrandept; medial, isothermic |
| SH 2A | 350 | Oxic Humitropept; very fine, kaolinitic, isohyperthermic |
| SH 2B | | Oxic Humitropept; very fine, kaolinitic, isohyperthermic |
| SH 3A | 160 | Orthoxic Palehumult; clayey, kaolinitic, isohyperthermic |
| SH 3B | | Typic Haplorthox; clayey, kaolinitic, isohyperthermic |
| SH 4A | 40 | Typic Haplorthox; clayey, kaolinitic, isohyperthermic |
| SH 4B | | Typic Haplorthox; clayey, kaolinitic, isohyperthermic |
| **Transmigration areas: Kuamang Kuning and Rimbo Bujang** | | |
| KK 1A | 50 | Orthoxic Palehumult; clayey, kaolinitic, isohyperthermic |
| RB 1A | 55 | Typic Haplorthox; clayey, kaolinitic, isohyperthermic |

* A indicates a pedon on the stable upland; B indicates a pedon on the adjacent sideslope; C indicates a toe slope position.

improved agronomic practices, and 3) to determine the phosphate retention characteristics of soils under the influence of the volcanic ash mantle.

## Procedures

For objective 1, pedons have been described and sampled by horizons to a depth of 2 m at the locations shown in Figure 1. To verify that a cover of volcanic ash is present, a NaF-pH test was performed by determining NaF-pH of the sample in a 1:50 soil-solution ratio after two and 60 minutes. Due to strong reaction of NaF replacing OH-groups of the active Al and Si bonds of the amorphous material, pH might rise to 12.0 if there is a sufficient amount of this material in the soil. A pH value of 10.6 is taken as an approximate boundary to define the presence of Al-rich amorphous material sufficient to impart serious P adsorption in soils.

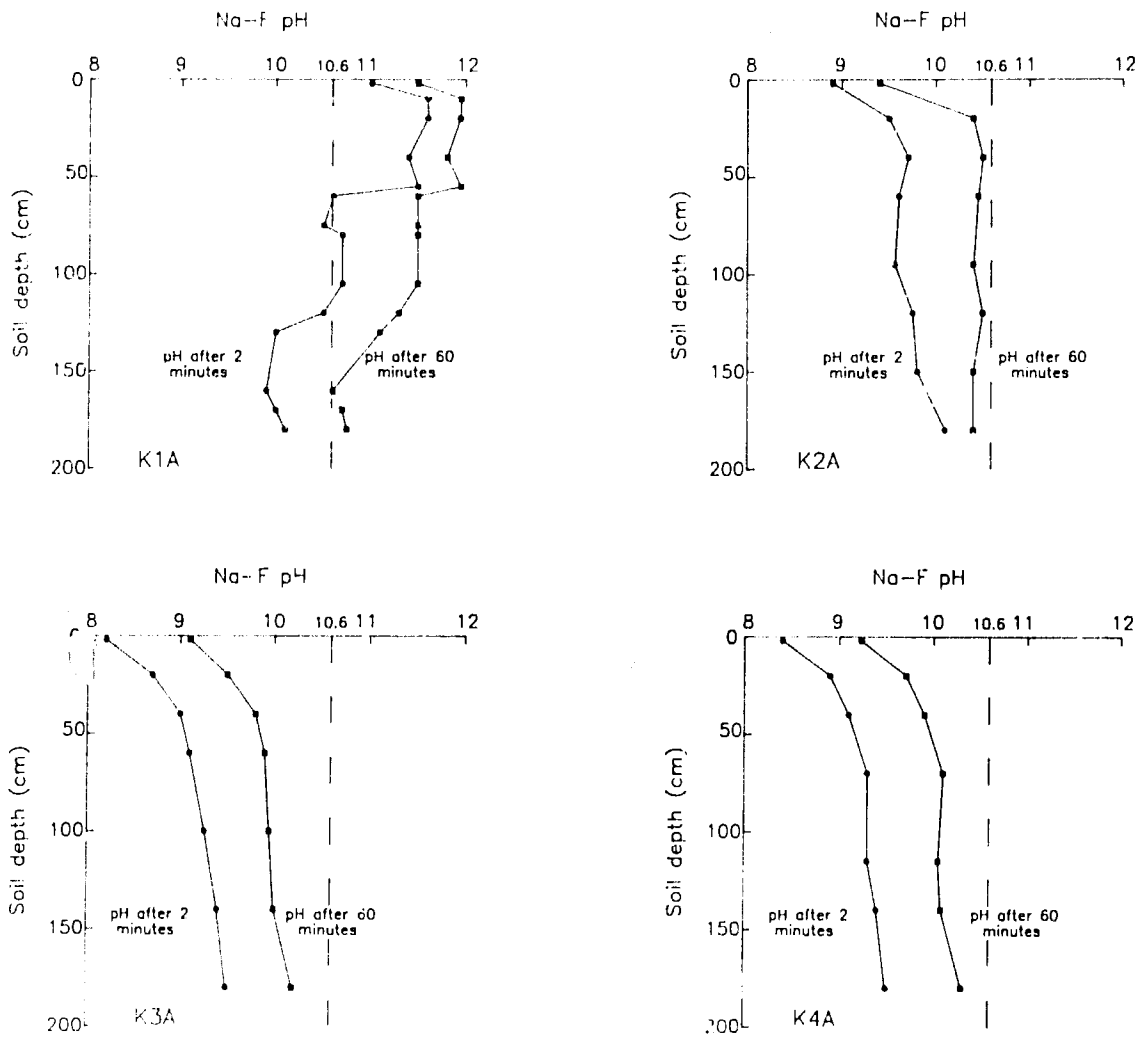


**Figure 2. NaF-pH of air-dry samples from pedons on the stable upland.**

Soil characterization studies, for objective 2, have almost been completed. However, a few analyses (i.e., mineralogy of the sand fraction) that help to clarify the origin of the soil parent material and clay mineral composition for better characterization of soil properties are still incomplete. Based on the available laboratory data, all pedons have been tentatively classified in Soil Taxonomy.

For objective 3, a P isotherm adsorption study has been completed. At present all data are being reviewed and processed.

## Results

The results of NaF-pH determination are summarized in Figure 2. The data suggest that, except for Dystrandepts (pedons K 1A and SH 1A) and Humitropepts (pedons SH 2A and 2B), soils are likely not covered by amorphous-rich material.

Soil Taxonomy placement is presented in Table 1. Location of these pedons is illustrated in Figure 1.

Table 1 indicates that, except for the Andepts in the mountains, the soils are classified either as Oxisols or Ultisols. Some pedons, for instance SH 2A and 2B, show the properties of Inceptisols but still exhibit low-charge oxic characteristics. Highly weathered, leached soils seem to predominate over the area studied.

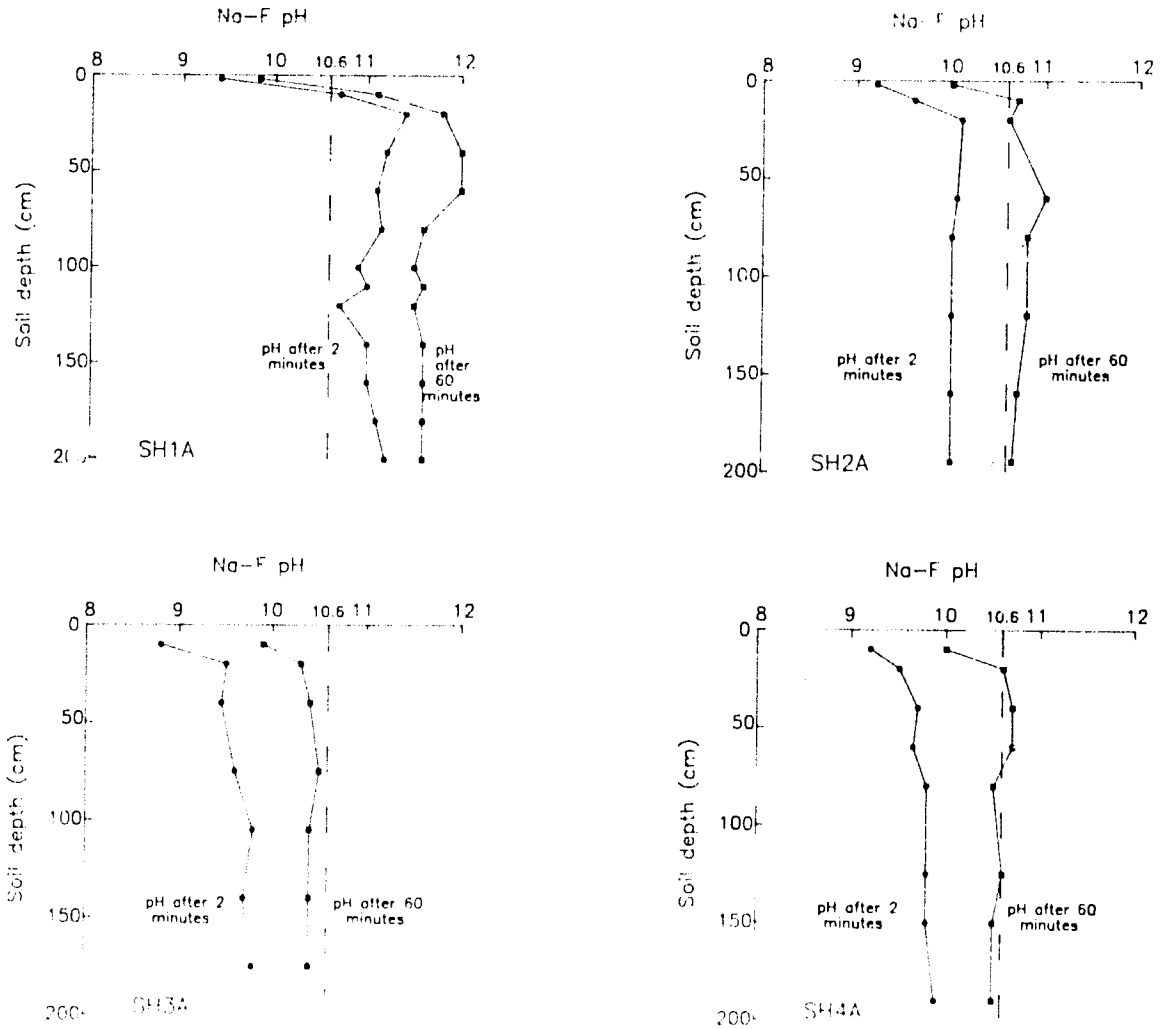


**Figure 2 (continued). NaF-pH of air-dry samples from pedons on the stable upland.**

## Tentative Conclusions

This report covers a stage of the study at which much of the work has been completed, but some key data are not yet available. Thus, the following summary is tentative.

1. Amorphous Al contributes to P adsorption only in the clearly identifiable Andepts at higher elevation and does not extend to the Ultisols and Oxisols near the central part of Sumatra.

2. The level of P adsorption in the Oxisols and Ultisols is considerably less than expected. This is believed to be a function of the relatively low Fe content of these soils.

3. Existing FCC criteria for predicting phosphate adsorption appear adequate for evaluating expected management responses, but further examination of the data is needed to evaluate if improvements in transfer technology can be gleaned from soil characterization data in this area. This will be done next year.

# Soil Fertility Management In Oxisols of Manaus

Seasonal semi-evergreen forests occupy approximately 57% of the Amazon. Oxisols predominate in 45% of this region, primarily in the near-ustic and ustic soil moisture regimes. These soil and climatic properties characterize the ecosystem in Central Amazonia and many areas of the African humid tropics.

This setting contrasts with the more humid tropical environment of Yurimaguas, Peru, where research has been conducted in the fine loamy, siliceous Typic Paleudults. Cooperative agreements with EMBRAPA and IICA have provided the opportunity to perform research at EMBRAPA's UEPAE-Manaus station with the objective of adapting and improving soil management practices developed in sandy Ultisols to clayey Oxisols in a less humid area of Central Amazonia.

Continuous monitoring of soil nutrient availability was a key factor in developing sustainable cropping systems at Yurimaguas. Soil test data provided a guideline for judicious fertilizer applications and identified a progressive sequence of nutrient constraints, which were repeated with several continuous cropping studies in the Typic Paleudults. Investigations at Manaus have centered on a long-term study designed to monitor soil nutrient dynamics and identify the time after slash-and-burn clearing when individual soil nutrient levels limited crop productivity. After identifying specific soil nutrient constraints, satellite experiments were initiated to further refine soil-management techniques.

Data confirmed the possibility of continuous cropping of annual crops in the clayey Oxisols. Banding small rates of P also permitted continuous profits and earlier profits than with broadcast P. Calcium movement into the profile was enhanced by the combination of lime and gypsum. Nitrogen is a major limiting factor for annual crop production in these soils, and several green manures were found to be a good source of N. Both N response and the amounts of N supplied by different green manure species varied, however.

## Nutrient Dynamics

*T. Jot Smyth, N. C. State University*
*Manoel S. Cravo, EMBRAPA*

### Procedures

An initial rice crop and three corn crops were grown in annual rotations with three crops of soybean and four crops of cowpea.

### Results

The contributions of nutrient inputs to cumulative crop yields, during five years of continuous cropping, are shown in Figure 1. A total of 21 t/ha of grain was harvested from the complete fertilization treatment, whereas only 1.7 t/ha were obtained from the plot without lime or fertilizers. Total fertilizer inputs for the complete treatment corresponded to an annual average of 67 kg/ha of N, 66 of P and 80 of K. Single applications were also made of Cu at 1, Mo at 0.2 and lime at 2000 kg/ha. Phosphorus fertilization significantly increased yields, beginning with the first crop after slash-and-burn clearing. Similar yield responses to K and lime occurred after the second and third consecutive crops. Two additional treatments (Figure 1) demonstrate the effects on crop yields resulting from the omission of lime and from a 50% reduction of K fertilizer inputs to the complete fertilization treatment. With no lime, soil acidity progressively increased to the current level of 82% Al saturation. Increased K inputs to 99 kg/ha/yr also depressed yields as a result of K/Mg imbalances.

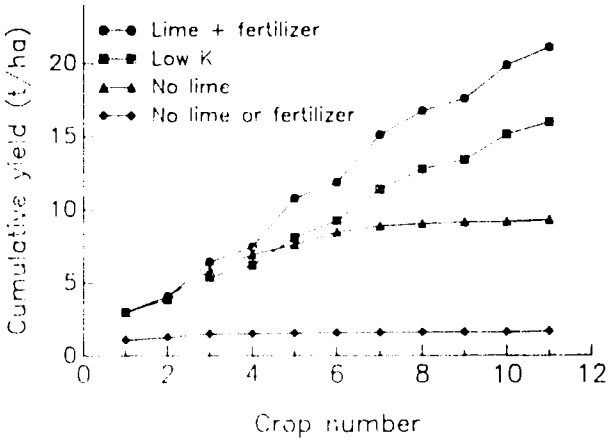


**Figure 1. Cumulative crop yields over a five-year growing period at different levels of fertilizer and lime additions in the nutrient-dynamics experiment at Manaus, 1981-1986.**

# Phosphorus Fertilizer Placement and Profitability

*T. Jot Smyth, N. C. State University*
*Manoel S. Cravo, EMBRAPA*

## Placement

The effects of P fertilizer placement methods were investigated during eight consecutive crops of corn-cowpea annual rotation. Treatments included comparisons between rates of broadcast P (0, 22, 44, 88 and 176 kg/ha) applied before the initial corn crop, in factorial combination with banded P rates (0, 11, 22 and 44 kg/ha), applied to each crop. Cowpea required greater amounts of external soil P than did corn, with Bray 1-extractable critical soil P levels of 19 and 9 mg/kg, respectively. Total yields during four years of cultivation, for corn and cowpea or both species combined, increased as a function of total P applied, regardless whether P was applied in bands or broadcast. Although these results suggest that placement method is not an important parameter in P fertilization management for these Oxisols, economic considerations indicate advantages to banded P applications in small increments to each crop.

## Profitability

Profitability for three P fertilization strategies during eight consecutive crops is shown in Figure 1. Without P fertilization, yields did not exceed 0.2 t/ha, obtained during the initial corn crop. Increasing economic losses resulted from expenses incurred by inputs other than P fertilizer. Cumulative yields for P treatments of both 176 kg/ha, broadcast-applied once before the initial crop, and 22 kg/ha, banded to each of the eight crops, were all similar, 17 t/ha. Similar profits were obtained after a total of eight crops, but banded P applications were advantageous during the initial four crops because P fertilizer costs were

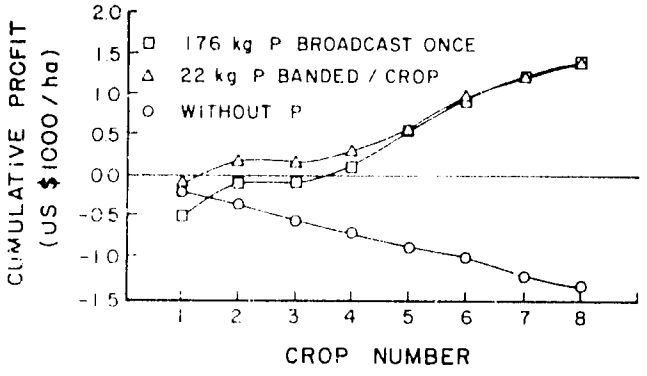


**Figure 1. Cumulative profitability of P fertilizer levels and placement over a four-year growing period. Manaus, 1981-1985.**

evenly distributed over each crop. Frequent banded applications of moderate amounts of P fertilizer are also compatible with the limited capital available to farmers in the region.

## Implications

These data confirm that continuous cultivation of annual crop rotations involving corn and cowpea is possible in clayey Oxisols, the other extreme in the range of well-drained acid soils of the humid tropics from the sandy or loamy Ultisols of Yurimaguas.

Since P deficiency is the first constraint encountered, the profitability of continuous cultivation depended on how P was managed. Without P fertilizers, no annual crops were profitable regardless of other inputs applied. Removing P as a constraint with a broadcast application of 176 kg P/ha cost so much that the economic break-even point was not reached until the fourth crop. Banding small rates of P permitted continuous profits, beginning with the second crop. This is obviously the recommended option.

## Lime and Gypsum Applications

*T. Jot Smyth, N. C. State University*
*Manoel S. Cravo, EMBRAPA*

Farmers in the Manaus region prefer concentrated fertilizer sources to minimize the high transportation costs from southern Brazil. Ordinary superphosphate, therefore, has seldom been used on these acid Oxisols, despite indications that the gypsum in this P source effectively reduced subsoil acidity and promoted deeper root growth in strong ustic soil moisture regimes. An ongoing study in the Typic Acrothox has compared the acid-ameliorating effects of lime and gypsum for corn, cowpea and soybean for three consecutive years.

### Procedures

At the study's inception, locally available calcitic lime (32% Ca and 0.8% Mg) was applied at the rates of 0, 0.5, 1, 2 and 4 t/ha. One t/ha of gypsum was applied in combination with lime rates of 0, 1 and 2 t/ha. An equivalent amount of gypsum was reapplied before planting corn in 1986.

During the last two years, plots were subdivided and two cowpea varieties were compared. IPEAN V-69 originated from locally collected germ plasm, whereas Vita-3 was introduced from IITA.

### Results

Individual crop yields are shown in Table 1. Increased corn yield responses to lime, with successive years of cultivation, are in agreement with a progressive increase in soil Al saturation. On a relative-yield basis, all corn crops exhibited similar relationships to Al saturation (Figure 1). Relationships for both corn and soybean suggested a critical Al saturation level of 30%. Predicted lime recommendations by the Acid 3B Expert System, developed by the University of Hawaii's TropSoils program, corresponded to the observed quantities required to reach this Al saturation level. After the second gypsum application, soil-profile sampling data indicated that subsoil Al saturation was effectively reduced by the combination of lime and gypsum (Figure 2); however, no significant differences were observed between lime rates of 1 and 2 t/ha. Comparisons of soil Ca levels between cropping years suggested that gypsum effects may be short-lived in this high-rainfall regime when no lime was applied.

In keeping with its known tolerance to acidity,

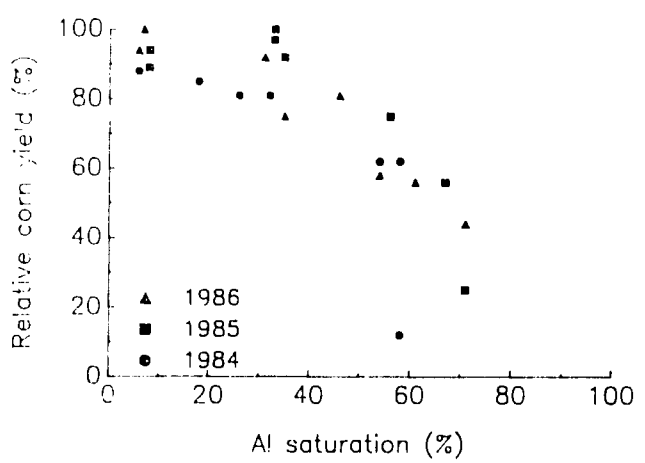


**Figure 1. Effect of soil Al saturation on relative corn yield. Manaus, 1984-1986.**

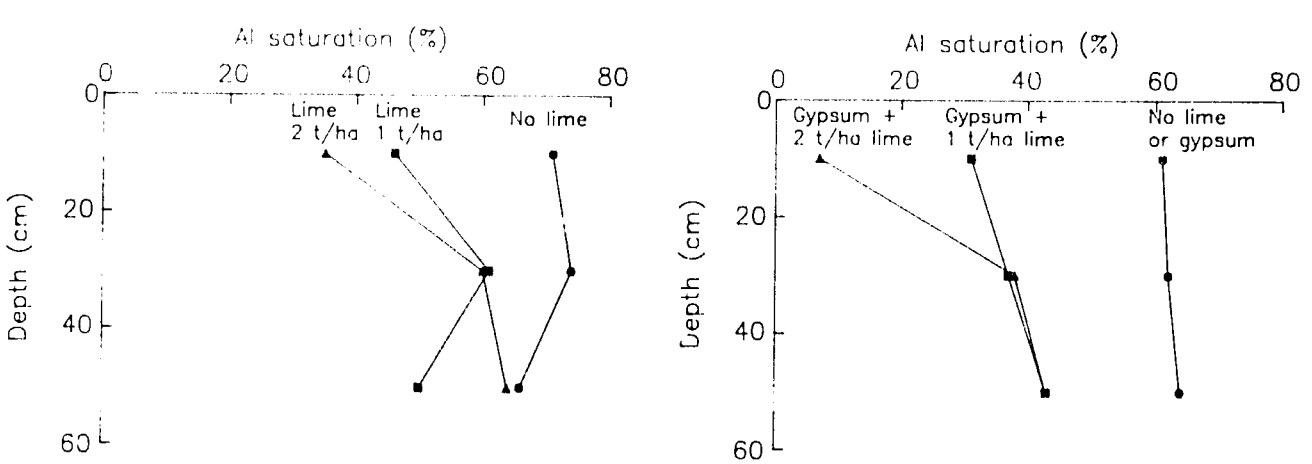


**Figure 2. Effect of lime and gypsum applications on percentage of Al saturation throughout the profile. Oxisols, Manaus, 1986.**

**Table 1. Effect of calcitic lime and gypsum applications to a Manaus Oxisol on corn, cowpea and soybean yields. Lime and gypsum were initially applied before planting corn in 1984. Gypsum was reapplied before planting corn in 1986.**

| Applied | | Grain yields | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Corn | | | Cowpea | | | | | Soybean |
| | | | | | '84 | '85 | | '86 | | |
| Lime | Gypsum | '84 | '85 | '86 | IPEAN | IPEAN | Vita-3 | IPEAN | Vita-3 | '85 |
| | | t/ha | | | | | | | | |
| 0 | 0 | 0.3 | 0.9 | 1.6 | 1.1 | 0.6 | 0.5 | 0.7 | 0.7 | 1.0 |
| 0.5 | 0 | 1.6 | 2.7 | 2.1 | 1.0 | 0.7 | 0.7 | 0.7 | 0.7 | 0.9 |
| 1 | 0 | 2.1 | 3.5 | 2.9 | 1.4 | 0.7 | 0.9 | 0.8 | 0.8 | 1.9 |
| 2 | 0 | 2.2 | 3.3 | 2.7 | 1.3 | 0.7 | 0.8 | 0.8 | 0.8 | 1.8 |
| 4 | 0 | 2.3 | 3.4 | 3.4 | 1.4 | 0.8 | 0.9 | 0.9 | 0.9 | 2.2 |
| 0 | 1 | 1.6 | 2.0 | 2.0 | 1.2 | 0.7 | 0.8 | 0.6 | 0.8 | 1.4 |
| 1 | 1 | 2.1 | 3.6 | 3.3 | 1.4 | 0.7 | 0.7 | 0.8 | 0.9 | 1.8 |
| 2 | 1 | 2.6 | 3.2 | 3.6 | 1.5 | 0.9 | 0.9 | 0.8 | 1.0 | 2.1 |
| $LSD_{0.05}$ | | | | | | | | | | |
| Lime | | 0.8 | 0.8 | 0.8 | ns | ns | | 0.1 | | 0.8 |
| Variety | | | | | | 0.1 | | 0.1 | | |
| Lime xVariety | | | | | | ns | | ns | | |

cowpea has not shown a marked yield response to either lime or gypsum application. In both years, however, the Vita-3 variety tended to respond slightly to liming. Increased cowpea yields were associated with significant increases in leaf Ca levels at the mid-flowering stage. In 1985, for example, leaf Ca levels between the lime treatments of 0 and 4 t/ha increased from 1.03 to 2.51% for Vita-3 and from 1.21 to 2.27% for IPEAN V-69. Increases in leaf concentrations by gypsum alone corresponded to the levels achieved with 2 t of lime/ha in both varieties.

The Acid 3B liming model developed by the University of Hawaii's TropSoils program was successfully validated with Manaus liming data.

## Nitrogen Management

*T. Jot Smyth, N. C. State University*
*Manoel S. Cravo, EMBRAPA*
*Ricardo J. Melgar, N. C. State University*

Preliminary evaluations for N fertilizer requirements entailed three N treatments in the nutrient dynamics study. Urea-N was applied to these treatments in three equal split applications to each crop of rice and corn. Yield data are shown in Table 1. Upland rice yields declined with 90 kg N/ha due to lodging by the tall-statured local cultivar.

In the first two corn crops, yields with N rates of 40-120 kg N/ha were not significantly different. These data suggest that native soil N, and perhaps applied N, carried over in residues of soybean and/or cowpea, were sufficient to limit yield response of corn to less than 40 kg N/ha. Nitrogen rates for the third corn crop, therefore, were reduced to 20-80 kg N/ha. Corn yields significantly increased in 1986 only with applications of 80 kg N. Although the 1984-1985 results suggest that N fertilizer inputs would be minimal in these Oxisols, 1986 data suggest reduction in native-soil as well as residue-N supply to corn after five years of continuous cultivation.

**Table 1. Effect of N fertilization on rice and corn yield during four years of cultivation. Manaus Oxisol.**

| | Grain yield | | | |
|---|---|---|---|---|
| | | Corn | | |
| Applied N | Rice '82 | '84 | '85 | '86 |
| kg/ha | t/ha | | | |
| 20 | | | | 1.5 |
| 30 | 2.9 | | | |
| 40 | | 2.7 | 2.2 | 1.6 |
| 60 | 3.0 | | | |
| 80 | | 2.5 | 1.8 | 2.7 |
| 90 | 2.1 | | | |
| 120 | | 2.9 | 2.3 | |
| $LSD_{0.05}$ | ns | ns | ns | 0.6 |

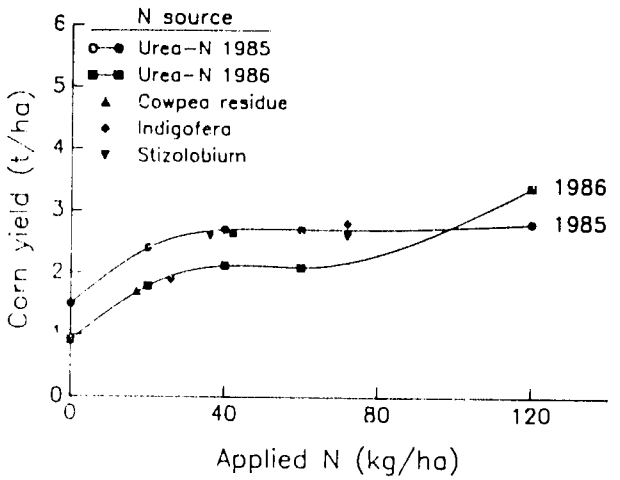


**Figure 1. Effect of nitrogen application on corn yield and equivalent yields produced by green manure crops. Manaus, 1985-1986.**

Nitrogen fertilization was further investigated in an experiment initiated in 1985 on land cultivated for two years after a four-year fallow. Treatments included five rates of urea-N (0, 20, 40, 60 and 120 kg N/ha), applied annually to corn in three equal amounts between planting and tasseling. Legume crops were not grown in rotation with these treatments. Nitrogen contribution from legumes, grown *in situ*, were compared in three additional treatments: cowpea residues (after grain harvest), and two green manures, *Indigofera tinctoria* and *Mucuna preta* (*Stizolobium aterrimum*). Residual N was evaluated with a rice crop after the first corn crop. Urea-N and legume treatments were repeated for the 1986 corn crop.

Corn-yield response curves to fertilizer N are shown in Figure 1. Corn yields for legume treatments are compared to urea-N treatments on a yield-equivalency basis. Yield and total N uptake by rice were not significantly affected by residual N treatments. Two management factors may have contributed to the increased response to N fertilization in 1986: decreased native soil N supply and improved placement of fertilizer N.

Nitrogen uptake in three consecutive crops is

shown in Table 2. During 1985, aboveground corn and rice N accumulation on the treatment without fertilizer N or legumes totaled 88 kg/ha. The fraction of fertilizer N applied at planting was banded below the seed in 1986, as opposed to broadcast incorporated in 1985. This change in fertilizer placement may have promoted early corn growth and increased the overall yield response to urea-N in 1986.

Corn yields among the green manure treatments also varied with years of cultivation (Figure 2). Grain yields with cowpea residue, *Indigofera* and *Stizolobium* were equivalent to yields obtainable with 42, 72 and 36 kg N/ha of urea in 1985 and to 17, 26 and 72 kg N/ha of urea in 1986. These differences in legume performance between years are in agreement with changes in N additions (Table 2). Whereas biomass for *Indigofera* and cowpea residues declined from 6.2 and 1.4 t/ha in 1985 to 3.2 and 0.3 t/ha in 1986, biomass for *Stizolobium* remained constant (7.1 vs. 7.0 t/ha in 1985 and 1986). Reductions in biomass production for the two former legumes may have been associated with a decline in available soil P. Mehlich-I extractable soil P declined from 14 to 9 mg/kg between the corn and rice crops in 1985. The latter level is below the established critical P

**Table 2. Annual additions and total N uptake by aboveground biomass in three consecutive crops.**

| | N additions | | N uptake | | |
|---|---|---|---|---|---|
| | Amount | | 1985 | | 1986 |
| Source | '85 | '86 | Corn | Rice | Corn |
| | kg/ha | | | | |
| None | 0 | 0 | 44.8 | 43.0 | 25.9 |
| Urea | 20 | 20 | 63.2 | 37.3 | 44.8 |
| | 40 | 40 | 66.9 | 41.4 | 50.2 |
| | 60 | 60 | 79.6 | 49.0 | 51.7 |
| | 120 | 120 | 80.8 | 47.9 | 81.0 |
| Cowpea residue | 32 | 7 | 68.0 | 39.4 | 45.4 |
| *Indigofera* | 152 | 91 | 72.8 | 49.4 | 48.3 |
| *Stizolobium* | 168 | 254 | 72.6 | 52.1 | 60.4 |
| $LSD_{0.05}$ | | | 17.2 | ns | 18.9 |

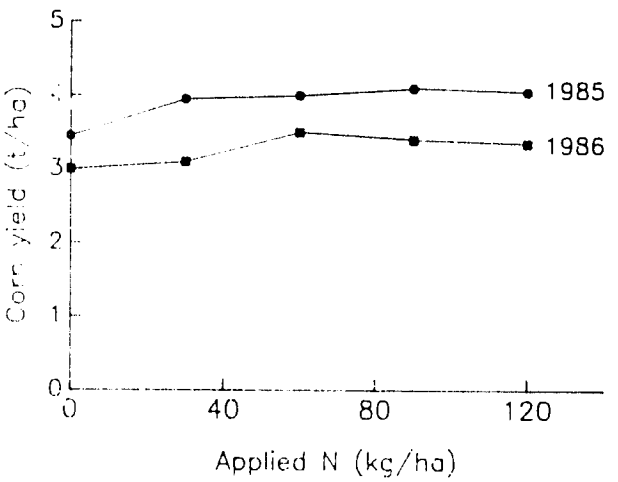


**Figure 2. Effects of nitrogen application in an alluvial (*várzea*) soil at Caldeirao, Amazonas.**

level for cowpea in this Oxisol. Additional reductions in soil P could also have occurred before P fertilizer was reapplied to corn in 1986, raising extractable P levels to 15 mg/kg. Differences between years in the performance of these two green manures would indicate a preference for *Stizolobium* in conditions of low nutrient availability.

Additional advantages to including green-manure cover crops in annual crop rotations are the suppression of weeds and recycling of nutrients other than N. Total ground cover under *Stizolobium* was achieved within 30 days after planting this legume. Weed incidence for this treatment, in both corn crops, was less than for treatments without green manures. Significant amounts of K were also measured in the green-manure biomass. Biomass K for *Stizolobium* and *Indigofera* were 63 and 68 kg/ha in 1985, and 90 and 39 kg/ha in 1986. In the absence of green manures, significant K movement had been detected to a soil depth of 75 cm with K fertilizer rates of 50 kg/ha/crop during continuous cultivation. Biomass K levels for these legumes are compatible with the recommended K fertilization rates for this soil.

Corn fertilizer N requirements in the Oxisol can be compared to similar data for the fertile lowland alluvial (*várzea*) soils along the Amazon River at Caldeirao (Figure 2). The high fertility of these soils is evident from the surface soil chemical characteristics of the experimental

site: pH in water of 5.6, 18 cmol/L of Ca + Mg, 0.4 cmol/L of K, 118 mg/kg of Mehlich-1 P and less than 5% Al saturation. Farmers often plant corn during the five- to six-month period each year when the river recedes and there is no risk of flooding.

Although corn yields are favorable (4-5 t/ha) in the first year of cultivation, yields often decline in successive years when visible symptoms of N deficiency develop. The site for this study was cleared in 1982 but had not been cultivated. Submergence by flooding has not occurred since 1983. Across the range of N rates studied, maximum yields were approached with the application of 60 kg N/ha in both years. With this N rate, yields were increased by 0.7 t/ha in 1985 and 1.0 t/ha in 1986. These data indicate the potential yield levels that may be achieved with available corn germ plasm, under nonlimiting nutrient conditions in the Manaus ecosystem.

### Implications

A major implication of the Manaus work is the recognition of N as a major limiting factor, with N response varying with time. Green manures are a good source of N, but there is considerable variability from year to year in the amounts of N supplied by different green manure species due to variations in dry-matter production and N content.

Research has also been initiated in the alluvial soils (*várzeas*) where N is also a major limiting factor in annual crop production.

# Brasilia: Improving and Modeling Soil Test Interpretations

Our collaborations in the acid savannas of Brazil are focused on refining soil test methods and interpretations for P and Zn fertilization. The Mehlich-1 extractant, also known as the double-acid or North Carolina method, has been the cornerstone of soil testing laboratories for Oxisol regions since it was tested in Brazil during the 1960s by the International Soil Fertility Evaluation Program. New methods have since been proposed. This project, conducted at the Cerrado Research Center of EMBRAPA, compares different methods using long-term field experiments and incorporates texture and the soil's P-buffering capacity in the prediction equations. We found that inclusion of soil properties that estimate P-buffering capacity (such as clay content) enhances soil test interpretations for P regardless of extraction method. Using an experiment established in 1972, critical Zn levels for corn were found to vary with soil pH, while laboratory studies show that considering clay content in prediction equations did not enhance Zn soil test interpretations. A model was developed to predict how much P should be applied to Oxisols using the Mehlich-1 method, and clay content. It worked well on Oxisols with kaolinitic mineralogy, but not on Oxisols with gibbsitic mineralogy. Modifications, including Resin-P and clay content or Resin-P and P-buffering capacity, did not solve this problem. In general it appears that Mehlich-3 and Resin-P are probably better extractants than Mehlich-1 for grain legumes in Oxisols.

# Comparison of Mehlich-1, Mehlich-3, Bray-1 and Anion Exchange Resin-P Soil Tests

*Iberê D. G. Lins, EMPAER*
*Fred R. Cox, N. C. State University*

The amount of P extracted with Mehlich-1 does not correlate well with plant availability under all conditions. For instance, on soils rich in Fe and Al oxides, such as Oxisols, when the soils are well-supplied with P, the amount extracted is generally low. The Mehlich-1 method also does not do well on soils that have previously received rock phosphate. In this situation, extractable soil P is often overestimated due to dissolution of more rock phosphate than would occur naturally. Such problems may not be as great with other extractant methods.

Both Bray-1 and Mehlich-3 have been shown to be more effective than Mehlich-1 when a wide range of soils varying in chemical properties is to be analyzed. Recently, a method to extract soil P, Ca, Mg and K, simultaneously, based on an anion-cation exchange resin, was developed in Brazil.

Several reports have shown that Mehlich-3, Bray-1 or the resin soil tests for P are superior to Mehlich-1. The majority of soil fertility laboratories operating in the Cerrado area of Brazil, however, use the Mehlich-1 extractant.

## Objectives

The objectives of this study are 1) to establish a relationship among four soil P extractants: Mehlich-1, Mehlich-3, Bray-1 and an anion-cation exchange resin; 2) to determine the effect of clay content on soil P concentration determined by each of the four extractants; and 3) to correlate percentage of maximum yield and percentage of P in leaves obtained from five long-term experiments with soil P extracted by Mehlich 1, Mehlich-3, Bray-1 and the anion-cation exchange resin.

## Procedures

Soybean grain yield and soil samples were collected from five long-term P experiments on soils differing in clay content in the Cerrado region of Brazil. These soils were cropped with soybean for an average of six consecutive years. Soil P levels were created by incorporating broadcast triple-superphosphate to supply P rates of 0, 66, 132, 264 and 528 kg/ha in a randomized complete block design with four replications. Leaf samples were collected from three of the sites over a two-year period.

Soil P was extracted by Mehlich-1 (M1P), Mehlich-3 (M3P), Bray-1 (B1P) and the resin (Resin-P) from soil samples collected yearly, just after each harvest. The Mehlich-1 was used at 1:10 soil:solution ratio.

## Results

Relationships among M1P, M3P, B1P and Resin-P were determined. The only linear relationship found was between M3P and B1P. It was highly correlated ($R^2 = 0.98$), had an intercept of less than 1, and had a slope of almost exactly unity (Table 1). This indicates that the amount of P extracted by these two soil tests is very similar.

Because M3P and B1P were similar, their prediction by M1P was also nearly alike. These functions were curvilinear, with an intercept of less than 1, an initial slope of 1.4, and a slight negative quadratic term (Table 1). The coefficient of determination, however, was very good ($R^2 = 0.965$). This function indicates that for most soil test values encountered, M3P and B1P would be about 40% greater than M1P.

The relationship between Resin-P and P extracted by any of the other extractants was also curvilinear, but the coefficient of determination was lower (average $R^2 = 0.80$). In this case the average intercept was about 4.5, the average initial slope was about 0.99, and there was a slight negative quadratic effect. The reason for the large intercept is not clear. This

**Table 1. Relationships among Mehlich-1 (M1P), Mehlich-3 (M3P), Bray-1 (B1P) and an anion-cation exchange resin (Resin-P) soil tests for phosphorus for five soils varying in clay content. Soils initially received five P rates and were cropped with soybean for six consecutive years.**

| Regression equation | $R^{2**}$ |
|---|---|
| $M3P = 0.2 + 1.38\ (M1P) - 0.0033\ (M1P)^2$ | 0.96 |
| $B1P = 0.7 + 1.40\ (M1P) - 0.0032\ (M1P)^2$ | 0.97 |
| $B1P = 0.6 + 1.01\ (M3P)$ | 0.98 |
| $Resin\text{-}P = 5.5 + 1.09\ (M1P) - 0.0030\ (M1P)^2$ | 0.81 |
| $Resin\text{-}P = 4.6 + 0.93\ (M3P) - 0.0022\ (M3P)^2$ | 0.77 |
| $Resin\text{-}P = 3.5 + 0.96\ (B1P) - 0.0023\ (B1P)^2$ | 0.83 |

** Linear and quadratic coefficients of all equations are significant at the 1% level of probability.

indicates that at low soil P unusual variability must have occurred.

To determine the effect of clay on these extractants, soil P was predicted as a function of applied P rate and clay content. The relationship between M1P and applied P was curvilinear, while the same relationships for M3P, B1P and Resin-P were linear (Table 2).

The coefficient of determination obtained for the relationship between recovered P and rate in the tests was 0.39 for M1P, 0.46 for M3P, 0.49 for B1P, and 0.68 for Resin-P (Table 2). However, including clay as our estimator of the soil P-buffering capacity increased $R^2$ to 0.81 for M1P, 0.91 for M3P, 0.87 for B1P, and 0.76 for Resin-P. These data clearly show that clay had a strong effect on the amount of P recovered from these five soils. The negative effect of the buffering capacity on the soil P levels extracted with M1P, M3P, B1P and, to a certain extent, Resin-P indicates that these extractants are sensitive to the capacity factor: M3P was the most sensitive and Resin-P was the least.

Regression equations between percentage of yield and each of the four extractants, using a quadratic model, were performed, and the results are in Table 3. These results show that the least sensitive extractant (Resin-P) was the best correlated with yield ($R^2$ = 0.60), while M1P was the worst ($R^2$ = 0.38).

The percentage of P in leaves predicted as a function of extractable P (Table 4) showed the same tendency as the relationship between yield and M1P, M3P and B1P. However, the relationship between leaf P and Resin-P was no better than those of the other extractants, as was the case with yield. This is apparently due to the small size of the data set used for leaf P.

## Conclusions

Among the four extractants, the overall results indicate that both Mehlich-3 and Bray-I have about the same potential as Mehlich-I for assessing soil P in the Cerrado area of Brazil.

The resin produced the best correlation between percentage of yield and soil P alone. However, with any of the four extractants, inclusion of soil properties that estimate the P-buffering capacity may enhance soil test interpretations for P.

**Table 2. Regression equations and $R^2$ values obtained for the relationships between M1P, M3P, B1P and Resin P as a function of five P rates (P Rate) applied to five soils varying in clay content.**

| Regression equation | $R^{2**}$ |
|---|---|
| M1P = 1.5 + 0.08(P Rate) + 0.0003(P Rate)$^2$ | 0.39 |
| M1P = 7.3 + 0.32(P Rate) + 0.0003(P Rate) + 0.0003(P Rate)$^2$ - 0.49(clay) + 0.006(clay)$^2$ - 0.005(P Rate)(clay) | 0.81 |
| M3P = -0.3 + 0.18(P Rate) | 0.46 |
| M3P = -0.6 + 0.44(P Rate) + 0.007(clay) - 0.0056(P Rate)(clay) | 0.91 |
| B1P = -0.4 + 0.18(P Rate) | 0.49 |
| B1P = -1.3 + 0.44(P Rate) + 0.02(clay) - 0.0054(P Rate)(clay) | 0.87 |
| Resin-P = 1.00 + 0.18(P Rate) | 0.68 |
| Resin-P = 0.5 + 0.26(P Rate) + 0.01(clay) - 0.0020(P Rate)(clay) | 0.76 |

** Linear and quadratic coefficients of all equations are significant at the 1% level of probability.

**Table 3. Regression equation and coefficient of determination ($R^2$) for percentage of soybean grain yield (Y) obtained during several years from five soils. Soils initially received five P rates. Soil P (X) extracted by Mehlich-1 (M1P), Mehlich-3 (M3P), Bray-1 (B1P) and an anion-cation exchange resin (Resin-P).**

| Regression equation | $R^{2**}$ |
|---|---|
| Y = 48.3 + 1.95 (M1P) - 0.0123 (M1P)$^2$ | 0.38 |
| Y = 42.8 + 2.23 (M3P) - 0.0160 (M3P)$^2$ | 0.47 |
| Y = 41.36 + 2.21 (B1P) - 0.0152 (B1P)$^2$ | 0.49 |
| Y = 32.48 + 2.76 (Resin-P) - 0.0225 (Resin-P)$^2$ | 0.60 |

**Intercept, B1 and B2 coefficients are significant at the 1% level of probability.

**Table 4. Regression equation and coefficient of determination ($R^2$) for percentage of P in leaves (Y) and extractable soil P (X) determined by Mehlich-1 (M1P), Mehlich-3 (M3P), Bray-1 (B1P) and an anion-cation exchange resin (Resin-P) after the second and third consecutive plantings from three soils with 63, 27 and 12% clay.**

| Regression equation | $R^{2**}$ |
|---|---|
| %P = 0.2 + 0.0047 (M1P) - 0.000036 (M1P)$^2$ | 0.44 |
| %P = 0.2 + 0.0048 (M3P) - 0.000036 (M3P)$^2$ | 0.48 |
| %P = 0.2 + 0.0052 (B1P) - 0.000040 (B1P)$^2$ | 0.50 |
| %P = 0.2 + 0.0067 (Resin-P) - 0.000067 (Resin-P)$^2$ | 0.50 |

**Intercept, B1 and B2 coefficients are significant at the 1% level of probability.

# Effects of Soil Texture, Zinc and pH on Corn Yield And Plant Zinc Concentration

*Iberê D. G. Lins, EMPAER*
*Fred R. Cox, N. C. State University*

When establishing the optimum rate of a given fertilizer element, soil properties directly or indirectly related to the constant supply of that particular element in the soil solution are usually not considered. For this reason, the correlation between extractable soil element and yield or uptake of that element by plants is often low.

One way to improve soil test interpretations to recommend fertilizer for cultivated plants is to combine extractable nutrient concentration and a soil property that is directly related to the availability of that particular nutrient. For example, the Mn recommendation for growing soybean, corn and other crops in North Carolina takes into account extractable Mn and soil pH. It is felt that the recommendation for Zn should be handled in a similar manner, but further investigation is necessary in this field.

## Objectives

The objectives of this study are 1) to evaluate the effect of Zn rate and soil pH on extractable soil Zn in the greenhouse on soils differing in clay content; 2) to evaluate the effect of extractable soil Zn and pH on Zn concentration and yield of corn grown in the greenhouse on several soils varying in clay content and grown in the field on one Haplustox, and 3) to determine if the critical level for extractable soil Zn differs with soil pH and clay content.

## Procedures

In a greenhouse experiment, each of four Oxisols with 21, 57, 63 and 68% clay were adjusted to pH 5.2, 5.7 and 6.2. Five Zn levels within each soil pH were created by applying Zn at 0, 0.8, 1.6, 3.2 and 6.4 g/m³. Three crops of Cargill 111-S corn (*Zea mays* L.) were grown, each for about four weeks.

In the field, the same variety of corn was grown one season in one of the original experiments established on a Typic Haplustox by F. R. Cox and Brazilian colleagues in 1972. Treatments imposed 13 years ago were rates of lime (7.5 to 22.5 t/ha) and Zn (0 to 9 kg/ha). Mehlich-1 was the soil extractant used to assess soil Zn in both greenhouse and field experiments.

## Results

Three harvests were obtained in the greenhouse experiment. However, only the third will be presented, as P nutrition was poor in the first and yield response to Zn less marked in the second.

Extractable soil Zn increased with rate of Zn applied (Table 1). About two-thirds of the applied Zn was recovered by Mehlich-1 at each rate, regardless of the soil clay content. Increase in soil pH from 5.2 to 6.2 did not decrease the concentration of soil Zn

**Table 1. Effect of Zn application on Mehlich-1 extractable Zn determined before the third crop on four soils varying in clay content at three pH levels. Average of three replications.**

| | | Zn applied (g/m³) | | | | | |
|---|---|---|---|---|---|---|---|
| Clay content | pH | 0.0 | 0.8 | 1.6 | 3.2 | 6.4 | Mean |
| % | | g/m³ | | | | | |
| 21 | 5.2 | 0.2 | 0.5 | 1.2 | 2.4 | 4.2 | 1.7 |
| | 5.7 | 0.3 | 0.7 | 0.8 | 2.2 | 4.6 | 1.7 |
| | 6.2 | 0.4 | 0.8 | 1.3 | 2.7 | 5.2 | 2.1 |
| 57 | 5.2 | 0.4 | 0.7 | 1.3 | 1.9 | 4.2 | 1.7 |
| | 5.7 | 0.3 | 0.7 | 1.2 | 2.3 | 4.1 | 1.7 |
| | 6.2 | 0.3 | 0.8 | 1.4 | 2.5 | 4.2 | 1.8 |
| 63 | 5.2 | 0.3 | 0.5 | 1.0 | 2.0 | 4.0 | 1.6 |
| | 5.7 | 0.4 | 0.7 | 1.1 | 2.2 | 4.1 | 1.7 |
| | 6.2 | 0.2 | 0.7 | 1.2 | 2.2 | 4.4 | 1.7 |
| 68 | 5.2 | 0.3 | 0.8 | 1.5 | 2.5 | 4.9 | 2.0 |
| | 5.7 | 0.5 | 0.9 | 1.5 | 2.6 | 5.0 | 2.1 |
| | 6.2 | 0.4 | 0.8 | 1.4 | 2.7 | 5.0 | 2.1 |
| Rate mean | | 0.3 | 0.7 | 1.2 | 2.4 | 4.5 | |

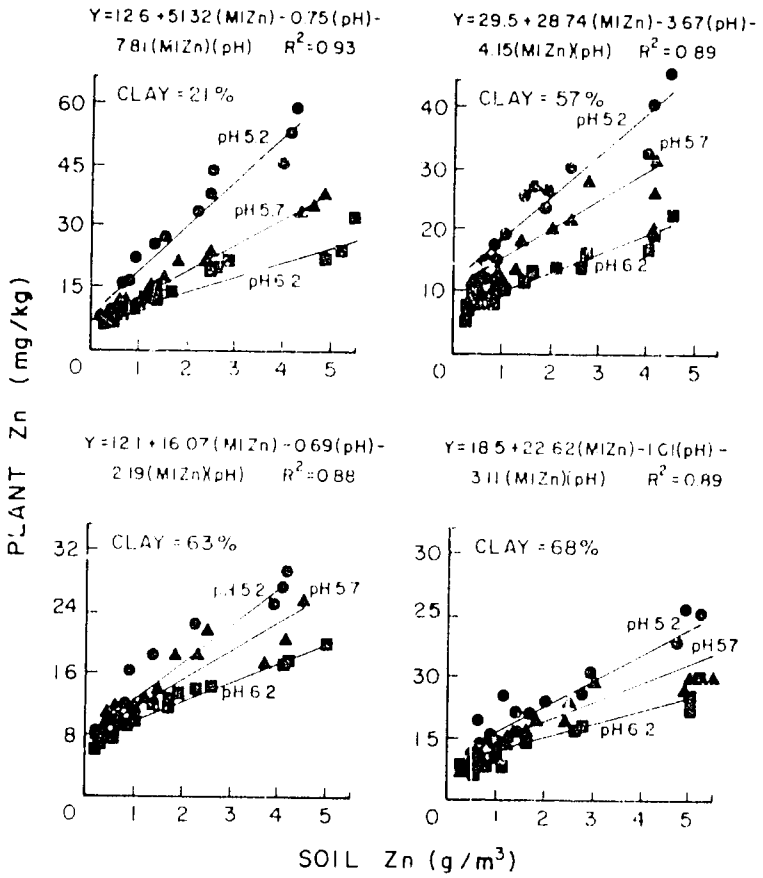


**Figure 1. The observed (points) and predicted (lines) effect of soil zinc and pH on zinc concentration in the corn plant for four soils varying in clay content, grown in the greenhouse. CPAC, Brasilia, 1986.**

extracted by Mehlich-1.

The yield of corn grown on this group of soils was increased by increased Zn rate. Mean yields across soil and pH were 4.5, 7.6, 10.4, 11.7 and 12.0 g/pot at Zn rates of 0, 0.8, 1.6, 3.2 and 6.4 g/m³, respectively. This indicates that the Zn rate of 3.2 g/m³ was sufficient to reach 90% or more of the maximum yield, regardless of the soil pH value.

Dry matter yield was depressed at high pH and low soil Zn. This may have occurred due to reactions of Zn with hydroxy and carboxyl groups.

The relationship between dry-matter yield and extractable soil Zn was expressed with a quadratic function. The $R^2$ values obtained were 0.68, 0.86, 0.56 and 0.51 for the 21, 57, 63 and 68% clay soils, respectively. With the inclusion of pH and their first-order interaction, the $R^2$ values for the 57, 63 and 68% clay soils increased to 0.91, 0.84 and 0.90, respectively; this increase was not observed in the 21% clay soil.

Plant Zn concentration decreased with an increase in soil pH for all soils (Figure 1). Including soil pH and the first-order interaction in the equation increased $R^2$

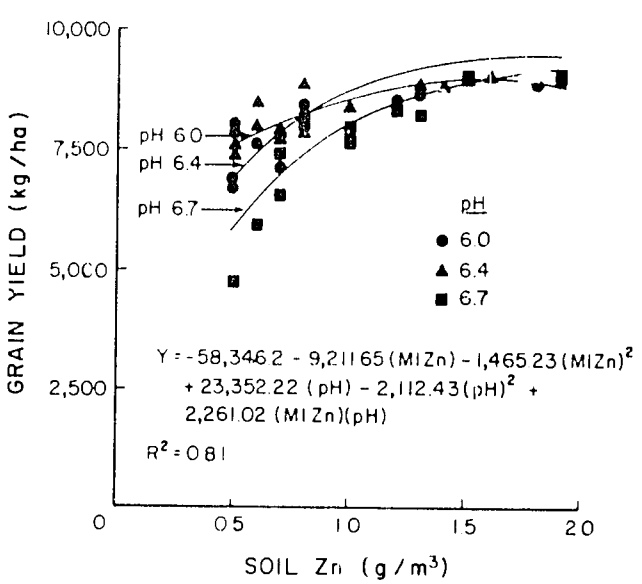


**Figure 2. The observed (points) and predicted (lines) effect of soil zinc and pH on corn grain yield, grown in the field. CPAC, Brasilia, 1986.**

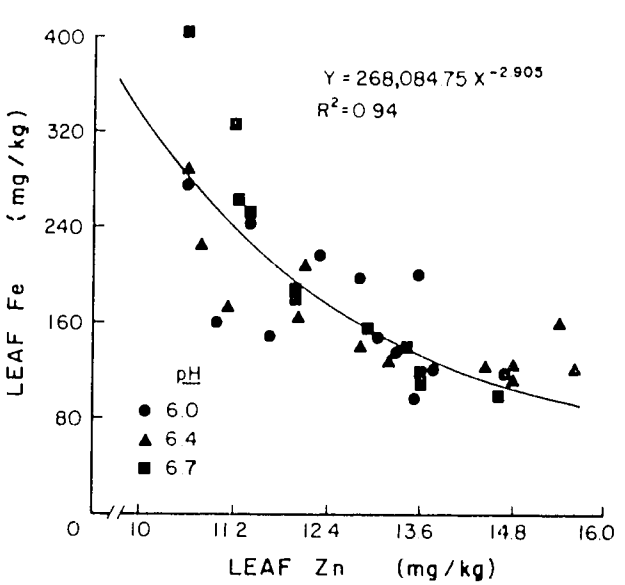


**Figure 3. Relationship between zinc and iron concentrations (determined in the ear leaf at tasseling) in corn plants, grown in the field, at three pH levels. CPAC, Brasilia, 1986.**

values in all four soils.

The critical level of Zn in the soil, obtained by the linear plateau technique, increased as soil pH increased and was similar for all four soils. The average critical level of soil Zn was 1.0 g/m³ for pH of 5.2, 1.4 g/m³ for pH 5.7, and 2.0 g/m³ for pH 6.2. In 1972, before cropping the average extractable soil Zn concentration across lime and Zn rates applied in the field ranged from 0.6 to 1.6 g/m³.

Lime application rates, which resulted in pH values of 6.0, 6.4 and 6.7, did not affect the level of extractable Zn. However, Zn rates of 0, 3 and 9 kg/ha gave extractable Zn levels of 0.6, 0.8 and 1.5 g/m³. This indicates that both lime and Zn had strong residual effects.

As in the greenhouse, at low soil Zn, leaf Zn concentration tended to decrease with an increase in soil pH (Figure 2). Also, there was a positive yield response of corn to extractable soil Zn concentration in the field (Figure 2). At the highest pH and lowest soil Zn, yields were depressed markedly. This trend was also observed in the greenhouse. The relationship between grain yield and soil Zn across pH treatments accounted for 52% of the variation. However, including pH and first-order interactions in the equation increased the $R^2$ to 0.81.

The soil Zn critical levels determined by the linear plateau technique were 0.9 g/m³ for pH 6.0, 1.5 g/m³ for pH 6.4, and 1.1 g/m³ for pH 6.7. Thus the Zn critical level at the highest pH was not as high as expected. It appears that there is a trend for the critical level to increase with an increase in soil pH. That relationship, however, is not really clear from these field data.

A strong antagonistic effect was observed between plant Fe and Zn (Figure 3). At low soil Zn, yield was apparently related more to large fluctuations in Fe than to minute changes in leaf Zn.

### Conclusions

The results reported here suggest that soil pH is an important soil property that should be considered in the development of a Zn soil test, but clay content is not. However, additional field work considering a wider range in soil pH would be beneficial.

## A P-test Interpretation Model for Kaolinitic Soils Using Mehlich-1 and Clay Content

*Iberê D. G. Lins, EMPAER*
*Fred R. Cox, N. C. State University*

It has been shown that the amount of P to be applied in fertilizing a given crop varies with soil properties. A model was developed to predict the amount of P fertilizer that should be applied when growing soybean (*Glycine max* [L.] Merr) in the Cerrado area of Brazil. It was based on yields obtained for four years on three soils of kaolinitic mineralogy that varied from 12 to 63% clay in relation to Mehlich-1 extractable P and clay content.

### Objectives

The objectives of this study are 1) to refine the model for soybean by using data collected for a longer period of time and from more sites, and 2) to validate the model.

### Procedures

Data from five long-term P experiments in the Cerrado cropped with soybean for an average period of six years were used in this study. The surface horizon of these soils had 68, 63, 57, 27 and 12% clay content. The 68% clay content soil had gibbsite as the dominant mineral in the clay fraction, while in the others kaolinite was the principal constituent of clay. These soils received five P rates (0, 66, 132, 264 and 528 kg/ha) as broadcast triple-superphosphate. In addition, data from two other experiments cropped with soybean for a period of one year were used to validate the model. The clay content of these soils in the surface horizon was 27 and 21%. Gibbsite was the dominant mineral of the clay fraction in the 27% clay soil, and kaolinite was dominant in the 21% clay soil.

Yield from the long-term experiments was related to extractable P, which, in turn, was related to the initial P soil level and P fertilization rate for a period of one year. Based on a soybean price of $0.23/kg and a fertilizer P price of $1.23/kg, rates of P were calculated for each of the five soils that would maximize net returns for various initial levels of extractable P.

## Results

The rates of fertilizer P differed markedly with clay content. The fertilizer P rates to maximize net returns at various initial soil P levels for the five soils are shown by calculated points in Figure 1. For clay soils, high rates of P are recommended at low soil P levels. The recommended rate decreases rapidly with increasing soil P, however, and none would be recommended if the extractable P concentration of the 68, 63, 57, 27 and 12% clay soils were below 8, 12, 14, 25 and 27 kg/ha (the critical levels).

Multiple regressions using both Mehlich-1 extractable P and percent clay to predict a recommended rate of P- fertilizer are shown in Figure 1. The fit between calculated and predicted lines for the 63, 57, 27 and 12% clay soils was good; however, the fit for the 68% clay soil was poor.

The model developed using these five soils was as follows:

$$\text{P Rate} = 98.8 - 3.22(\text{M1P}) + 0.0037(\text{clay})^2 - 0.0013(\text{M1P})(\text{clay})^2. \quad (1)$$

This model was valid only for the 27% clay soil but not for the 21% clay soil.

This indicates that the procedure used here should be calibrated separately for gibbsitic and kaolinitic soils. With this reasoning, the 68% clay gibbsitic soil was deleted and a new model for kaolinitic soils only was developed as follows:

$$\text{P Rate} = 95.6 - 3.14(\text{M1P}) + 0.0046(\text{clay})^2 - 0.0012(\text{M1P})(\text{clay})^2. \quad (2)$$

This model accounted for 95% of the variation in P rates for the kaolinitic soils and predicted quite successfully the P rate to reach 90% of the maximum soybean yield for the 27% clay soil cropped for one year. The fit between calculated (points) and predicted (lines) P rates is shown in Figure 2.

## Conclusions

The results indicate that the proposed model is appropriate for soils of the Cerrado region of Brazil where kaolinite is the dominant mineral in the clay fraction. A validation for gibbsitic soils is needed to use this model on those soils.

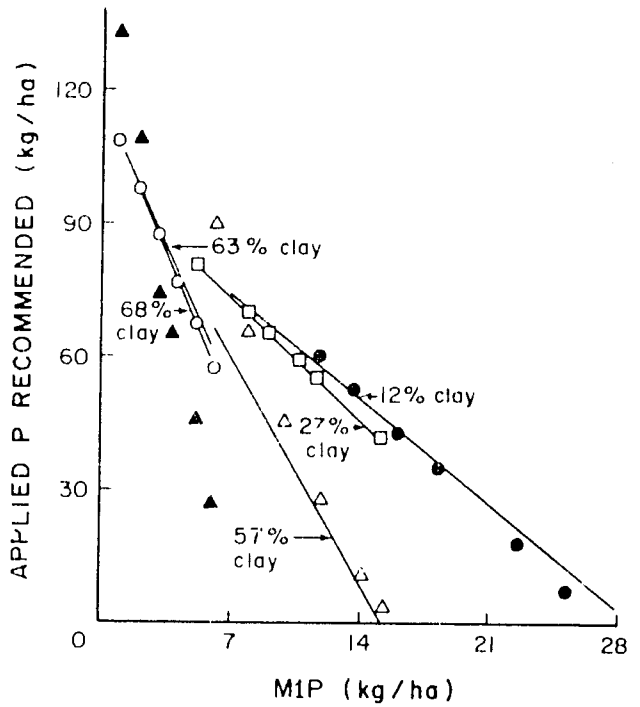


**Figure 1. A soil test interpretation for P showing the calculated (points) and predicted (lines) optimum P rates for five soils varying in Mehlich-1 extractable P (M1P) and percentage of clay. Soybean price = US $0.23/kg and fertilizer P cost = US $1.23/kg.**

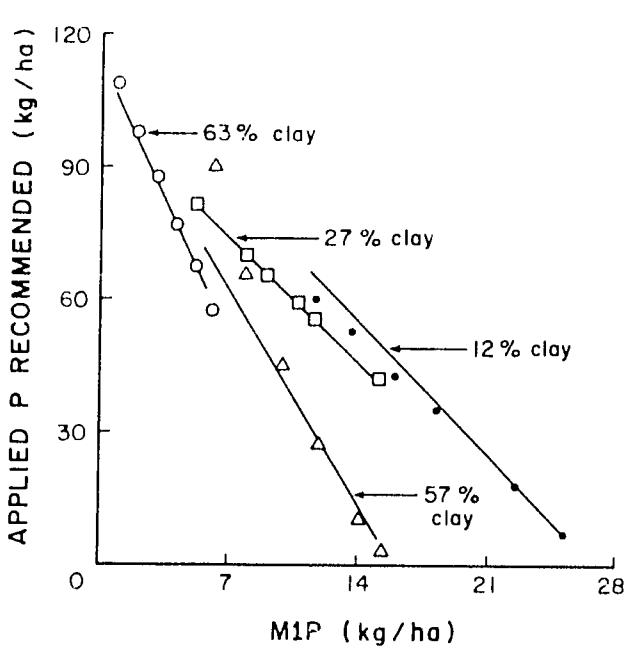


**Figure 2. A soil test interpretation for P showing the calculated (points) and predicted (lines) optimum P rates for four soils varying in Mehlich-1 extractable P (M1P) and percentage of clay. Soybean price = US $0.23/kg and fertilizer P cost = US $1.23/kg.**

# A P-test Interpretation Model For Oxisols Using Mehlich-3, Resin Extractants and Estimates of Capacity Factor

*Iberê D. G. Lins, EMPAER*
*Fred R. Cox, N. C. State University*

A model developed to recommend P rate as a function of Mehlich-1 and buffering capacity was previously shown to be applicable only to kaolinitic soils. However, when Fe-containing solutions or a resin extractant were used in our exploratory greenhouse experiment, which included a wide range of soil conditions, it seemed reasonable to pool kaolinitic and gibbsitic soils when interpreting soil tests for the purpose of P fertilizer recommendations. It is unknown, however, if soils with either of these two minerals dominating will respond similarly in the field.

## Objectives

The objectives of this study are 1) to evaluate a mathematical approach developed to predict P fertilization rates for soybean cropped in the field on soils with different mineralogy based on soil P extracted by Mehlich-3, Bray-1 or an anion-cation exchange resin and selected soil properties, and 2) to validate the proposed models using data from two soils with different chemical composition which were cropped with soybean for a period of one year.

## Procedures

Long-term P experiment data used in this study, as well as data used to validate the proposed model, are reported in the previous report.

Soil P was extracted with Mehlich-3, Bray-1 and an anion-cation exchange resin. In addition to clay, estimates of the capacity factor were included, such as surface area, percentage of minerals in the clay fraction, P-absorption coefficients obtained by the Langmuir equation, and P-buffering coefficients. P-buffering coefficient estimates were determined by the slope of the linear regression equation obtained for the relationship between recovered P using the three extractants described above and applied P after two hours, four days and eight weeks of equilibration.

## Results

Mehlich-3, Bray-1 and resin-extractable P explained 67, 57 and 62% of the variation in the optimum P fertilizer rate to be applied on the pooled soils where either kaolinite or gibbsite was the predominant mineral in the clay fraction.

The combination of Mehlich-3 with clay[2] increased the proportion of the variation to 84%. Clay content and P-buffering coefficient, obtained after two hours of equilibration ($R^2 = 0.82$), were the two best practical properties that could be combined with Mehlich-3 to improve the soil test for P. The same trend was observed with the other soil extractants.

Among the three soil P extractants used in this study, the resin seems to be the best when used in combination with estimates of the soil P-buffering capacity. The combination of clay with Resin-P explained 95% of the variation in the optimum P rate for growing soybean in this group of soils.

The equation obtained to predict P fertilizer rate as a function of soil P extracted by resin and clay was as follows:

$$\text{P Rate} = 31.6 + 0.0742(\text{Resin-P}) + 1.4903(\text{clay}) - 0.0624(\text{Resin-P})(\text{clay}). \quad (1)$$

The Resin-P also showed a higher potential than the other extractants to improve the soil test interpretation when other estimates of the buffering capacity are used. The combination of the Resin-P with the P-buffering coefficient obtained after two hours of equilibration was as good as that obtained for the combination of Resin-P and clay. This is shown by the good fit between the calculated (points) and predicted (lines) optimum P rates in Figure 1.

The predicted (lines) P rate in Figure 1 was obtained with the following equation:

$$\text{P Rate} = 372.8 - 7.41(\text{Resin-P}) - 337.92(\text{PBC}) + 5.66(\text{Resin-P})(\text{PBC}) \quad (2)$$

where PBC = P-buffering coefficient after a two-hour equilibration period.

## Conclusions

The models developed with the combination of Mehlich-3, Bray-1 and Resin-P with clay successfully predicted the P rate to be applied in the 27% clay soil cropped with soybean for one year to reach

90% of the maximum yield. However, none of the models reported here accurately predicted the P rate required to reach 90% of maximum yield for the 21% gibbsitic soil. This soil called for 204 kg P/ha to obtain 90% of the maximum yield. This indicates that it may not be economical to crop this soil with soybean.

For kaolinitic and clayey gibbsitic soils, however, these three extractants are all good, and probably better than Mehlich-1, for recommending the optimum P rate for soybean.

Even when using any of these three extractants, this approach should not be used for coarse-textured Oxisols in which gibbsite is the dominant mineral in the clay fraction.

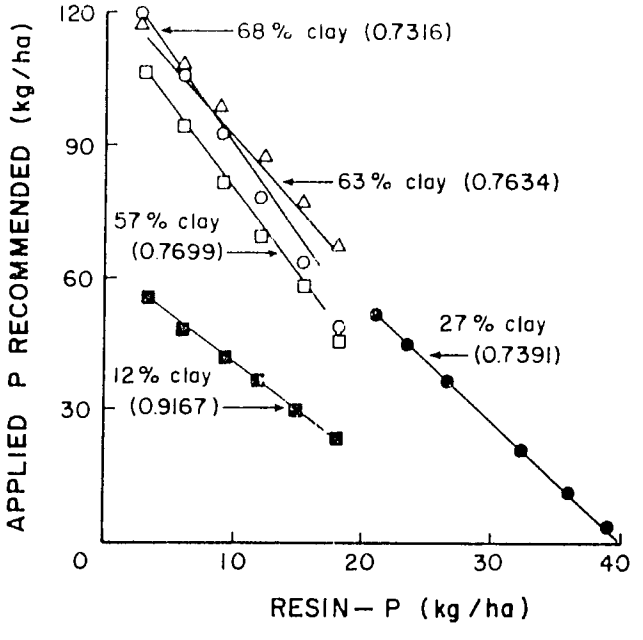


**Figure 1. A soil test interpretation for P showing the calculated (points) and predicted (lines) optimum P rates for five soils varying in clay content as a function of extractable Resin-P and P-buffering coefficient (in parentheses). Soybean price = US $0.23/kg and fertilizer P cost = US $1.23/kg.**

# High Jungle Extrapolation: Pichis and Alto Huallaga Valleys

The Pichis-Palcazu region of the Central Selva of Peru is being rapidly colonized and developed through a massive project, the Proyecto Especial Pichis Palcazu (PEPP). PEPP has requested the assistance of INIPA and N. C. State University in validating and transferring the principles developed at Yurimaguas to the Pichis area. TropSoils work in the region is based at the La Esperanza Experiment Station near Puerto Bermudez and with INIPA, the Universidad Nacional Agraria de la Selva, in Tingo María, and USAID/Lima. Descriptions of climate, topography and soils were given in the previous TropSoils technical report.

Last year the valley became connected to Pucallpa and Lima, resulting in a large influx of new settlers along the Marginal Highway. Most of the road crosses steep hills (30 to 70% slopes) with virgin forest and Ultisols with a perudic soil moisture regime. Work describing the runoff and erosion processes in a virgin forest catchment will serve as a baseline for assessments of land-clearing consequences. Technologies for rapid establishment of a plant canopy in eroded Ultisol steeplands developed in the Alto Huallapa Valley provide a direct way for eliminating erosion from mismanaged acid humid tropical steeplands. Given a period of fairly predictable flooding in extensive alluvial terraces, the Yurimaguas low-input system was modified to allow the growth of nonirrigated paddy rice during flood periods followed by a ratoon rice crop and then cowpea. Different species of pasture grass and legumes behave better at Pichis than in less wet areas. Recuperation of a degraded pasture dominated by *Homolepsis aturensis* appears promising when simple management techniques and improved germ plasm are used.

# Runoff and Erosion Processes In a Primary Forest Catchment Of the Humid Tropical Steeplands

*Helmut Elsenbeer, N. C. State University*
*D. Keith Cassel, N. C. State University*
*Luis Zúñiga, INIPA*

The increasing trend of converting forest to agroecosystems in the humid tropics has caused concern about both the environmental impact and the decline of productivity after such changes in land use, particularly in areas of pronounced relief.

To assess the consequences of such conversions in a quantitative and comparative fashion, benchmark data on hydrologic and erosion processes in an undisturbed forest ecosystem are required. This study is the first phase of an extensive investigation of the suitability of various agroecosystems to allay the environmental impact of forest conversion and to maintain productivity.

## Objectives

The objectives of this study are 1) to monitor catchment inputs (rainfall and solutes) and outputs (streamflow, solutes and sediments), and 2) to define source areas of runoff, sediments and solutes within the catchment as a function of topographic and pedologic conditions.

## Procedure

A catchment called "La Cuenca" was selected in a forest reserve at the La Esperanza station. The catchment is representative of the dissected uplands between the Pichis River and the San Matias Cordillera. Rainfall is measured with an automatic recording rain gauge; solute input is analyzed in weekly samples collected outside and within the forest. Streamflow is monitored at the catchment outlet by an automatic water-level recorder; stream water is collected on a weekly and a within-event basis and analyzed for solutes and sediments. Two topographically different hillslopes are instrumented with tensiometers, piezometers, pressure-vacuum soil water samplers and runoff-collecting devices to monitor water, solute and sediment fluxes. The spatial distribution of occurrence of surface runoff is defined by means of a large number of surface runoff detectors. The watershed is not affected by human traffic in the process of measurement due to a system of plankways installed to avoid foot traffic.

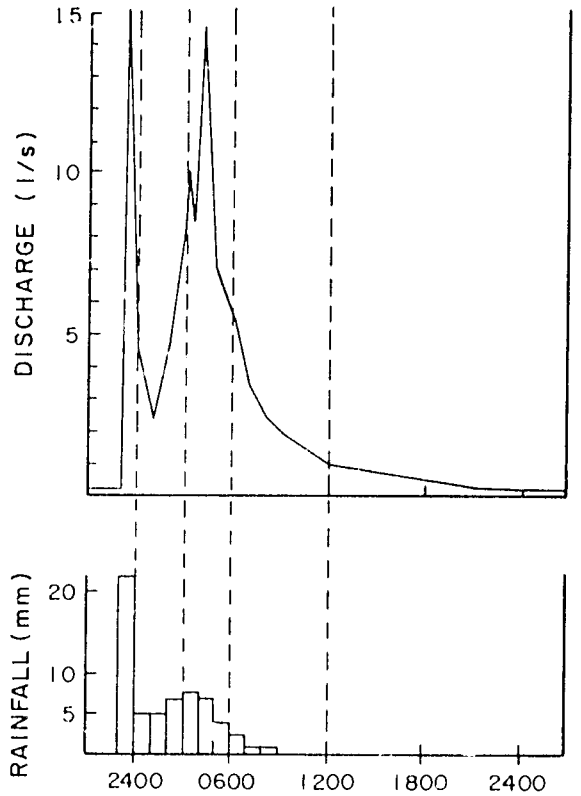


**Figure 1. Precipitation and discharge hydrograph for event of 10-11 October, 1986.**

## Results

### *Precipitation*

In the period monitored so far, monthly precipitation ranged from 587 mm (March) to 73 mm (June 1986). The highest daily precipitation recorded was 121 mm (in March). Although short-term intensities of up to 84 mm/hr were observed, these were not maintained over longer periods. The highest 30-min intensity recorded was 28 mm/hr.

### *Streamflow*

The instantaneous discharge ranged from 0.08 to 18 L/s. Storm hydrographs are characterized by a very short time lag between the onset of precipitation and peak discharge (Figure 1). This rapid transmission of incoming precipitation to the stream channel suggests surface runoff and/or subsurface stormflow in macropores as the dominating mechanism.

### *Sediment*

The sediment output from the catchment was rather low. During low flow conditions, sediment

**Table 1. Average concentrations of selected cations in three hydrologic compartments of a primary rainforest.**

| Compartment | Mean concentration | | | |
|---|---|---|---|---|
| | Ca | Mg | Na | K |
| | ppm | | | |
| Precipitation | 0.5 | 0.05 | 0.9 | 0.4 |
| Throughfall | 1.5 | 0.7 | 2.5 | 3.0 |
| Stream water | 3.0 | 0.5 | 2.2 | 1.6 |

concentration was 30 mg/L; in storm events, it increased to 200 mg/L.

*Solutes*

Concentrations of selected elements in open-land precipitation, within-forest precipitation (throughfall and crowndrip) and stream water are compared in Table 1. Other elements, e.g., S, Fe, P and Si, were present in traces only (less than 0.05 ppm).

*Occurrence of surface runoff*

In a well-defined part of the catchment, characterized by the presence of gullies and rills with steep gradients and topographic follows at the gully heads, surface runoff does occur, especially during high-intensity rainfall events. Its occurrence is more localized during dry-season events than during rainy-season events. Surface runoff is rare outside the zone described above. The gullies and rills are not a result of human intervention.

**Conclusions**

Despite the short period covered by monitoring and sampling so far, some preliminary conclusions may be drawn:

1. Surface runoff does occur in some parts of the catchment under certain meteorological conditions.
2. The sediment production and, by implication, the rate of erosion under primary rainforest is extremely low.
3. Concentrations of Ca, Mg, Na and K increase as rainwater passes through the vegetation-soil complex, i.e., there is an export of those elements from this primary forest catchment.

# Establishing a Plant Canopy In Eroded Ultisol Steeplands

*José R. Benites, N. C. State University*
*Hemilce Ivazeta, INIPA*
*Marta Gallo, INIPA*
*Rodolfo Schaus, INIPA*
*Manuel Flores, INIPA*
*Jorge Figueroa, INIPA*

Many hillsides along the High Selva of Peru are being rapidly cleared for cultivation on slopes exceeding 100%. Rainfall is usually high, so when the plant cover is lost due to mismanagement, rivers literally "run red" with eroded sediments. Joint work was initiated with the INIPA Tulumayo Station, the Universidad Nacional Agraria de La Selva and the USAID-sponsored Alto Huallaga Valley Special Project.

**Objective**

The objective of this study is to develop a simple means for establishing a plant canopy on steep, eroded Ultisols of the High Selva that will stop erosion and permit establishment of acid-tolerant tree crop plantations.

**Procedures**

In an attempt to recover a degraded steep Ultisol in Pumahuasi, Tingo María, which had been abandoned after coca cultivation, four acid-tolerant cropping legumes were tested: *Desmodium heterophyllum*, *Desmodium ovalifolium*, *Centrosema pubescens* 438 and *Pueraria phaseoloides*. Prior to planting, the topsoil was acid (pH 4.9, 1.7 cmol/L of exchangeable Al, and 81% Al saturation) and had low ECEC (2.1 cmol/L) and low available P (2 ppm by the modified Olsen extraction). Slopes ranged from 30 to over 100%.

The area was partially covered by *macorillo* (*Pleridium* spp.), a fern indicative of acid soils. The standing vegetation was slashed and burned. The legumes were planted at 50 x 50 cm spacing with a planting stick. A P differential with application of 0 or 22 kg P/ha as Bayovar rock phosphate to the planting hole was included in the design. Rate of cover formation at 84, 119 and 175 days was collected. After the legumes were established, acid-tolerant, high-value tree seedlings of *achiote* (*Bixa*

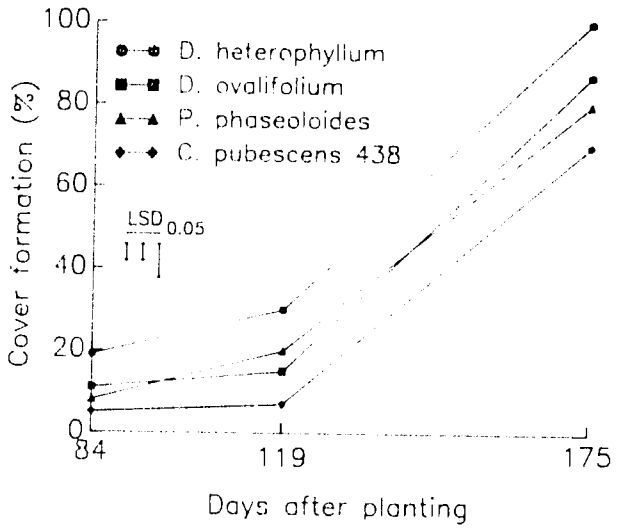


**Figure 1. Rate of cover formation of four acid-tolerant creeping legumes on a degraded steep Ultisol at Pumahuasi, Tingo María.**

*orellana*) were planted at spacings of 6 x 6 m. The tree species received NPK applications according to recommended amounts after they were established. Coffee was interplanted but did not establish itself.

## Results

*Soil cover establishment*

Soil cover by the four legumes is shown in Figure 1. At 84 days after planting, there was less than 20% of soil cover by *D. heterophyllum* and 10% or less by the other three legumes. At 175 days, 100% of the soil was covered by *D. heterophyllum*, 91% by *D. ovalifolium*, 84% by *P. phaseoloides* and 76% by *C. pubescens*.

For better legume establishment, application of

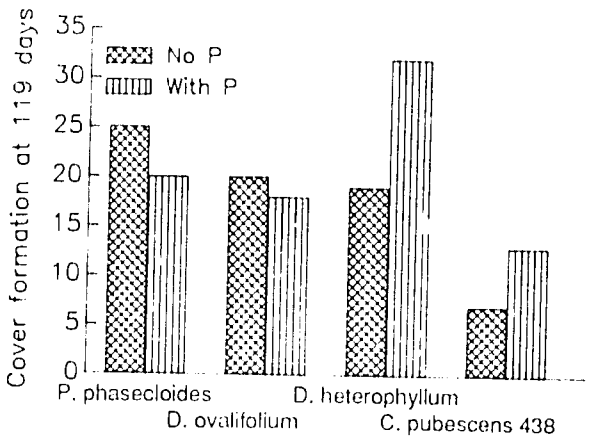


**Figure 2. Effect of 22 kg P/ha as Bayovar phosphate rock on ground-cover development four months after planting on a steep Ultisol at Pumahuasi, Tingo María.**

25 kg $P_2O_5$/ha at planting is recommended for *D. heterophyllum* but not for *D. ovalifolium* or kudzu. Response of the four legumes to P at 119 days after planting is shown in Figure 2. The highest soil cover was obtained by *D. heterophyllum* with P application. With such treatments the soil was protected from further erosion by a total legume cover.

*Tree production*

Tree and cover crop growth were monitored during the next two years. All legumes produced fairly thick covers, particularly *D. ovalifolium* and kudzu (which climbed trees as well). Natural regrowth, however, was even higher, although not as dense. *Achiote* production was very high with *D. ovalifolium* covers but significantly less in the others (Table 1). Without a legume cover, *achiote* yields were zero.

## Conclusions

1. Acid-tolerant creeping legumes can rapidly produce an almost total ground cover within six months after planting in eroded and highly infertile Ultisols of humid tropical steeplands. An application of 22 kg P/ha as rock phosphate accelerates ground cover development in some legumes. This is a simple way to arrest erosion in such tropical steeplands.

2. *Desmodium ovalifolium* favored the production of acid-tolerant, high-value *B. orellana* trees, planted after the legume was established.

**Table 1. Effect of legume covers on tree growth in a previously degraded Ultisol steepland at Pumahuasi, near Tingo María, Peru, two years after establishment.***

| Cover | Cover height | *Achiote* trees Height | *Achiote* trees Yield |
|---|---|---|---|
| | cm | cm | kg/ha |
| *D. ovalifolium* | 89 a | 162 a | 393 a |
| *D. heterophyllum* | 44 a | 142 ab | 22 b |
| *C. pubescens* 438 | 57 a | 101 b | 3 b |
| *P. phaseoloides* | 83 a | 179 a | 14 b |
| Natural | 205 b | 197 a | 0 b |

* Values followed by same letter are not statistically significant at the 5% level.

# Rainfed, Low-Input Crop Rotation Patterns In Alluvial Soils Subject To Seasonal Flooding

*Dennis del Castillo, N. C. State University*
*Juan Lermo, PEPP*

The Pichis River Valley in the Central Selva of Peru is a rainfed area with two distinguishable seasons: (a) the rainy season, which normally begins in the middle of October, reaches a peak of 500-700 mm in December, January or February, and ends in March; (b) the dry season, which begins in April, during which rainfall often does not drop below 100 mm/m, enabling grain-legume cropping. With an adjustment in cropping technology according to the environmental conditions, it may be possible to grow crops before and after rice.

## Objectives

The objectives of this study are 1) to establish a rice-based cropping pattern in low terraces, periodically flooded and relatively fertile soils of the valley (Table 1), and 2) to study the possibility of increasing cropping intensity with minimum inputs.

## Procedures

In 1984-85 two rotation patterns were tested (Figure 1): rice-cowpea-cowpea and rice-soybean. In the second rainfed year (1985-86) two other rice-based rotations were tested (Figure 2): rice-drybean (*Phaseolus vulgaris*) and rice-ratoon rice-cowpea. Incorporation of the ratoon-rice system into the study was due to the heavy rainfall during March and May of 1986, making it difficult to plant grain legumes.

**Table 1. Selected soil chemical properties of rice-based crop rotation at the floodable alluvial terraces before rice planting, La Esperanza station, Pichis Valley, Peru.**

| Depth | pH | Exchangeable Al | Exchangeable Ca | Exchangeable Mg | Exchangeable K | Al sat. | O.M. | Olsen P |
|---|---|---|---|---|---|---|---|---|
| cm | | cmol/L | | | | % | | ppm |
| 0-9 | 5.4 | 0.3 | 9.00 | 2.08 | 0.24 | 3 | 3.4 | 2.5 |
| 9-24 | 5.5 | 0.5 | 9.45 | 1.83 | 0.14 | 4 | 1.3 | 1.0 |

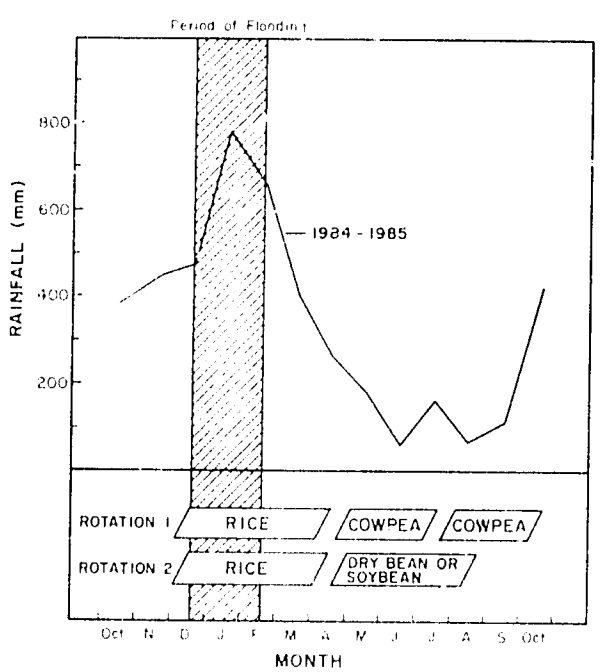


**Figure 1. Rainfall pattern (1984-85) and crop rotation patterns tested in an alluvial terrace, Pichis Valley.**

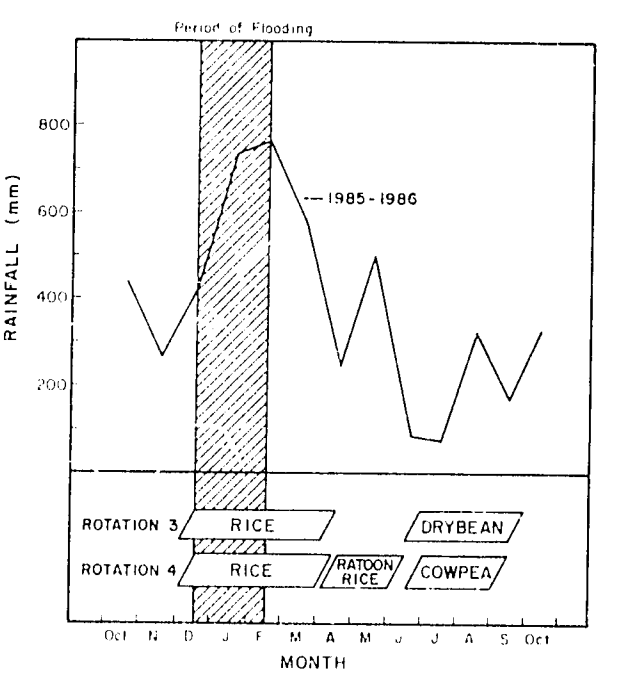


**Figure 2. Rainfall pattern (1985-86) and new cropping patterns tested.**

The seedbed was prepared in November of each year by plowing to a 10-cm depth with a garden rotary tiller; rice was planted by hand in rows 30 cm apart. The seedbeds for cowpea, soybean and drybean were prepared after the rice was harvested by incorporating the rice straw into the soil with the rotary tiller; the crop was planted in rows spaced 60 cm apart. In 1984-85, no fertilizer was used, but in 1985-86 the first crop of rice was fertilized by broadcasting urea at a rate of 50 kg N/ha in split applications at 25 and 60 days after planting. The ratoon was also fertilized with 60 kg N/ha after 20 days of cutting the first rice crop.

During the first year of study (1984-85), the rainfall distribution pattern was similar to the long-term average (Figure 1), which helped rotation 1 (rice-cowpea-rice). Rice cv. PA2 had a slightly higher yield than cv. CICA 8 (Table 2). Cowpea cv. Molina I also had a slightly higher yield in the first planting, but this advantage declined sharply in the second planting, primarily because of fungus diseases during the heavy rain at harvesting. The cv. VITA-7 seemed more resistant than Molina I to diseases under high humidity. In rotation 2 (rice-soybean), rice yielded well, but soybean performed poorly. The soybean leaves had a yellowish color, showing N deficiency. The seeds had not been inoculated with *Rhizobium*. In the second year, the rainfall distribution was different from that of the average and the 1984-85 season (Figure 2): the high rainfall peak in May did not allow good planting of drybean and cowpea. Rice yields in each rotation during 1985-86 were satisfactory, but legume yields were very low (Table 3) because of heavy fungus diseases that damaged grain yield and quality. Although the grain yields of ratoon rice in rotation 4 were low, the rotation pattern seems promising in years when rainfall does not allow land preparation for grain legumes.

**Table 2. Yields of the first, second and third crops in the rice-based pattern rotation, 1984-1985.**

**Rotation 1: Rice-Cowpea-Cowpea**

| Cultivars (rice-cowpea-cowpea) | Grain yield: Rice (Dec 1984) | Cowpea (May 1985) | Cowpea (July 1985) | Total Cowpea |
|---|---|---|---|---|
| | t/ha | | | |
| CICA 8 - Vita 7 - Vita 7 | 4.2 | 1.80 | 1.60 | 3.40 |
| PA2 - Vita 7 - Vita 7 | 4.5 | 1.75 | 1.70 | 3.45 |
| PA2 - Molina I - Vita 7 | 4.5 | 2.10 | 1.60 | 3.70 |
| PA2 - Molina I - Molina I | 4.5 | 2.00 | 1.00 | 3.00 |

**Rotation 2: Rice-Soybean**

| Cultivars (rice-soybean) | Grain yield: Rice (Dec 1984) | Soybean (May 1985) |
|---|---|---|
| | t/ha | |
| PA2 - Jupiter | 4.5 | 0.82 |
| PA2 - Nacional | 4.5 | 0.56 |
| PA2 - Mandarin | 4.5 | 0.66 |
| PA2 - PR-13-101-2 | 4.5 | 0.75 |

### Conclusions

The performance of the various cropping patterns is highly environment-specific: that is, performance varies from year to year. It was also evident that high-yield rice cultivars produced satisfactory yields under rainfed conditions when they were planted during the rainy season, but there is need to look for more crop rotation patterns during the dry season that may fit better with more rainfall variations. The rice-rice ratoon-cowpea rotation appears to offer the most promise.

**Table 3. Yields of the first, second and third crops in the rice-based pattern rotation, 1985-1986**

Rotation 3: Rice-Drybean

| Cultivars (rice-drybean) | Grain yield: Rice (Dec 1985) | Grain yield: Drybean (June 1986) |
|---|---|---|
| | t/ha | |
| 22196 - CIAT 1020 | 5.00 | 1.58 |

Rotation 4: Rice-Ratoon Rice-Cowpea

| Cultivars (rice-cowpea) | Grain yield: 1st rice Harvest | Grain yield: Ratoon rice with 60 kg N/ha | Grain yield: Total rice | Grain yield: Cowpea (June 86) |
|---|---|---|---|---|
| | t/ha | | | |
| PA2 - Vita 7 | 4.68 | 1.69 | 6.37 | 1.11 |
| CICA 8 - Vita 7 | 4.88 | 1.30 | 6.18 | 1.20 |
| 22196 - Vita 7 | 5.10 | 1.66 | 6.76 | 1.15 |
| 13965 - Vita 7 | 4.90 | 2.50 | 7.40 | 0.90 |

## Evaluation of Pasture Germ Plasm Under a Perudic Rainfall Regime

*Kenneth Reátegui, N. C. State University*
*José Merino, INIPA*
*Dennis del Castillo, N. C. State University*
*R. Ruíz, PEPP*
*G. Cantera, PEPP*
*E. Acuña, PEPP*
*Esteban Pizarro, CIAT*
*Mario Calderón, CIAT*

Pasture production is the traditional activity of Pichis Valley settlers and the one that accounts for the largest cleared areas. Given the pattern of very high annual rainfall (3300 mm), it is expected that the grass and legume accessions that have been successful in udic rainfall regimes at Yurimaguas might not do well at Pichis.

### Objectives

The objectives of this study are 1) to evaluate and select pasture germ plasm adapted to acid soils and to the very high rainfall conditions at Pichis, and 2) to select germ plasm resistant to spittlebug (*Aeneolamia* sp.) attacks in this perudic area.

### Procedures

A germ plasm-introduction experiment was established in 1984 in a high terrace on an Ultisol with pH 3.7, 94% Al saturation and 4.2% topsoil organic C contents. Evaluations in 1985 and 1986 were made during periods of minimum and maximum precipitation every three, six, nine and 12 weeks after cutting. Growth rate, percentage of cover, and resistance to pests and diseases were measured.

### Results

Pastures evaluated included 19 legumes (Figure 1) and three grasses (Figure 2). A direct relationship existed between the amount of biomass produced and ground cover, as well as between biomass produced and resistance or tolerance to pests and diseases.

Of the legumes, *Desmodium ovalifolium* 350 was selected for use in the zone due to its good cover and good seed production, although it did not show uniformity in dry-matter yield (Figure 1). Both

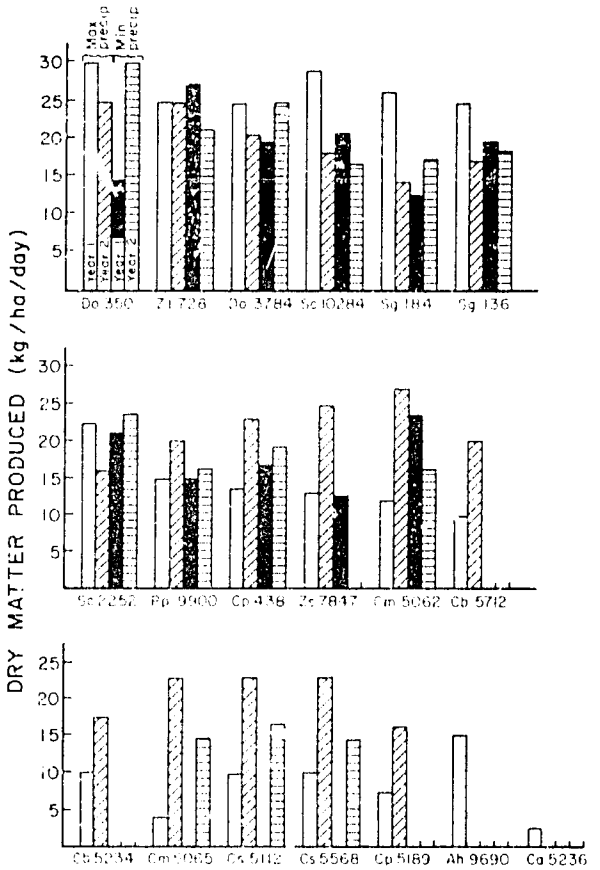


**Figure 1. Legumes evaluated for growth rate under periods of maximum and minimum precipitation, Pichis River Valley, Peru, 1985-1986.** Do=*Desmodium ovalifolium*, Zi = *Zornia latifolia*; Sc=*Stylosanthes capitata*; Sg=*Stylosanthes guianensis*; Pp=*Pueraria phaseoloides*; Cp=*Centrosema pubescens*; Zs=*Zornia* sp.; Cm=*Centrosema macrocarpum*; Cb=*Centrosema brasilanum*; Ah=*Aeschynomena histrix*; Ca=*Centrosema arenarium*.

accessions of *Stylosanthes capitata* (10280 and 2252) were adapted to conditions at Pichis, where they survived periods of maximum and minimum precipitation; this species did not perform well however, in Yurimaguas and Pucallpa. *Stylosanthes guianensis* 184 cv. Pucallpa was similar to *S. capitata* 10280 in dry-matter yield. At the beginning of the dry season in the first year, all *Stylosanthes* accessions were severely attacked by stem borer (*Calloptilia* sp.), but the plantings recovered through seed generation.

Although *Zornia latifolia* 728 had initial good yields, yields were reduced due to seasonal defoliation. Kudzu (*Pueraria phaseoloides* 9900) grows wild in the Pichis Valley; it showed good cover and uniform production, all important characteristics for its selection.

None of the *Centrosema* accessions showed sufficient benefits for selection in Pichis as they did in other regions of the Peruvian Amazon, such as Pucallpa, Tarapoto and Yurimaguas. Apparently these accessions do not tolerate the soil's high water saturation, so that several accessions appeared to be dormant in periods of maximum precipitation.

Of the grasses, *Brachiaria dictyoneura* 6133 survived with desirable characteristics for further evaluation. *Andropogon gayanus* 621 cv. San Martín was aggressive during the dry season but yields diminished during maximum precipitation. *Brachiaria decumbens* 606 is widespread throughout the area, but it was sensitive to spittlebug attack.

Spittlebug attacks all grasses, especially *Brachiaria* spp., throughout tropical America, but it is believed to be most serious in very high rainfall regions. In the Pichis River Valley spittlebug control is critical during periods of maximum precipitation. A total of 23 accessions of *Brachiaria* spp. were evaluated for resistance or tolerance to spittlebug by the International Network for Evaluation of Tropical Pastures (RIEPT), CIAT, over a period of two years.

Data (not presented) showed presence of spittlebug in all species and accessions and in both seasons. Severe attacks were present during periods of high rainfall, but so were the greatest dry-matter yields. *Brachiaria brizantha*, *B. dictyoneura* and *B. humidicola* combined the highest yields of dry-matter production with the greatest tolerance to spittlebug. Damage was most critical in *B. ruziziensis* 655, *B. eminii* 6241 and *B. radicans* 6020, which almost disappeared after the rainiest season.

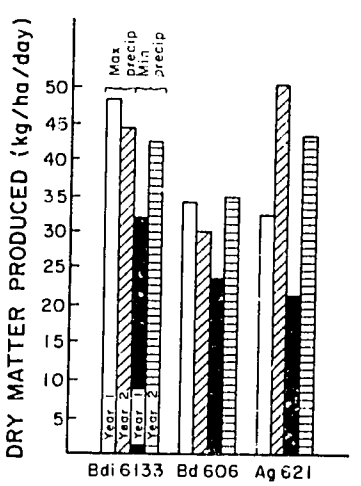


**Figure 2. Grasses evaluated for growth rate under periods of maximum and minimum precipitation.** Bdi=*Brachiaria dictyoneura*; Bd=*Brachiaria decumbens*; Ag=*Andropogon gayanus*.

# Recuperation of Degraded Pastures Dominated by *Homolepsis aturensis*

*Kenneth Reátegui, N. C. State University*
*R. Ruíz, PEPP*
*G. Cantera, PEPP*
*Dennis del Castillo, N. C. State University*
*José Merino, INIPA*

One of the greatest problems in the Pichis River Valley is the degraded state of pasture land, most of which has been invaded by scarcely palatable grasses such as *Homolepsis aturensis*, known in the area as *arrocillo* or *pasto amargo*. Unlike other forms of degraded pastures observed in Yurimaguas and Pucallpa, *Homolepsis* pastures look beautifully green and with a full ground cover. The problem is that the cattle do not eat it. One solution is to renovate the pastures by eradicating *Homolepsis* and using germ plasm adapted to the soil.

## Objectives

The objectives of this study are 1) to renovate degraded pastures by using improved germ plasm, and 2) to ensure that the change in germ plasm is economic for the producer and that it does not alter the soil ecology.

## Procedures

Three species were tested: *Brachiaria decumbens*, *B. dictyoneura* and *Desmodium ovalifolium*. Three land-clearing treatments were used: none, herbicides and tillage mechanization. Tillage and mechanization were done only in 30% of the area along the contour. Treatments were replicated three times, each with a minimum fertilization of 10 kg P/ha.

Every three months, measurements were taken of dry-matter production of existing plot components (grass species, kudzu and *Homolepsis*) and of the expansion in the plot of the planted species.

## Results

Only *B. decumbens* was well-established in the plots after six months; neither of the other two species was aggressive enough to compete with *Homolepsis aturensis*. There were no effects of herbicide vs. tillage in the successful establishment of *B. decumbens*.

## Conclusions

With minimum inputs and an adapted species, it appears that degraded pastures dominated by *Homolepsis aturensis* can be recuperated in perudic soil moisture regimes.

# Sitiung: Extrapolation to Transmigration Areas of Indonesia

Last year we reported on the reclamation of bulldozed lands, liming, phosphorous management, green manure, potassium and sulfur management for sustained production of annual food crops in Sitiung, West Sumatra. Because of budget cuts received during 1986, North Carolina State University had to discontinue our participation in Indonesia. This report focuses on the response of upland crops to lime and potassium and a study of the agroforestry potential of the area. Potassium applications were very important in increasing crop yields and decreasing disease or lodging effects. A TropSoils bulletin is being prepared, summarizing our program's results on overcoming soil fertility constraints in this region.

# Response of Upland Crops To Potassium and Lime Applications

*Dan W. Gill, N. C. State University*
*Antonius Kasno, Centre for Soils Research*
*Eugene J. Kamprath, N. C. State University*

The central Sumatran peneplain is dominated by Oxisols and Ultisols, which are low in bases and high in exchangeable Al. The Government of Indonesia has recognized this problem and has sought to provide large quantities of lime (up to 4 t/ha) to farmers who were associated with the soybean production program in the region. There was concern that the addition of lime to the soil would decrease even further the levels of soil K available for crop growth, perhaps to the extent that lime applications would not lead to increased yields. Initial experimentation revealed that rice, soybean and corn grown in the Sitiung region exhibited a strong response to KCl applications.

## Objectives

The objectives of this study are 1) to study the response of several upland crops in West Sumatra to KCl applications at three levels of base saturation, and 2) to measure the effects of lime and KCl applications on the soil at four depths over a two-year period.

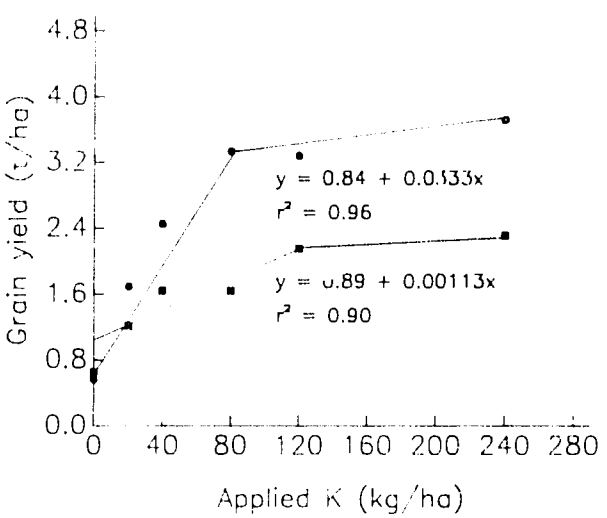


**Figure 1. Response of upland rice to applied KCl. Sitiung, 1985 and 1986.**

## Procedures

Two separate experiments with similar treatments were established in two different areas of Sitiung. Both experiments were complete factorials with lime rates establishing approximately 70, 40 and 10% Al saturation (0.375, 1.5 and 5 t/ha, respectively) and with 0, 20, 40, 80, 120 and 240 kg K/ha applied as KCl. On a Typic Haplorthox at Sitiung II, with about 75-80% Al saturation and 0.05 cmol/L of K, a rice-soybean rotation, probably the most common rotation in the region, was grown for two years. On another Typic Haplorthox with slightly higher levels of exchangeable Al and bases (Al saturation was about 75%), the treatments were applied to a corn-peanut rotation. Crop parameters measured included yield of and stover and percentage of K in both grain and stover, thus permitting calculation of K uptake. In addition, levels of exchangeable Al and bases in the soil were measured before and after each crop in the rotation at four depths (0-15, 15-30, 30-50 and 50-75 cm).

## Results

Grain yield of the rice crop in both 1985 and 1986 did not respond to applications of lime greater than 0.375 t/ha, due to the tolerance of this species to Al. When no lime was applied, the rice yielded very poorly (data not shown) but the application of just 0.375 t/ha supplied enough Ca so that there were no further responses to lime levels above this rate. However, response to applied K was quite strong in both years (Figure 1). In 1985, yields did not reach a maximum if less than 120 kg K/ha were applied. Potassium applications were effective in decreasing rice blast (*Pyricularia oryzae*) incidence (Table 1), and this added resistance to disease was at least partially responsible for the grain response to applied K. More rainfall events, as well as higher total rainfall during the growing season, occurred in 1986, leading to higher grain yields. However, yields were maximized at an application rate of 80 kg K/ha, less than the 120 kg K/ha required the previous year (Figure 1). Rice grain returns of 11.3 and 33.3 kg per kg of applied K were obtained in 1985 and 1986, respectively, for the portion of the curve showing a positive response.

Grain yield in 1985 was related to percentage of K in the straw at harvest time (Figure 2). The higher the K levels in the straw, the greater the grain yields. Total K uptake for the first crop of rice can be observed in Figure 3. As can be seen in Figure 3, K uptake in the grain varied from about 2 kg/ha with 0 kg of applied K to a maximum of about 7 kg K/ha at high rates of applied KCl. The majority of the K taken up by the plant was in the straw.

Potassium uptake efficiency (KUE) for the 1985 rice crop was calculated. KUE is defined as ([A-B]/C) 100, where A = total crop K uptake under treatment X, B = total crop K uptake with 0 applied KCl, and C = K applied as KCl under treatment X. Results are shown in Table 2. At the lower rates of applied K, the crop actually took up more K than that applied, apparently because the addition of small doses of K permitted roots to develop more vigorously and take up more soil K than they would have without the addition of KCl. KUE remained relatively high up to 120 kg of applied K/ha.

The response of rice grain yield in 1985 to levels of exchangeable K can be seen in Figure 4. The linear response and plateau (LRP) model showed a "critical level" or break point at 0.20 cmol of exchangeable K/L of soil.

In both 1985 and 1986, the upland rice crop was followed by soybean. Soybean grain response to K, unlike that of the rice, depended on the level of lime applied (Figure 5). In 1985, no response to K was observed at the low rate of lime; a response to 20 kg K/ha at the medium lime rate was seen, while yields

**Table 1. Rating of rice crop grown in the Sitiung region in 1985 for rice blast (*Pyricularia oryzae*) incidence at various levels of KCl applications (0 = no blast, 5 = all plants killed by blast).**

| Treatment | Rating |
|---|---|
| kg K/ha | |
| 0 | 4.9 |
| 20 | 2.9 |
| 40 | 2.2 |
| 80 | 2.1 |
| 120 | 1.8 |
| 240 | 2.0 |

**Table 2. Potassium uptake efficiency for the rice crop grown in the Sitiung region in 1985.**

| Treatment | Total K uptake | K uptake efficiency |
|---|---|---|
| kg K/ha | kg K/ha | % |
| 0 | 9.4 | - |
| 20 | 30.7 | 125 |
| 40 | 53.9 | 130 |
| 80 | 77.9 | 95 |
| 120 | 92.0 | 78 |
| 240 | 123.5 | 53 |

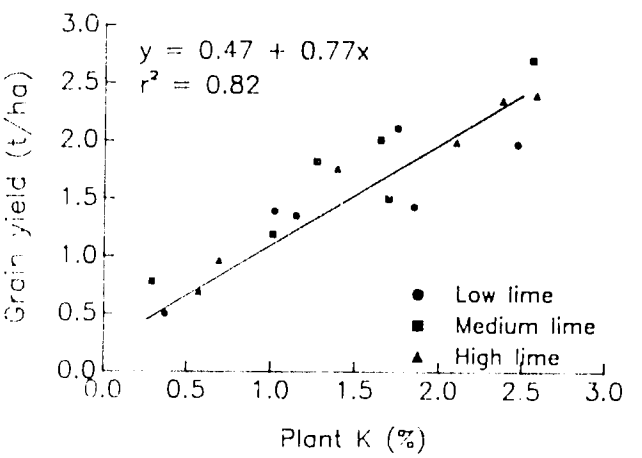


**Figure 2. Relationship between percentage of K in straw at harvest on upland rice grain yield at three lime levels (0.375, 1.5 and 5 t/ha). Sitiung, 1985.**

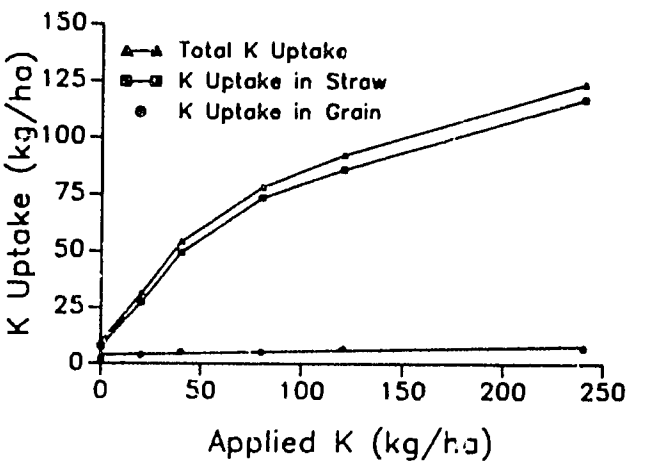


**Figure 3. Potassium uptake of a rice crop at varying KCl rates. Sitiung, 1985.**

were maximized at the 80 kg K/ha rate under the high lime treatment. This response is related to the crop's sensitivity to soil Al as shown in Figure 6, where grain yield is related to Al saturation.

KUE values for soybean at the three lime levels are shown in Table 3. At the low lime rate, Al inhibited uptake and KUE was low. Under the medium rate of lime, KUE was higher at low K rates, but dropped off rapidly at the higher K rates, since root growth was still restricted by soil Al. KUE remained relatively high over a wider range of K application rates under the high lime treatment, since most soil Al in the topsoil was neutralized and potential for crop yield and K uptake was increased.

Soybean yields during 1986 were higher than in 1985 (Figure 5), primarily due to increased rainfall. Responses to K were obtained up to approximately 30 kg K/ha at the low lime rate, while at the medium lime rate reached a plateau at 40 kg K/ha. Grain yields at the high lime rate did not reach a plateau, but rather showed a response with two ascending curves. A model describing this function has the following equation:

$$y = 0.453 + 0.0232\,(X_1) + 0.00187\,(X_2)\ (r^2 = 0.92),$$

where $X_1$ = K application rates from 0 to 40 and $X_2$ = from 40 to 240 kg K/ha. Soil analysis is not yet available for this crop and thus no correlations of

**Table 3. Potassium uptake efficiency for the soybean crop grown in the Sitiung region in 1985.**

| Treatment | Lime level (t/ha) Low (0.37) | Medium (1.5) | High (5.0) |
|---|---|---|---|
| kg K/ha | % KUE | | |
| 0 | - | - | - |
| 20 | 40 | 65 | 60 |
| 40 | 25 | 50 | 50 |
| 80 | 4 | 26 | 56 |
| 120 | 13 | 22 | 33 |
| 240 | 5 | 14 | 16 |

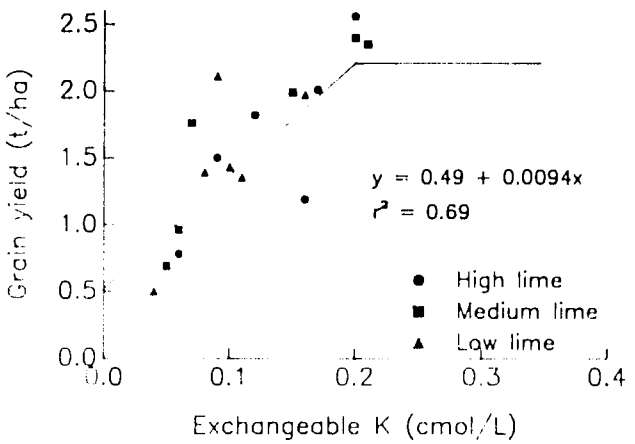


**Figure 4. Effect of exchangeable K levels in the soil on rice grain yield. Sitiung, 1985.**

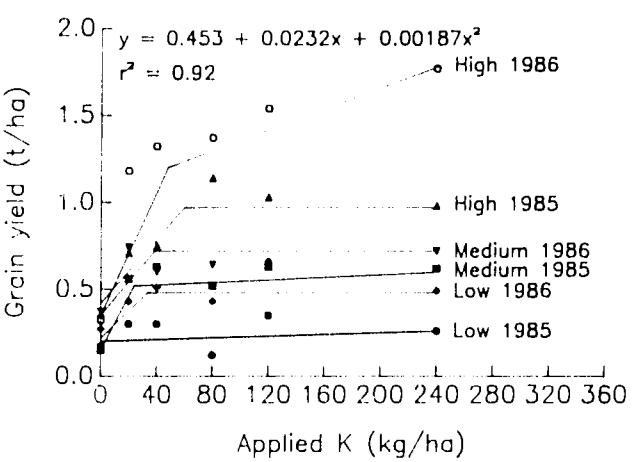


**Figure 5. Effect of applied KCl at three lime levels on soybean grain yield. Sitiung, 1985 and 1986.**

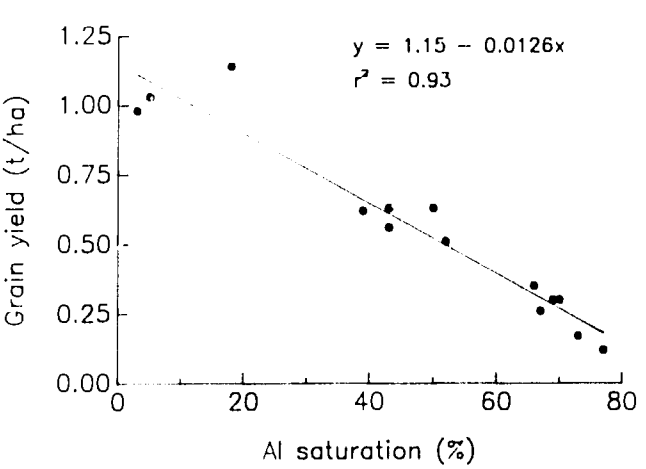


**Figure 6. Effect of Al saturation in the soil on soybean grain yield. Sitiung, 1985.**

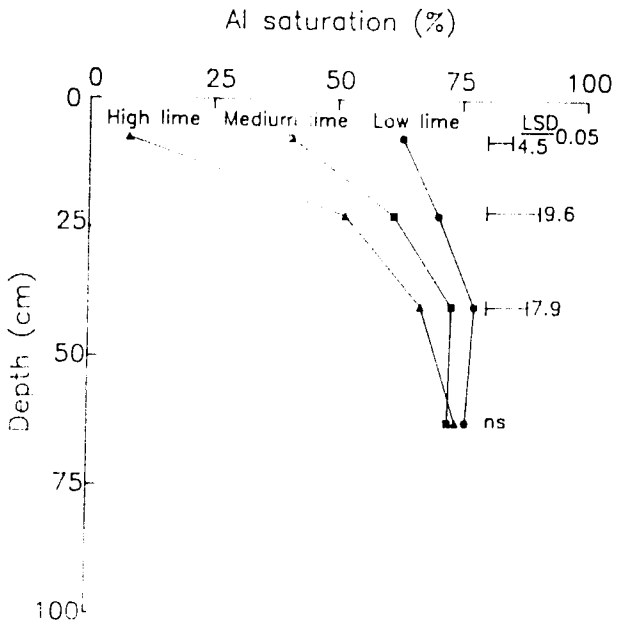


**Figure 7. Percentage of Al saturation of a Typic Haplorthox in Sitiung, measured one year after application of lime.**

crop growth with levels of K or Al in the soil have been performed.

Soil samples at four depths were taken one year after lime application. Lime applications significantly decreased Al saturation, not only at the 0-15 cm depth, but also at the 15-30 and the 30-50 cm depths (Figure 7). At the 15-30 cm depth, Al saturation fell from 71 to 51% over the range of lime treatments, while at the 30-50 cm depth, it fell from 77 to 67%. This decrease in Al corresponded to an increase in Ca at each depth (data not shown) and indicates that subsoil chemistry is becoming more favorable for the development of crop root systems.

The second experiment involved a rotation of corn-peanut for both 1985 and 1986. Since the majority of the plant and soil samples, as well as much of the data for this experiment, have yet to be analyzed, and since yield data for the corn and peanut grown in 1985 were reported in the previous TropSoils technical report, only yields for the 1986 crops and lodging for the corn are reported here. The effect of KCl applications at three levels of Al saturation on corn grain yields is shown in Figure 8. There was a significant response to lime, with greater yield achieved as more soil Al was neutralized. Differences in yield due to lime treatments became greater as the rate of K was increased. Response to K was rather dramatic at all three lime rates, with maximum yields obtained only when 80 kg K/ha were applied. Potassium applications were very effective in decreasing lodging incidence (Table 4). A high proportion of the corn plants in the low K plots fell onto the ground and some of the grain was lost.

Yield response to lime and K of the following peanut crop is shown in Figure 9. Response to lime was significant, as would be expected with a crop sensitive to soil Ca levels. Unlike the previous year, when significant responses to K were obtained only at the two higher lime rates and even then only to 20 kg K/ha, in 1986 a response was obtained at all lime rates to approximately 80 kg K/ha.

**Table 4. Effect of applied KCl on lodging of corn grown in 1986 in Sitiung.**

| Treatment | Lodging |
|---|---|
| kg K/ha | plants/plot |
| 0 | 43 |
| 20 | 26 |
| 40 | 11 |
| 80 | 5 |
| 120 | 4 |
| 240 | 2 |

## Conclusions

Upland crops in these experiments varied in their tolerance to soil Al, with tolerance decreasing in the

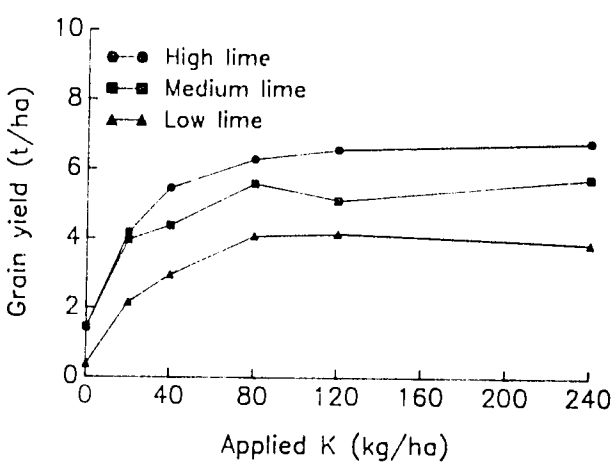


**Figure 8. Effect of applied KCl at three lime levels on corn grain yield. Sitiung, 1986.**

following order: rice, peanuts, corn and soybean. Since soybean is the most sensitive of these crops to soil Al and rice is the most tolerant, perhaps farmers in the region should be encouraged to grow rotations that include crops more similar in their need for lime, i.e., a "high-input" system. A corn-soybean rotation would probably be more appropriate in soils which were naturally lower in Al or had been limed more, while those farming soils with high levels of Al and low rates of applied lime would perhaps be better off with a rice-peanut rotation (a lower input system). To grow more peanuts and corn in the region, however, an economic solution to the wild pig problem will have to be developed.

All crops responded quite strongly to K and, if government yield targets are to be reached for upland crops in this region, low to moderate levels of K (20-80 kg K/ha, depending upon crop and soil Al levels) will have to be applied. Applications of lime without addition of K sometimes resulted in no yield increases, while KUE was improved with the neutralization of soil Al, especially for Al-sensitive crops such as soybean. Potassium was shown to decrease disease incidence in rice and decrease lodging in corn.

While many farmers in the region are quite careless with their crop residues, frequently piling them on the edge of their fields and burning them, most of the K taken up by the crop is in the residue. Farmers need to be made aware of the importance of recycling that residue in their farming operation, either through livestock (especially with peanut and corn tops) or by returning residues to their fields. Proper management of residue will remove less K from the soil and permit crops to be grown with higher yield potentials while fertilizing with lower K rates.

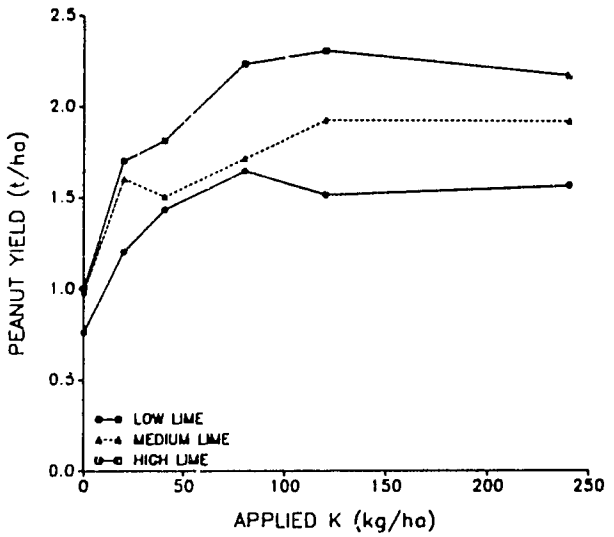


**Figure 9. Effect of applied KCl at three lime levels on peanut grain yield. Sitiung, 1986.**

Initial results from analysis of soil samples seem to indicate a critical level for exchangeable K of 0.20 cmol/L for rice. Applications of KCl increase soil K levels initially, but these levels drop off over a period of several months, and since they are apparently not recovered in samples analyzed from the subsoil (down to 75 cm), it is assumed that this K is leaching below the root zone. However, only one year after lime was applied, sufficient amounts of Ca had leached down to the 30-50 cm depth to decrease percentage of Al saturation significantly (Figure 7). This is very encouraging as it permits greater root growth down to these depths, allowing for greater water and nutrient utilization. It is probable that this subsoil amelioration will only increase as more lime leaches downward with time, increasing yield potentials of crops in the region.

## Agroforestry Research Needs

*Erick C. M. Fernandes, N. C. State University*

The use of lime, fertilizers and pesticides is essential for continuous cultivation of crops at Sitiung. Despite these inputs, which the Indonesian government provides at highly subsidized prices, farmers in Sitiung find it difficult to satisfy annual food needs and obtain adequate cash for inputs to ensure good production in the next season. Furthermore, it is unlikely that current subsidies on inputs will be maintained due to declining government revenues, as indicated by the 45% devaluation of the Indonesian rupiah against the U.S. dollar in November 1986.

Oil and gas account for about 70% of Indonesia's foreign exchange earnings and 55% of government tax revenues. As a result of international oil prices, Indonesia's petroleum export revenues were predicted to fall by $5.8 billion (47%) for 1986 alone. It is imperative that transmigrant farmers develop a range of sustainable food- and cash-cropping systems to counter the inevitable decline in government subsidies and rise in cost of living.

Agroforestry technologies have the potential to reduce the levels of inputs and, more importantly, to provide a diverse range of cash-generating enterprises. This not only minimizes risk, but also enables the farmer to raise cash to purchase the inputs required for successful cropping. This report presents a diagnosis of the constraints within the various production subsystems at Sitiung and identifies agroforestry alternatives that have the potential to provide solutions to pressing problems of declining productivity and sustainability.

Agroforestry is a collective name for systems of land use in which woody plants (trees and shrubs) are deliberately managed on the same land management unit, either simultaneously or in rotation, with annual crops and/or animals. For a land use to qualify as agroforestry, there should be both ecological and economic interaction between the woody plants and the other components of the system.

Agroforestry may involve the integration of trees and shrubs into farming systems or crops and livestock into forests. In practice, a high proportion of agroforestry systems involve the growing of trees (for various products and services) on what is essentially farmland.

### Objectives

The objectives of this study are:

1. To undertake a diagnosis of the current land-use systems in Sitiung and identify suitable agroforestry technologies to overcome productivity and/or sustainability constraints in the existing systems. This would enable TropSoils to determine what research is needed to generate and refine the required technologies. Implicit in this is the development of a research-extension methodology and general prototypes of agroforestry technologies to be modified and tested in similar environments at other transmigration sites in Indonesia.

2. To identify individuals and institutions involved in agroforestry research in Indonesia. This would facilitate not only an exchange of research experiences and data, but also provide an indication of potential collaborators for the future.

### Procedures

The general diagnostic and design (D&D) approach followed that developed by the International Council for Research in Agroforestry (ICRAF) for diagnosis of existing land management practices and design of agroforestry alternatives.

The procedural sequence was as follows:

1. Review of baseline biophysical and socioeconomic information for Sitiung from TropSoils' and CSR publications and discussions with researchers at Sitiung and CSR, Bogor.

2. Diagnostic interviews with sample farmers to identify a) problems as perceived by the farmer with respect to household needs; b) land management problems and constraints resulting in present (productivity) and future (sustainability) problems; and c) current farmer strategies to counter these problems.

3. Diagnostic analysis to evaluate the land-use problems clarifying relationships among contributing factors and assigning priorities to them.

4. Derivation of functional and general specifications for problem-solving interventions.

5. Analysis of a range of agroforestry technology options for addressing the identified design specifications.

6. Analysis of alternative systems plus technologies and comparison with technological improvements in existing systems.

7. Evaluation of design alternatives and choice of a limited set of best-bet options.

8. Identification of research needs to generate the required technology if not already available.

9. Analysis of the existing institutional infrastructure responsible for developing and disseminating the proposed technological alternatives.

## Results

*Diagnosis of the farming systems at Sitiung*

Based on research experiences from the TropSoils program at Yurimaguas, Peru, and on-site validation of such results, the Government of Indonesia adopted TropSoils' recommendations for both lime and fertilizer inputs to enable transmigrant farmers to successfully grow crops on the infertile, Al-saturated soils at Sitiung on a continuous basis. The initial allowance that the transmigrant farmers receive and the facilities for purchasing these inputs at subsidized prices have had a dramatic, positive effect on crop production at Sitiung. Despite the impact of lime and fertilizers, however, farm families interviewed at Sitiung most often mentioned food and cash as the basic needs not being adequately filled.

All the transmigrant farmers at Sitiung have spontaneously developed agroforestry-based home gardens involving multistoried mixtures of trees, annual crops and stall-fed livestock. This diversity in the home gardens not only supplements production from the cropland but also minimizes risk of crop failure. Recent studies have shown that home gardens account for 44% of total agricultural products and provide between 28 and 60% of the total cash value of agricultural produce in the various communities in Sitiung. It is important to note that development of these home gardens has been based solely on previous farmer experiences. The fact that many were landless before arriving at Sitiung and the lack of adequate germ plasm would indicate that most of the home gardens are currently producing well below their potential.

The food problem primarily involves an inadequate production of rice (especially upland) to meet year-round family needs, resulting in an annual requirement to purchase rice. This causes competition for scarce cash resources that are also required for the purchase of lime, fertilizers and pesticides to ensure adequate production in the next season.

Low soil nutrient levels are reflected by low crop yields without fertilization and good response to fertilizers for most crops. In particular, Sitiung soils are particularly low in exchangeable Ca and Mg; very low in available P; and possibly low in Mo, Mn, Zn, B and Cu. High levels of exchangeable Al combined with low CEC result in Al saturation levels greater than 60%. All these problems, however, can be corrected by lime and fertilizers. Farmers differentiate between "dark" (good) soils and red or yellow (poor) soils and tend to concentrate inputs on the poor soils.

Moisture stress is a major problem for crop production due to shallow rooting of many crops (probably related to high Al saturation and/or low supply of bases in the subsoil) and the high permeability of most Sitiung soils. Droughts in certain years exacerbates the problem. The implications of the transmigrants' practices of thoroughly digging the soil before planting are serious. In contrast, the indigenous Minang are aware that drought stress is most severe when the topsoil is disturbed by tillage and thus use no-till planting methods.

None of the farmers interviewed mentioned lack of labor as a constraint. The main reason for this is likely to be the availability of cooperative labor (*gotong royong*). This system involves groups of 20-25 farmers working in rotation on each others' fields. The farmer whose land is being worked pays for this labor by providing meals for the group. Despite this system, however, it is likely that some bottlenecks occur, especially at planting and harvesting, when all the farmers are involved at approximately the same time. The relatively high wages of off-farm labor (lumber camps, road construction) make it difficult for farmers to neglect wage labor at any time of the year.

Soil erosion is severe on some transmigrant farmers' fields because they were allocated steeply sloping land for production of their food crops. Erosion control practices currently used by some transmigrants at Sitiung include bench terracing (very labor intensive) and contour planting.

Pests and diseases are major constraints to crop production in Sitiung. The main pest of peanut, corn and cassava is the wild pig, which is capable of totally destroying unprotected fields. Rice blast (*Pyricularia oryzae*), seedling fly (*Atherigona exiqua*), brown planthopper (*Nilaparvata lugens*) and stem borer (*Chilo* sp.) are major constraints of upland rice. Soybeans are attacked by seedling fly soon after germination and by a pod borer (*Etiella zinckenella*)

at the pod-filling stage. The weed *Imperata cylindrica (alang-alang)* was also mentioned as a problem. Most farmers lack cash resources to purchase pesticides and adopt avoidance strategies. Thus, upland rice is planted early in the rainy season, when the incidence of blast is low. Corn and peanut are not planted in areas prone to wild pig damage—i.e., close to forest margins.

Poor supply of agricultural inputs is often a problem throughout Sitiung. Both inadequate supplies and untimely delivery of fertilizers and pesticides were cited as problems by farmers in Sitiung II and III. In newer settlements such as Sitiung V there was a long period between the end of government fertilizer allocations in 1984 and establishment of a local distributor. Heavy rains sometimes make the roads from the Trans-Sumatran Highway into the settlements impassable, thereby limiting the supply of inputs at critical periods such as planting. Even when adequate supplies exist, however, farmers lack cash to purchase inputs and are reluctant to participate in credit programs.

Cash crop production is limited by low yields and low prices. The low yields of soybean, peanut and corn are due primarily to the acid, infertile soils, which require adequate liming and fertilizer inputs, to damage caused by pests (pigs, insects, rats, monkeys), and to drought (once in three or four years). Current income from tree crops (cloves, coconuts, coffee, *rambutan*) is low, due mainly to the low prices of these crops in local markets. Farmers are unable to transport their produce to the large markets at Padang and fall victim to exploitation by middlemen. Most farmers are reluctant to participate in government credit programs because of fears of crop failure resulting in their inability to repay loans.

Although most farmers in Sitiung I have cattle, farmers in recent settlements (Sitiung V) are yet to receive their cattle from the government. The current scheme involves each farmer being given a cow with the condition that two calves be returned to the government within five years. The advantages of livestock over food and cash crops include lower production costs in terms of labor and inputs and reduced risks since livestock production is less affected by rainfall variability and timely inputs.

Farmers in Sitiung I appreciate the advantages of their cattle, which are used for land preparation and as an investment. In addition, most farmers use the manure on their home gardens and crop lands. Animals are sold to generate cash as needed (for school fees, medical expenses, purchase of inputs and food). It is interesting to note that of the ten farmers interviewed, the only farmer who did not mention lack of cash and fertilizers as constraints to productivity had a small herd of five cows. He used manure to supplement fertilizer inputs and over the years had sold several animals from his gradually expanding herd. To ameliorate the problems of fodder scarcity, improved fodder grasses had been planted within and on the boundaries of the home garden.

Although disease is apparently not a problem, most cows in Sitiung appeared in poor condition. This is not surprising considering the scarcity of fodder, which consists mainly of grasses and weeds harvested from the roadsides and croplands. Even assuming an adequate nutrient content of these species, their high moisture content probably implies an inadequate daily dry-matter intake resulting in reduced productivity (poor weight gain, low reproductive rates).

**Agroforestry Alternatives**

Three major areas for agroforestry intervention were identified:

1. Soil fertility and Al toxicity.
2. Livestock feed.
3. Cash crops.

It is important to appreciate that most agroforestry technologies are still at the national or hypothesis-testing stage with relatively few data available from extensive field tests. The technologies proposed here must hence be viewed within this context and not as guaranteed solutions.

The design and testing of agroforestry technologies at both the farm and community levels should provide a wider range of options and also considerably enhance the potential for improving system productivity.

*At the farm level*

1. Alley-cropping with fast-growing, Al-tolerant, N-fixing woody perennials in hedgerows along the contours to address one or more of the following:

   a. Reducing Al toxicity via complexing of Al by freshly added leaf and woody material;

   b. Recycling leached nutrients from fertilizers

added to crops by the deeper rooted woody species;

c. Minimizing cropland erosion, especially on slopes, via formation of natural terraces;

d. Providing high-protein fodder supplement for livestock;

e. Providing fuelwood, all of which is currently obtained from surrounding natural forests.

*Albizia falcataria* and *Calliandra calathyrsus* have been tested on a limited scale at Sitiung and show potential as alley-cropping species. The good performance of *Inga edulis* on acid soils in Yurimaguas, Peru, warrants its inclusion in trials at Sitiung. *Inga* would be especially suitable where fuelwood production is a major function of the woody hedgerows.

2. Live fences on field boundaries to minimize wild pig damage to crops such as corn, cassava and peanut. Apart from the labor to establish the live fences, little maintenance would be required and the fences could be managed to produce green manures, mulch or fodder.

Closely planted, easy-to-grow species such as *Gliricidia sepium*, *A. falcataria* and *C. calathyrsus* should be tried. *Peronema canescens* (known locally as *sungkai*) could be managed to produce good-quality poles in addition to being an excellent live fence. Other potential live fence species include *Ceiba pentandra* and *Jatropa curcas*. Like *Gliricidia*, they can also be propagated vegetatively from cuttings but are not as good for green manure production.

3. Intensification of fodder production in home gardens and on upland fields. Most transmigrant home gardens are currently devoted to woody perennials for food and cash and a few annual crops. There is, however, good scope for fodder production on currently underutilized boundary areas. Although shade-tolerant grasses could also be used in the understory, transmigrant farmers prefer to keep the ground bare in home gardens because of a deep-rooted fear of snakes.

Woody species with potential for fodder production on boundaries include *G. sepium*, *Codariocalyx gyroides* (*Desmodium gyroides*) and *Desmodium rensonii*.

4. Enhancement of tree cash crop enterprises in home gardens. Species with potential but currently used only on a limited scale include clove (*Syzigium cumini*), rambutan (*Nephelium lappaceum*), coconut (*Cocos nucifera*), durian (*Durio zibethinus*) and mangosteen (*Garcinia mangostana*). Moderately shade-tolerant high-value species such as vanilla and black pepper should also be tried.

*At the community level*

If farmers in each Sitiung community agreed to pool their promised 0.75-ha plots, the cash crop and livestock feed leverage points could be addressed by a tree crop/grazing system. A promising option appears to be a community rubber plantation with grazing of the cover crops (*Pueraria phaseoloides*, *Calopogonium muconoides*, *C. caeroleum* and *Centrosema pubescens*). Additional land will be required for grass pastures. The possibility of the government allocating adequate additional land to each community for such a plantation should not be overlooked.

Small ruminants such as goats are very suitable for such an animal protein enterprise. Goats have the advantage of a high milk-producing capability coupled with sturdiness and an ability to thrive under a wide variety of feeds. There are also more animal units per unit of feed, thus spreading risk and increasing sales opportunities over milk cow enterprises. The annual demand for goats for the celebration of Ramadan by the predominantly Muslim population (equivalent to the demand for Christmas turkeys in the U S.) offers good scope for an economically profitable goat-rearing enterprise. A high instinct for survival, however, also make the goats a potential hazard if left unmanaged.

A latex processing plant already exists near Sitiung and the economic returns from rubber appear promising. Each administrative unit would have their own rubber plantation, which would be planted and tapped on a communal basis. Tapping could be undertaken by women, thereby increasing their involvement in cash-generating off-farm labor. A communal herd of goats and/or sheep could be allowed to graze the cover crops on a rotational basis. Rotational grazing coupled with wider than normal spacing of the rubber trees would be required to ensure adequate persistence of the cover crops.

There is good potential for development of community-owned, rotationally grazed pastures containing a mixture of woody legumes and pasture grasses by a communal herd of cattle. The govern-

ment could allocate a suitable amount of land to each community. Although this would be a new concept to the Javanese farmers who are used to cut-and-carry systems, the potentially high returns to labor would be a powerful incentive. Legume-based pastures developed at Yurimaguas should be tested at the grazing level.

Leguminous trees and shrubs should minimize the possibility of invasion by shade-intolerant *Imperata cylindrica* (*alang-alang*), a noxious weed that colonizes cleared areas including pastures. The tree/shrub component can be harvested for high protein foliage and/or pods, thereby allowing adequate light for grasses in the understory. If *alang-alang* starts to become a problem, a simple solution would be to allow the trees to close canopy and shade it out. It is a lot easier and cheaper to establish pasture grasses than it is to eradicate *Imperata*.

## Conclusions

This report provides a comprehensive analysis of the farm as a whole. Research priorities reflect the most relevant problems as perceived by the farmers. The hypothesis is that technologies designed to overcome problems perceived by farmers would be more easily adaptable than those that do not consider farmer perceptions.

The technologies proposed in this report, however, were designed on the basis of a preliminary diagnosis. Furthermore, the design of agroforestry technologies normally requires the combined input of a multidisciplinary team to incorporate relevant aspects of all disciplines concerned. Due to the time constraint and the unavailability of key TropSoils personnel, this was not possible.

The diagnosis in this report is a static type, primarily useful to indicate the outstanding features of proposed technologies. A more refined design would require an analysis of both the system dynamics and the farmers' reactions to introduced innovations. It is assumed that a better understanding of both factors may lead to modifications in the preliminary designs. This, in turn, would lead to an enhanced adaptability of practices by generating more appropriate technologies (i. e., those that address a felt need, can be easily understood, and use resources readily accessible to farmers).

In this context, research on integration of technologies in existing systems at Sitiung has to do essentially with monitoring of both existing system dynamics and systems' response to introduced innovations. The latter is accomplished through on-farm experimentation, which plays a critical role in technology development.

Given that most of the technologies proposed are still tentative, two phases are envisaged for research on integration of technologies of this project. The first phase will focus on improving the preliminary diagnosis by monitoring the existing systems and will carry out researcher-managed trials on farms, mainly geared at evaluating the technical performance of proposed technologies (while learning about farmer perceptions of such innovations).

The second phase will concentrate on farmer-managed trials to evaluate the technical and economic performance at the enterprise level (livestock, food crops, cash crops) of practices developed in phase one, and the fit of such practices into the whole system.

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# Humid Tropics Program
# University of Hawaii

*Prepared by*
*The TropSoils Project, Department of Agronomy and Soil Science*
*College of Tropical Agriculture and Human Resources*
*Goro Uehara, Program Coordinator*

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# Introduction

The principal goal of the TropSoils program is to uncover principles which will enable resource-poor farmers to adopt soil management practices that will increase family income and farm productivity and, at the same time, preserve land quality. The research strategy is designed to ensure that social, cultural, economic, and environmental factors that enhance adoption of a soil-management innovation are made an integral part of the research plan. To achieve its goal, the project conducts a major portion of the soil-management research with farmers and in farmers' fields using systems-based research, crop simulation models, and expert systems.

### The Setting

A 100,000-hectare transmigration site in Sitiung, West Sumatra, Indonesia serves as the project's research area. Six thousand transmigrant families and 1500 indigenous families live in the area. Large cultural and language differences between the Javanese and Sudanese transmigrants, and between the transmigrants and indigenous groups present unparalleled opportunities to study the responses of different ethnic groups to soil management innovations.

The soils of the region range in quality from moderately fertile Inceptisols on river terraces to highly leached and impoverished Oxisols and Ultisols of the dissected peneplain. Mean annual rainfall is 2800 mm and mean annual air temperature is 26° C. The tropical rain forest is gradually giving way to rubber plantations and subsistence farming by new settlers.

The first large group of transmigrants settled in Sitiung in 1976. A modest home, 1.25 hectares of recently cleared land, and a year's supply of food, fuel, other living essentials, seed, and fertilizer awaited each family upon its arrival. Since then, five additional areas in Sitiung have been settled. Bulldozer crews continue to clear more land to accommodate new settlers from the densely populated islands of Java and Bali. The productive land on the river terraces has long been settled and the newest transmigrants are being placed on the less-desirable lands of the dissected peneplain.

### Developing a Collaborative Project

A major aim of the Collaborative Research Support Program is to produce research outputs that are relevant to both the United States and the collaborating host country. To achieve this aim, the Indonesia TropSoils project is capturing, preserving and organizing research information generated in Indonesia and Hawaii to produce decision aids to enable users at the national and farm levels to make sound soil-management decisions not only in Sitiung but in Indonesia

and the U.S. These decision aids consisting of expert systems and simulation models are designed to operate in any location which has the required data to make soil-management decisions. Since the making of soil-management decisions is strongly influenced by socioeconomic factors, the project research is conducted jointly by agronomists and social scientists.

# Personnel

**Program Coordinator**
Goro Uehara, UH

**Project Manager**
Gordon Tsuji, UH

**Senior Scientists**
Lalit Arya , Physics, UH
Carol Colfer, Anthropology, UH
Samir El-Swaify, Conservation, UH
Ronald Guyton, Management, UH
Nguyen Hue, Chemistry, UH
Stephen Itoga, Info. Science, UH
Harold McArthur, Anthropology, UH
Barbara Newton, Sociology, UH
Ir. Sholeh, Management, CSR
Suwardjo, Conservation, CSR
I.P.G. Widjaja-Adhi, Fertility, CSR
Russell Yost, Fertility, UH

**Researchers**
Fahmuddin Agus, Conservation, CSR
Ada Chu, Chemistry, UH

**Junior Scientists**
Djohan Aluisius, Physics, UH/AU
Tom Dierolf, Fertility, UH
Carl Evensen, Fertility, UH
Stacy Evensen, Nutrition, UH
James Hansen, Chemistry, UH
Amien Istiqlal, Fertility, CSR/UH
Stephenie Kan, Agr. Economics, UF
Phoebe Kilham, Geog. Info. Sys., UH
Eko Legowo, Physics, UH
Zhi Cheng Li, Expert Systems, UH
Li-Ling Lin, Modeling, UH
Janet Schultz, Conservation, UH

**Graduate Assistant**
Ruey Huang, Biochemistry, UH

**Administration**
Ada Demb, Administrator, UH
Khairul, Administrative Assistant, UH/CSR
Naomi Murabayashi, Secretary, UH
Suemi Sakumoto, Fiscal Accounting, UH
M. Ray Smith, Administrator, UH
M. Sudjadi, Administrator, CSR

# Site Characterization

# Soil Variability in Forest Land Mechanically Cleared

*Russell Yost, University of Hawaii*
*Michael Wade, North Carolina State University*
*Dan Gill, North Carolina State University,*
*Jean-Pierre Ndiaye, University of Hawaii*
*Istiqlal Amien, Centre for Soils Research*

The first phase of this subproject included quantifying and characterizing the spatial variability of properties important for the development of appropriate soil management. This variability, both macro (several kilometers) and micro (several meters) has been characterized, and published reports are listed in the publication list.

The second phase of the work is concerned with determining what can be done about the high variability, particularly with reference to two situations: the situation of the transmigrant farmer and secondly with reference to the large-scale variability that land-use planners must manage. In the first case, that of the small-field or micro variability, a continuation of the soil variability experiment was devised as follows.

### Objectives

The objectives were (1) to construc[illegible]ni-variograms of soil properties to determine structure in the variance of soil properties; (2) to use the structure in the variance of soil chemical and physical properties by geostatistical methods to predict soil properties in unsampled locations; (3) to relate soil and crop variability patterns using geostatistical approaches to match soil management inputs to spatially variable soils, and (4) to analyze soil variability with the purpose of suggesting alternative means of managing such variability in field research and in farmer's gardens and dry land fields.

### Procedures

The field site was subdivided into standard randomized complete block layout. Lime was applied using two approaches: Method 1 was the traditional method of applying the lime uniformly across the entire plot. Method 2 required lime to be spread in a fashion such that it would be applied only on those areas which had shown poor growth of the previous crop. The smaller areas were selected based on height of the previous rice crop and were in 1 m square increments.

### Results

Early results of the study were somewhat surprising in that there seemed to be little response to the subdivision of the treatments into the smaller units. This suggests that some of the yield-causing factors were not alleviated by simply adding lime to the poorer areas. Data from several crops have yet to be analyzed.

Efforts continue to develop the necessary geostatistical computation software and to provide it to others. These efforts have produced four software packages in various stages of evaluation and publication. The first is a package which computes semivariograms. This software accepts data, including missing values, and computes the semivariograms in several directions for up to 1500 data points. Recently several plant pathologists have begun using the software to quantify spatial distributions of disease organisms associated with soil properties. Diseases can be of randomly distributed type or of 'clumped' type. A semivariogram is useful in distinguishing between the two.

The other software uses the results of the semivariogram to compute kriged estimates in either of three methods, point kriging, block kriging and cokriging. In the first example, values of individual locations are predicted and the associated variance is given. In the second example, the value of an area is predicted, again with its associated variance. Cokriging, in data-sparse conditions, permits one to use data from other variables which are highly correlated with the primary variable to improve the prediction in a specific location. These options have been thoroughly discussed and described in the references at the end of this section.

In all cases the software, herein described, can be obtained from the University of Hawaii, Department of Agronomy and Soil Science. Please send a diskette (360K, 720K, or 1.2M), which will be returned with the software.

### Geographical Information System

Work continues with further application and use of the soils information obtained in the Sitiung area

from various earlier surveys (Trangmar et al. 1984). These data have been coded and analyzed using a geographical information system (GIS). A GIS system is designed to assemble and analyze spatial data that are important in formulating a plan for land use, for management of the area, or for a variety of planning or management purposes where location and distance is important. The system operates by manipulating 'overlays' which are maps of data for particular variables. In the example explored here (Figure 1), we have combined overlays of extractable Al and effective CEC using the Cochrane equation to estimate lime requirements for areas of arbitrary size (using block kriging) the entire region. After estimating these requirements one can estimate their cost by multiplying the lime requirement by estimates of lime cost. Lime cost, however, depends in part on transportation. The cost of transportation can be estimated with a GIS system by measuring the distance from markets and roads. An overlay of the transportation costs can then be added to the overlay of lime costs to produce an overlay of estimated costs at each location on the map. In this manner one can see where lime costs are highest.

Most of the GIS methods to date do not incorporate considerations of reliability of the data and the confidence warranted by such composite maps. Geostatistical methods provide one of the best ways to quantify such variation and facilitate its use in qualifying predictions of lime quantity, cost, and other predictions of management options.

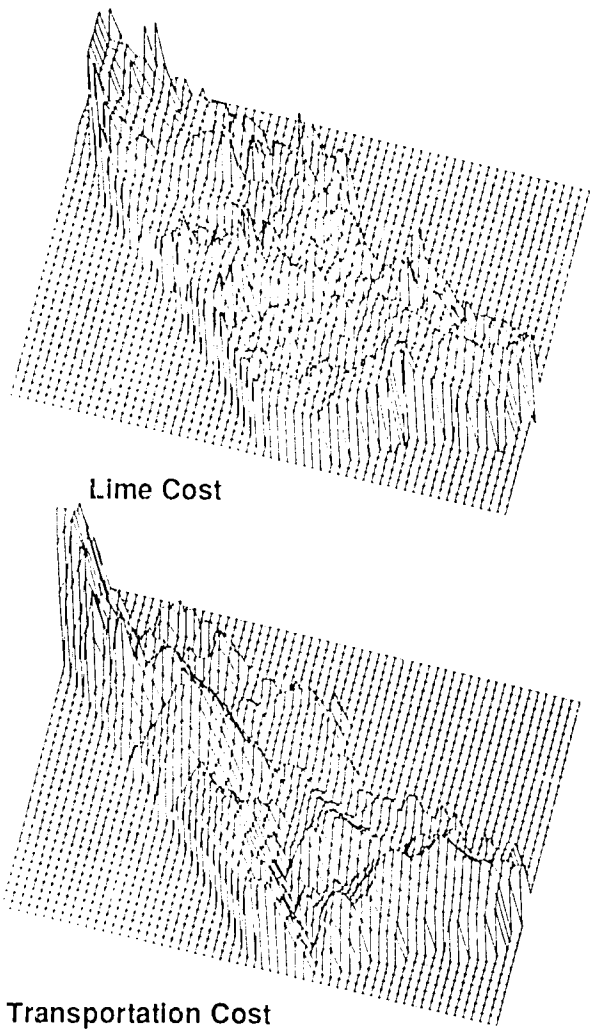


**Figure 1. Estimated cost of providing lime for the Sitiung region considering lime requirements for selected crops and a relative transportation cost.**

## Conclusions and Implications

The results from the investigations reported in the manuscripts listed demonstrate that there is, indeed, enormous variability in soil properties, affecting crop growth and production. There are many scales of this variability—from that occurring over a few meters to that occurring over several kilometers. Much of soil science is indirectly or directly related to the understanding and management of this variability. We suggest that it is important to have tools at our disposal to work with and manage such variability. The geostatistical tools developed by this project and described herein have already demonstrated wide applicability throughout the tropics and provide a useful, new approach to measure and quantify variability. We are likely to see many new applications developed in the near future which use these concepts and approaches as a basis. This is already becoming apparent in research in geographical information systems and in expert systems.

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# Soil Management and People

*Interpreting Existing Soil-Management Systems*

# Indigenous Knowledge Systems Related to Soil Management

*Carol J. Pierce Colfer, University of Hawaii*
*Dan Gill, North Carolina State University*
*Barbara Newton, University of Hawaii--West Oahu*
*Herwasono Soedjito, Herbarium Bogoriense*

The work performed within this subproject has blossomed into a total of six distinct activities, at varying stages of completion. Each will be discussed below in detail, but can be summarized in the following manner: 1) Galileo, 2) Soil Classification, 3) Forest Regeneration, 4) Land Ownership in Pulai, 5) Income in Pulai and 6) Expert Systems.

**Objectives**

1) Galileo. Compare conceptual and cognitive "maps" among Sitiung's three ethnic groups and soil scientists, to ascertain significant differences.

2) Soil classification. Document Minang notions of soils relative to their classification and ascertain whether there is a demonstrable basis from a scientific point of view for these "folk" classifications.

3) Forest regeneration. Document indigenous knowledge and utilization practices of partially cleared and forested areas to better understand concerns related to soil management in developing agroforestry systems.

4) Land ownership. Describe land ownership patterns in Pulai relative to field size, animal ownership and wealth indicators.

5) Income in Pulai. Identify major sources and amount of income available to residents or household.

6) Expert systems. Document human (heuristic) factors involved in crop selection for cultivation in two or more areas in Indonesia and identify "gaps" in our indigenous knowledge base for action and research.

## Galileo

Work on this study this year has been done by Dr. Barbara Newton of West Oahu College and Colfer, with statistical support from Dr. Paul Brandon, and interviewing by Endang Hidayat of the Centre for Soils Research and Megan Colfer. A complete description of the methods employed in this study was provided in the *TropSoils Technical Report, 1985-1986*. Briefly, the study employs a multidimensional scaling technique to measure the distances perceived by respondents to exist between pairs of concepts. The 21 concepts were selected from the people's own discourse on soil management. People were asked to use the distance between "black" and "white" as a conceptual measuring stick (100 units), and estimate the differences between concept pairs like "soil" and "fertilizer," "me" and "fertilizer," and every other permutation of the 21 concepts utilized. Interviews were conducted in five languages, depending on the native language of the respondent. The study was designed to answer the question: How do people look at the soil?

During this past year, we completed the administration of the survey instrument to 100 Sundanese farmers in Sitiung V, and administered it as well to 25 soil scientists in Indonesia.

**Objective**

The objective was to compare conceptual and cognitive "maps" among Sitiung's three ethnic groups and soil scientists, to ascertain differences.

**Results**

This study was designed to "map" the way people look at soil. We have used such maps in TropSoils to:

1) demonstrate the markedly different farming systems of transmigrants and indigenous Minang farmers in Sitiung,

2) identify people's perceptions of existing agricultural roles for men and women,

3) aid in our choice of experimental crops that are of interest to particular kinds of farmers in the area,

4) show the different receptivity of various ethnic groups to different management practices, such as tillage or fertilizing. Such maps can also be used effectively in attempts to disseminate the technology developed in TropSoils.

Since ethnicity is such an important factor in the Sitiung agricultural setting, one of our first priorities was to determine the ethnic differences in perceptions of the soil. In general, the differences we had observed qualitatively were reflected quantitatively

in the Galileo results, though not always significantly so. We focus on those differences identified as statistically significant.

Interpretation of the results is not difficult, but requires some explanation. The most interesting and complete information is available in the Means Matrices (Figures 1 to 3); however, they are also difficult to read. The Means Matrix is derived by averaging the distances between each pair of concepts from all respondents (in this case, of a given ethnic group). It is read like a matrix showing distances between cities. If a number is small, it means most people felt the two concepts (like two cities) are closely related. If the number is large, people, on average, felt the concepts were distantly related.

A glance at the means matrices will show that the Minang tend to have far greater distances between agricultural concepts than do the transmigrants. Indeed, the overall average of all distances on the

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil-1 | | | | | | | | | | | | | | | | | | | | | |
| Garden-2 | 11 | | | | | | | | | | | | | | | | | | | | |
| Unirrig. fld-3 | 8 | 57 | | | | | | | | | | | | | | | | | | | |
| Wet rice fld-4 | 7 | 60 | 50 | | | | | | | | | | | | | | | | | | |
| Home garden-5 | 13 | 63 | 67 | 69 | | | | | | | | | | | | | | | | | |
| Rubber-6 | 17 | 42 | 66 | 72 | 76 | | | | | | | | | | | | | | | | |
| Fruits-7 | 28 | 54 | 60 | 73 | 54 | 70 | | | | | | | | | | | | | | | |
| Rice-8 | 10 | 55 | 20 | 11 | 63 | 72 | 60 | | | | | | | | | | | | | | |
| Other fld crop-9 | 19 | 55 | 42 | 45 | 58 | 70 | 55 | 46 | | | | | | | | | | | | | |
| Vegetables-10 | 19 | 52 | 43 | 58 | 49 | 71 | 58 | 45 | 37 | | | | | | | | | | | | |
| Water-11 | 36 | 56 | 43 | 17 | 64 | 56 | 48 | 21 | 38 | 30 | | | | | | | | | | | |
| Fertilizer-12 | 38 | 43 | 35 | 28 | 68 | 35 | 42 | 24 | 36 | 29 | 47 | | | | | | | | | | |
| Pests-13 | 72 | 61 | 61 | 54 | 77 | 70 | 49 | 42 | 53 | 52 | 76 | 62 | | | | | | | | | |
| Yield-14 | 49 | 50 | 50 | 45 | 49 | 51 | 46 | 46 | 56 | 48 | 43 | 63 | 52 | | | | | | | | |
| Cultivation-15 | 34 | 34 | 24 | 26 | 32 | 26 | 4 | 24 | 27 | 27 | 52 | 29 | 46 | 59 | | | | | | | |
| Good-16 | 60 | 60 | 59 | 58 | 56 | 64 | 56 | 55 | 62 | 62 | 46 | 34 | 68 | 61 | 66 | | | | | | |
| Enough-17 | 62 | 61 | 58 | 62 | 56 | 61 | 58 | 59 | 66 | 63 | 30 | 20 | 76 | 68 | 64 | 63 | | | | | |
| I/me-18 | 16 | 27 | 20 | 16 | 20 | 26 | 32 | 11 | 31 | 29 | 29 | 29 | 54 | 53 | 28 | 55 | 66 | | | | |
| Male-19 | 16 | 14 | 17 | 13 | 26 | 14 | 29 | 10 | 33 | 34 | 52 | 47 | 50 | 44 | 23 | 49 | 60 | 27 | | | |
| Female-20 | 20 | 30 | 21 | 19 | 17 | 38 | 26 | 14 | 26 | 20 | 48 | 76 | 46 | 46 | 30 | 46 | 58 | 23 | 20 | | |
| Government-21 | 58 | 65 | 82 | 77 | 50 | 72 | 74 | 44 | 40 | 29 | 27 | 43 | 68 | 37 | 48 | 29 | 31 | 23 | 12 | 18 | |

Figure 1. Means Matrix, Minang, Sitiung, West Sumatra 1985.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil-1 | | | | | | | | | | | | | | | | | | | | | |
| Garden-2 | 22 | | | | | | | | | | | | | | | | | | | | |
| Unirrig. fld-3 | 22 | 32 | | | | | | | | | | | | | | | | | | | |
| Wet rice fld-4 | 29 | 36 | 28 | | | | | | | | | | | | | | | | | | |
| Home garden-5 | 24 | 25 | 32 | 33 | | | | | | | | | | | | | | | | | |
| Rubber-6 | 58 | 66 | 62 | 67 | 66 | | | | | | | | | | | | | | | | |
| Fruits-7 | 28 | 22 | 34 | 42 | 24 | 45 | | | | | | | | | | | | | | | |
| Rice-8 | 19 | 24 | 20 | 21 | 30 | 48 | 27 | | | | | | | | | | | | | | |
| Other fld crop-9 | 18 | 23 | 19 | 25 | 27 | 47 | 28 | 26 | | | | | | | | | | | | | |
| Vegetables-10 | 23 | 19 | 27 | 30 | 22 | 46 | 28 | 28 | 24 | | | | | | | | | | | | |
| Water-11 | 20 | 18 | 27 | 25 | 26 | 48 | 22 | 21 | 22 | 22 | | | | | | | | | | | |
| Fertilizer-12 | 24 | 16 | 19 | 21 | 22 | 46 | 23 | 19 | 22 | 22 | 27 | | | | | | | | | | |
| Pests-13 | 69 | 64 | 70 | 66 | 67 | 71 | 59 | 62 | 63 | 56 | 63 | 24 | | | | | | | | | |
| Yield-14 | 26 | 27 | 28 | 28 | 29 | 42 | 24 | 24 | 26 | 24 | 28 | 28 | 23 | | | | | | | | |
| Cultivation-15 | 23 | 21 | 20 | 22 | 21 | 44 | 27 | 22 | 21 | 20 | 23 | 18 | 25 | 28 | | | | | | | |
| Good-16 | 31 | 27 | 27 | 30 | 28 | 41 | 29 | 25 | 30 | 24 | 25 | 28 | 52 | 26 | 23 | | | | | | |
| Enough-17 | 34 | 32 | 29 | 37 | 29 | 47 | 31 | 29 | 29 | 28 | 22 | 19 | 52 | 27 | 24 | 30 | | | | | |
| I/me-18 | 24 | 23 | 24 | 24 | 19 | 53 | 21 | 22 | 23 | 18 | 22 | 30 | 54 | 24 | 21 | 24 | 22 | | | | |
| Male-19 | 22 | 22 | 22 | 23 | 24 | 50 | 24 | 24 | 24 | 28 | 56 | 27 | 55 | 26 | 16 | 25 | 23 | 20 | | | |
| Female-20 | 29 | 21 | 24 | 22 | 20 | 52 | 24 | 20 | 21 | 19 | 24 | 63 | 56 | 26 | 19 | 24 | 25 | 20 | 14 | | |
| Government-21 | 23 | 23 | 25 | 29 | 29 | 34 | 25 | 22 | 23 | 30 | 20 | 28 | 44 | 29 | 23 | 26 | 23 | 19 | 21 | 23 | |

Figure 2. Means Matrix, Javanese, Sitiung, West Sumatra 1985.

means matrices are: Minang—44; Javanese—30; and Sundanese—22. Some have argued for artificially reducing this difference, by some kind of overall averaging, but this has been resisted, because the larger numbers used by the Minang reflect two important aspects of their lives—one physical and one more conceptually substantive—which differentiate them from their neighbors.

The first aspect is the relative size of their landholdings. West Sumatra has traditionally had a comparatively small population, and the Sitiung area in particular was very sparsely populated. The feeling that land is in abundance remains with the local farmers. Fields and agricultural endeavors tend to be dispersed geographically, so it is not surprising that this would be reflected in the cognitive maps. Indeed, the population densities in the three home areas of these ethnic groups parallel the differences in average distances reflected in the means matrices.

The second matter relates to the integration of the respective farming systems. Clifford Geertz was so impressed by the interconnections and integratedness of agriculture on Java that he wrote *Agricultural Involution*, describing its inward-turning nature. It is not surprising that some of this integration is transported to Sitiung. A transmigrant's house-lot, for instance, may have a plot of grass growing on it, on which cows and goats feed. The animals live in a stable nearby, and their dung is used for manure on a food crop which is grown for home consumption. Each component feeds into another.

Minang agriculture, on the other hand, is scattered, with a water buffalo feeding on a communal plot a couple of kilometers from the village. A wet rice field is 5 km away. When a village moves, people continue to use the old house lots, with their tree crops, even though they are three-quarters of a kilometer from home. The new houselot may be used only for some drying until the new tree crops bear. Because of such considerations, we have not altered the original data.

Since we are concerned, not with the simple measuring of abstract concepts, but rather with people's behavior and values for practical purposes, two concepts are of particular interest. These are "good" and "me." The particular interest of these two concepts derives from their links with values and behavior, respectively. Concepts that are viewed as close to "good" (small numbers in the means matrix) tend to be valued by people. Concepts that are seen as close to "me" tend to be behaviorally related. That is, if I say that "me" is close to "fertilizer," it is probable that I use fertilizer regularly (or possibly live near a fertilizer plant—an example of a potential problem with this method). The following discussion focuses on the concept pairs that showed significant difference between ethnic groups.

Statistical analyses were completed on these tables by Dr. Paul R. Brandon, following their publication in the *Centre for Soils Research*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil-1 | | | | | | | | | | | | | | | | | | | | | |
| Garden-2 | 9 | | | | | | | | | | | | | | | | | | | | |
| Unirrig. fld-3 | 12 | 19 | | | | | | | | | | | | | | | | | | | |
| Wet rice fld-4 | 13 | 22 | 28 | | | | | | | | | | | | | | | | | | |
| Home garden-5 | 14 | 18 | 26 | 28 | | | | | | | | | | | | | | | | | |
| Rubber-6 | 23 | 30 | 31 | 37 | 37 | | | | | | | | | | | | | | | | |
| Fruits-7 | 20 | 15 | 22 | 30 | 20 | 30 | | | | | | | | | | | | | | | |
| Rice-8 | 18 | 16 | 19 | 19 | 21 | 31 | 21 | | | | | | | | | | | | | | |
| Other fld crop-9 | 22 | 18 | 19 | 22 | 23 | 31 | 18 | 25 | | | | | | | | | | | | | |
| Vegetables-10 | 12 | 16 | 22 | 21 | 20 | 33 | 19 | 18 | 21 | | | | | | | | | | | | |
| Water-11 | 12 | 20 | 26 | 18 | 23 | 32 | 20 | 14 | 23 | 18 | | | | | | | | | | | |
| Fertilizer-12 | 16 | 21 | 29 | 16 | 16 | 28 | 24 | 16 | 22 | 17 | 25 | | | | | | | | | | |
| Pests-13 | 24 | 27 | 23 | 19 | 23 | 26 | 26 | 21 | 27 | 21 | 32 | 24 | | | | | | | | | |
| Yield-14 | 22 | 26 | 21 | 21 | 22 | 22 | 26 | 20 | 17 | 21 | 25 | 22 | 25 | | | | | | | | |
| Cultivation-15 | 21 | 13 | 22 | 18 | 19 | 24 | 18 | 22 | 16 | 19 | 25 | 24 | 24 | 26 | | | | | | | |
| Good-16 | 23 | 19 | 25 | 23 | 20 | 26 | 20 | 24 | 19 | 24 | 24 | 16 | 26 | 27 | 24 | | | | | | |
| Enough-17 | 22 | 21 | 27 | 24 | 24 | 26 | 22 | 26 | 23 | 22 | 18 | 17 | 27 | 22 | 26 | 25 | | | | | |
| Time-18 | 14 | 19 | 23 | 25 | 20 | 30 | 21 | 15 | 21 | 24 | 17 | 22 | 29 | 23 | 24 | 24 | 19 | | | | |
| Male-19 | 15 | 19 | 26 | 26 | 22 | 32 | 23 | 16 | 23 | 16 | 21 | 25 | 28 | 25 | 18 | 27 | 22 | 22 | | | |
| Female-20 | 18 | 20 | 25 | 17 | 16 | 34 | 24 | 18 | 23 | 17 | 21 | 32 | 30 | 24 | 20 | 26 | 22 | 22 | 23 | | |
| Government-21 | 22 | 29 | 28 | 26 | 23 | 22 | 27 | 23 | 28 | 22 | 19 | 25 | 33 | 25 | 24 | 30 | 27 | 24 | 22 | 24 | |

Figure 2. Means Matrix, Sundanese, Sitiung, West Sumatra 1985.

*Technical Meetings Proceedings*. He first did a multivariate analysis of variance (MANOVA) looking for overall differences between the ethnic groups, with the mean differences between concept pairs as the dependent variables. He then did univariate analysis of variance (ANOVAs, significant at 0.0001), looking at the differences between groups on each of the dependent variables. Where the ANOVA was significant he did Scheffe's post hoc test (0.05), to ascertain which groups showed statistically significant differences from each other.

In Table 1, we have selected some relevant concept pairs to examine from the perspective of ethnic difference. Table 1 shows the concept *good* paired with 15 concepts closely related to TropSoils activities (kinds of fields, crops and management issues). This table tells us a bit about the value systems of the three ethnic groups. The Minang consistently consider agricultural matters to be distant from *good* (or not valued) in comparison with the transmigrants (Javanese and Sundanese); and these differences are all statistically significantly different from the transmigrants' valuations. This is consistent with qualitative observations. Our sense that the transmigrants are more similar to each other than to the Minang is also borne out by these data. For the Javanese and Sundanese, only their valuation of *rubber*, *other* (non-rice) *field crop*, *fertilizer* and *pests* show a significant difference between these two ethnic groups. This table on values reflects the differences the team has observed in the motivation and attitude toward agricultural matters between the ethnic groups. It suggests that agricultural planning requires differentiation between the Minang and the transmigrants (and in some cases, between the Javanese and Sundanese transmigrants as well).

**Table 1. A measure of values, relating to selected soil-management concepts. Sitiung, West Sumatra 1985.**

| Good and | Minang(m) | Javanese(j) | Sundanese(s) |
|---|---|---|---|
| Soil | js 60 | m 31 | 23 |
| Garden | js 60 | m 27 | m 19 |
| Unirrigated field | js 59 | m 27 | m 25 |
| Wet rice field | js 58 | m 30 | m 23 |
| Home garden | js 56 | m 28 | m 20 |
| Rubber | js 64 | ms 41 | mj 26 |
| Fruits | js 56 | m 29 | m 20 |
| Rice | js 55 | m 25 | m 24 |
| Other field crop | js 62 | ms 30 | mj 19 |
| Vegetables | js 62 | m 24 | m 23 |
| Water | js 46 | m 25 | m 24 |
| Fertilizer | s 34 | s 28 | mj 16 |
| Pests | js 68 | ms 52 | mj 26 |
| Yield | js 61 | m 26 | m 27 |
| Cultivation | js 66 | m 23 | m 24 |

Note: the smaller the number the more highly valued the concept. If there is a letter before the number, there is a significant difference between ethnic groups. In the Minang column, the distance between "good" and "soil" (60) is significantly greater than that perceived by Javanese (j) and by Sundanese (s).

**Table 2. A measure of behavior, relating to selected soil-management concepts. Sitiung, West Sumatra 1985.**

| Me and | Minang(m) | Javanese(j) | Sundanese(s) |
|---|---|---|---|
| Soil | 16 | 24 | 14 |
| Garden | 27 | 23 | 19 |
| Unirrigated field | 20 | 24 | 23 |
| Wet rice field | 16 | 24 | 25 |
| Home garden | 20 | 19 | 20 |
| Rubber | j 26 | ms 53 | j 30 |
| Fruits | 32 | 21 | 21 |
| Rice | 11 | 22 | 15 |
| Other field crop | 31 | 23 | 21 |
| Vegetables | 29 | 18 | 24 |
| Water | 29 | 22 | 17 |
| Fertilizer | 29 | 30 | 22 |
| Pests | s 54 | s 54 | mj 29 |
| Yield | js 53 | m 24 | m 23 |
| Cultivation | 28 | 21 | 24 |

Note: the smaller the number, the closer the concepts. If there is a letter before the number, there is a significant difference between ethnic groups. In the Javanese column, the distance between "me" and "rubber" (53) is significantly greater than that perceived by the Minang (m) and the Sundanese (s).

Table 2 reflects the reality that all three ethnic groups gain their livelihood by agricultural endeavors. Differences among kinds of fields do not appear to be significant. Among crops, only the pair, *rubber* and *me*, shows any significant difference across ethnic groups. However, looking at differences within ethnic groups provides some fascinating leads for agricultural planning. Note for instance the proximity of *rice* and *rubber* to the Minang *me*, relative to other crops—suggesting that these two crops would be good for agricultural experimentation among that group. Or note the distance of *rubber* from *me* among the Javanese, again relative to other crops—suggesting that rubber might not be a good crop to use in collaborative work with these Javanese. Rubber appears, in Sitiung, to have acquired significance as a Minang "ethnic marker," giving its cultivation important symbolic value (much as growing cassava symbolizes poverty to the Javanese).

**Table 3. A measure of soil's relationship to field types, crops and soil-management concepts. Sitiung, West Sumatra 1985.**

| Soil and | Minang(m) | Javanese(j) | Sundanese(s) |
|---|---|---|---|
| Garden | 11 | 22 | 9 |
| Unirrigated field | j [illegible] | ms 22 | j 12 |
| Wet rice field | j 7 | ms 29 | j 13 |
| Home garden | 13 | 24 | 14 |
| Rubber | j 17 | ms 58 | j 23 |
| Fruits | 28 | 28 | 20 |
| Rice | 10 | 19 | 18 |
| Other field crop | 13 | 18 | 22 |
| Vegetables | 19 | 23 | 12 |
| Water | js 36 | m 20 | m 12 |
| Fertilizer | js 38 | m 24 | m 16 |
| Pests | s 72 | s 69 | mj 24 |
| Yield | js 49 | m 26 | m 22 |
| Cultivation | 34 | 23 | 21 |

Note: the smaller the number, the closer the concepts. If there is a letter before the number, there is a significant difference between ethnic groups. In the Javanese column, the distance between "soil" and "rubber" (58) is significantly greater than that perceived by the Minang (m) and the Sundanese (s).

Among the practices directly related to soil management, only *pests* and *yield* show significant differences among ethnic groups. The closeness of pests to *me* among the Sundanese is a bit of a puzzle (which recurs in all the tables). Yields may well be differentially evaluated by transmigrants vis-à-vis Minang because of their life experiences. The Minang are probably comparing their agricultural yield (not radically different from transmigrant yields) to their other sources of income; whereas the transmigrants may well be comparing their yields in Sitiung to their means of livelihood in Java. This may also reflect the comparative importance of agricultural yields to a transmigrant, compared to a Minang.

*Soil*, TropSoils' raison d'etre, and its distance from related management practices, kinds of fields, and crops, is presented in Table 3. There is a significant difference between the distances perceived by Javanese, on the one hand, and Minang and Sundanese on the other, between *soil* and both *unirrigated fields* and *wet rice fields*.

Among crops, *soil* and *rubber* are the only concept pair showing a significant inter-ethnic difference, with the Javanese perceiving *rubber* to be quite distant from *soil*, relative to the Minang and Sundanese. This reinforces the earlier observation that using rubber in a soil-management experiment with the Javanese might not be the best choice; but that it might be very appropriate among the Minang or Sundanese.

The soil-management concepts vary more among the ethnic groups. The Sundanese and Javanese perceive a significantly closer relationship between *soil* and *water* than do the Minang. Similarly, *fertilizer* and *yields* are seen as more closely connected to *soil* among the transmigrants than among the Minang. Interestingly, *soil* and *pests* are seen as close by the Sundanese, providing one of the few cases where the Minang and Javanese concur in a significant difference from the Sundanese. This suggests that collaborative experiments on soil-water, soil-fertilizer and soil-yields relationships, might best be undertaken with the transmigrants rather than with the Minang. A study of soil and pests might be best done with the Sundanese, since the concepts are already perceived as comparatively close. Suggestions such as these are by no means intended to be hard and fast rules, but are based rather on simple tendencies.

**Table 4. A measure of perceptions of fertilizer as related to field types, crops and soil-management concepts. Sitiung, West Sumatra 1985.**

| Fertilizer and | Minang(m) | Javanese(j) | Sundanese(s) |
|---|---|---|---|
| Garden | js 43 | m 16 | m 21 |
| Unirrigated field | 35 | 19 | 29 |
| Wet rice field | 28 | 21 | 16 |
| Home garden | js 68 | m 22 | m 16 |
| Rubber | 35 | 46 | 28 |
| Fruits | js 42 | m 23 | m 24 |
| Rice | 24 | 19 | 16 |
| Other field crop | 36 | 22 | 22 |
| Vegetables | 29 | 22 | 17 |
| Water | js 47 | m 27 | m 25 |
| Pests | js 62 | m 24 | m 24 |
| Yield | js 63 | m 28 | m 22 |
| Cultivation | 29 | 18 | 24 |

Note: the smaller the number, the closer the concepts. If there is a letter before the number, there is a significant difference between ethnic groups. In the Javanese column, the distance between "fertilizer" and "garden" (16) is significantly smaller than that perceived by the Minang (m).

In Table 4, we look at *fertilizer*, a favorite component in agricultural research. The pattern of transmigrants' more often having views significantly different from the Minang holds consistently, with regard to fertilizer. The necessity to gain a livelihood from very small landholdings, dictated by the transmigrants' earlier residence on overcrowded Java, makes the importance of fertilizer in their views of agriculture reasonable. Transmigrants have also been more routinely exposed to agricultural extension efforts aimed at increasing fertilizer usage than have farmers on the Outer Islands in remote areas like Sitiung.

Significant differences among the ethnic groups are apparent in regard to fertilizer's relationship to kinds of land holdings. The transmigrants consider *fertilizer* to be closer to *gardens* and *home gardens* than do the Minang. (Note: *garden* is the translation used for Indonesian *kebun*, and it is, in local parlance, an unirrigated field of tree crops; *home garden* is the homelot.) The transmigrants, in comparison to the Minang, also perceive *fertilizer* as significantly closer to *fruits*.

Turning to *fertilizer*'s relationship to other soil-management concepts, *fertilizer*'s relationship to *water*, *pests* and *yield* is significantly closer for the transmigrants than for the Minang. We have observed what appears to be a greater congruity between transmigrants' views of agriculture and soil scientists', in that both lean toward more intensive soil management than do the Minang. The transmigrants expect high labor inputs, value other inputs such as fertilizer and pesticides, and seek higher yields on smaller plots of land than do the Minang. The Minang focus more on low-labor crops and management strategies, with the expectation that they will subsist on their agricultural endeavors and supplement their income by non-agricultural means. They also, in effect, suffer from no land shortage.

The frequent lack of funds among all ethnic groups to buy agricultural inputs suggests that perhaps the Minang strategy may have important hints for us in trying to develop usable agricultural technologies for environments like Sitiung. Certainly the Minang emphasis on tree crops is consistent with scientific consensus about appropriate crops for rolling lands such as one finds in the Sitiung area. Investigation of the Minang system, being so different in its strategy from traditional (soil) scientific approaches, can provide an exciting stimulus for new research that is more appropriate for Outer Island conditions. This is one of the reasons for the development of the four extra sub-components of the indigenous-knowledge study reported below.

TropSoils was particularly interested in the perceived relationship of *cultivation* to other agricultural concepts, because we have observed strong reticence on the part of the Minang to cultivate upland fields with a hoe (in contrast to transmigrants). Table 5 provides these measurements. The Minang consider *cultivation* (in the sense of land preparation) to be significantly farther from *garden* (the tree crop fields) than do the transmigrants. It is reasonable that the Minang would consider their gardens to require little cultivation, since trees are planted when the field is freshly cleared of forest and planted to rice. Once the rice is harvested, very little care of any kind is provided until the trees begin to bear.

Transmigrants, on the other hand, own cleared fields of one hectare, part of which they can now use for such gardens. But given their small overall landholdings (2 hectares), they are unlikely to use the extensive management methods of the Minang. *Cultivation*, like *fertilizer*, is viewed by transmigrants as significantly closer to *water*, *pests* and *yields*, than among the Minang. The closer relationship between *cultivation* (normally with a hoe) and *rubber* is another of the few cases where the Sundanese and Minang show significantly different views from the Javanese (who see almost everything as distant from *rubber*). The *cultivation* and *fruits* pair reverts to the more usual pairing, with the transmigrants regarding these as closer than the Minang. This suggests that whereas the Minang and Sundanese would be effective collaborators on experiments requiring the cultivation of rubber, the Sundanese and the Javanese would more likely be willing to cultivate, or prepare land for growing fruit trees. All ethnic groups grow some fruit trees on their home gardens, but the Minang are far more likely to have additional gardens (resembling orchards) of fruit trees.

The final tables (6 and 7) compare views of *men* and *women* as they are seen to be related to the agricultural concepts. No significant difference emerges for either sex in relation to the various kinds of fields. For *men* and *rubber*, each ethnic group is significantly different from every other (with the Minang *men* closest to *rubber* and the Javanese *men* furthest from it). Minang *men* are seen as significantly closer to *rice* than are Javanese *men*; and Sundanese *men* are seen as significantly closer to *vegetables* than are *men* of the other ethnic groups. No significant differences occur in people's views of *women* and different crops.

Management presents a different story. In the *water/men* link the Sundanese show significantly smaller distances than the Minang and Javanese. The Javanese and Sundanese place *women* about the same distance from *water* as Sundanese *men* (close), in sharp contrast to the Minang view of *women* and

**Table 5. A measure of perceptions of cultivation as related to field types, crops and soil-management concepts. Sitiung, West Sumatra 1985.**

| Cultivation and | Minang(m) | Javanese(j) | Sundanese(s) |
|---|---|---|---|
| Garden | js 34 | m 21 | m 13 |
| Unirrigated field | 24 | 20 | 22 |
| Wet rice field | 26 | 22 | 18 |
| Home garden | 32 | 21 | 19 |
| Rubber | j 26 | ms 44 | j 24 |
| Fruits | js 49 | m 27 | m 18 |
| Rice | 24 | 22 | 22 |
| Other field crop | 27 | 21 | 16 |
| Vegetables | 27 | 20 | 19 |
| Water | js 52 | m 23 | m 25 |
| Pests | js 46 | m 25 | m 24 |
| Yield | js 59 | m 28 | m 26 |

Note: the smaller the number, the closer the concepts. If there is a letter before the number, there is a significant difference between ethnic groups. In the Sundanese column, the distance between "cultivation" and "garden" (13) is significantly smaller than that perceived by the Minang (m).

**Table 6. A measure of perceptions of women and soil-management concepts. Sitiung, West Sumatra 1985.**

| Women and | Minang(m) | Javanese(j) | Sundanese(s) |
|---|---|---|---|
| Garden | 30 | 21 | 20 |
| Unirrigated field | 21 | 24 | 25 |
| Wet rice field | 19 | 22 | 17 |
| Home garden | 17 | 20 | 16 |
| Rubber | 38 | 52 | 34 |
| Fruits | 26 | 24 | 24 |
| Rice | 14 | 20 | 18 |
| Other field crop | 26 | 21 | 23 |
| Vegetables | 20 | 19 | 17 |
| Water | js 48 | m 24 | m 21 |
| Fertilizer | js 76 | ms 63 | mj 32 |
| Pests | s 46 | s 56 | mj 30 |
| Yield | js 46 | m 26 | m 24 |
| Cultivation | 30 | 19 | 20 |

Note: the smaller the number, the closer the concepts. If there is a letter before the number, there is a significant difference between ethnic groups. In the Sundanese column, the distance between "women" and "fertilizer" (32) is significantly less than that perceived by the Javanese (j) and the Minang (m).

*water* (Minang *women* are slightly closer to *water* than Minang *men*).

*Fertilizer* and *men* are seen as close by the transmigrants vis-à-vis the Minang. Among all ethnic groups *women* are seen as further from *fertilizer* than *men* of their own ethnic group; and each ethnic group places *women* at a significantly different distance from *fertilizer* than every other group (with Sundanese *women* the closest to *fertilizer* and Minang *women* the furthest). One reason for this general distancing of women from fertilizer may be the fact that fertilizers require more money than women typically have, or it may be related to the male bias evident throughout the extension service. Men's predominance in land preparation, and the frequent necessity of applying fertilizer at that point in the production cycle, may be a factor as well.

Minang and Javanese *men* and *women* are perceived as similarly far from *pests* compared to Sundanese *men* and *women*.

**Table7. A measure of perceptions of men and soil-management concepts. Sitiung, West Sumatra 1985.**

| Men and | Minang(m) | Javanese(j) | Sundanese(s) |
|---|---|---|---|
| Garden | 14 | 22 | 19 |
| Unirrigated field | 17 | 22 | 26 |
| Wet rice field | 13 | 23 | 26 |
| Home garden | 26 | 24 | 22 |
| Rubber | js 14 | ms 50 | mj 32 |
| Fruits | 29 | 24 | 23 |
| Rice | j 10 | m 24 | 16 |
| Other field crop | 33 | 24 | 23 |
| Vegetables | s 34 | s 28 | mj 16 |
| Water | s 52 | s 56 | mj 21 |
| Fertilizer | js 47 | m 27 | m 25 |
| Pests | s 50 | s 55 | mj 28 |
| Yield | js 44 | m 26 | m 25 |
| Cultivation | 23 | 16 | 18 |

Note: the smaller the number, the closer the concepts. If there is a letter before the number, there is a significant difference between ethnic groups. In the Minang column, the distance between "men" and "rubber" (14) is significantly greater than that perceived by the Javanese (j) and the Sundanese (s).

Transmigrant *men* and *women* are seen as about equally close to *yield*, and significantly different from Minang *men* and *women* as related to *yield*.

### Conclusions and Implications

The data produced by the Galileo technique can be used in many ways, and we have only begun the long process of analyzing it. Additional information can easily be gleaned from perusing the means matrices (Figures 1 to 3), in line with specific soil-management research interests. Although we have focused on statistically significant differences in this report, examination of the actual distances shown in the tables can provide good leads as well.

The work reported here comes from one analysis: the inter-ethnic differences analysis. However, means matrices for two others of interest have been prepared by Barbara Newton. One divides the responses by sex; the other divides the responses into three categories (Minang, newly settled Javanese transmigrants, and long-settled Javanese transmigrants). These are available for writeup.

## Soil Classification

Dan Gill from North Carolina State University and Colfer collaborated on the planning and conduct of this study, with laboratory support from Kasno (Centre for Soils Research). Syarif Lipati, a resident of Pulai, served as a field assistant. Pulai, a Minang village near Sitiung I, Blok A, was chosen as our research site, primarily because of proximity, and apparent representativeness.

### Objective

The objective was to document Minang notions of soils classification and to ascertain whether there is a demonstrable basis from a scientific point of view for these "folk" classifications.

### Procedures

The study was designed to employ participant observation at the outset, gradually moving over toward the more focused methods used in ethnoscience. Colfer went to the village of Pulai regularly between October 1985 and July 1986, participating in village activities. Special effort was made to

identify the agricultural activities of importance in the village, and to go with the villagers as they performed their agricultural work. She planted, weeded and harvested wet rice; went rubber tapping, weeding citrus trees, processing coffee beans; planted, weeded and harvested upland rice; fished and panned for gold; and in general went along on any activity she could. Whenever possible, the conversation was turned to soil and soil-related matters.

As time went on and her understanding grew, she was able to form questions about soil that made sense in the local context. Although the formal techniques of ethnoscience (taxonomy elicitation, triadic sorting and componential analyses) were used in this study, they were not adhered to strictly. Our goal was an understanding of the ways the soil terms were used, and the system of thought they represent, rather than an elegant academic exposition. Given the processual nature of Minang conceptions of soil (*tanah*), the taxonomic structure preferred by ethnoscientists was insufficient. Once the indigenous soil types were identified, soil tests were done in selected areas, with the intention to compare indigenous notions with those of the scientists.

**Results**

Pulai is about a five-minute drive from Sitiung I, Blok A, and was a sub-village (*jorong*) of the original Sitiung until 1984. It is situated along the Batang Hari River, and has lands reaching across the river to the boundary with Sitiung VI. Downriver, its lands (not formally certified with the Government) go to Sungai Kandi, and upriver to Sungai Mengkasih. The usual estimate of village landholdings is 1,000 ha for the 82 households of Pulai. Land is owned by clans, traditionally, and ideally inherited matrilineally (from mother to daughter). Formal alienation of land (by sale) is difficult, but access to use rights seems quite flexible. Rubber and wet rice are the agricultural bases of the community, with considerable effort also devoted to upland rice, coffee and fruit trees. Important sources of income include the making of beams (*balok*) in the forest with a chainsaw, logging, fishing, animal husbandry (water buffaloes, goats, chickens) and panning for gold.

The word normally translated as "soil" in both Indonesian and Minang is *tanah*. *Tanah* means both soil and land, and both will be encompassed in the following discussion. English glosses (translations) that are particularly non-comparable (like "hot" and "cold" as used for soil) will be preceded by "lit" (meaning literally). Words for which our own understanding remains fuzzy will be followed by a question mark. Thirty-five terms were elicited describing soil.

The first step in an ethnoscientific inquiry is normally to ask a question (called a frame) such as, "Are there different kinds of soil?" (*Apakah ada jenis tanah?*) or "What kind of soil is this?" (*jenis apa tanah ini?*). The resulting responses represent a jumble of ways of organizing soil. Further inquiry is required to get at the organization of these different "kinds of soil." The language used in these interviews was a mixture of Indonesian and Minang (though the dialect in Pulai is considered substandard by educated Minang), two extremely closely

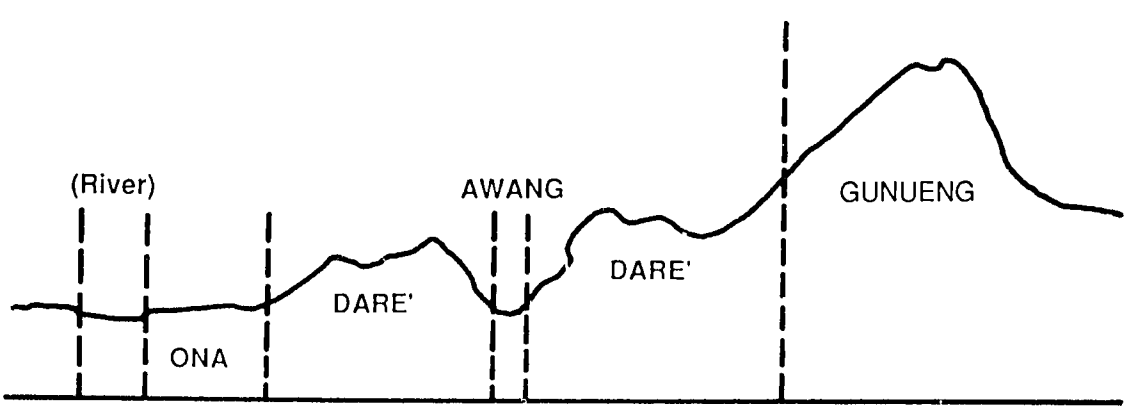


Figure 4. Minang topographical categories, Pulai 1986.

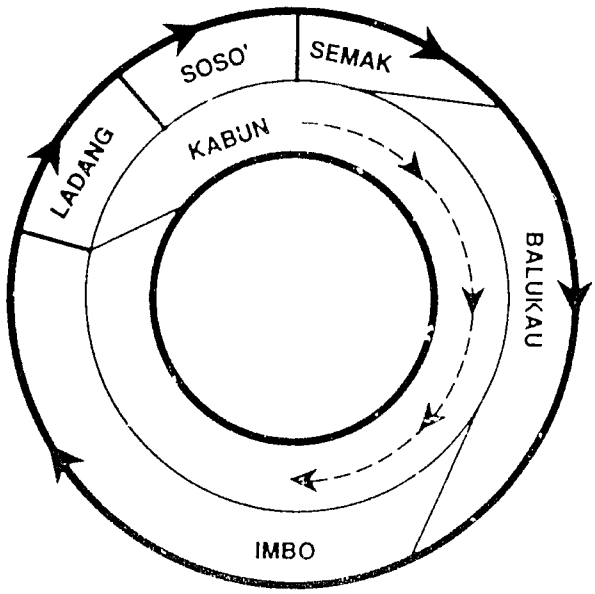


Figure 5. Indigenous agroforestry cycle, Pulai 1986.

related languages with many cognates.

All soils can be classified within the following principle of organization relating to water and topography (Figure 4). Swampy areas are called *awang*, and efforts are consistently made these days to convert them to *sawah* (wet rice fields). Alluvial areas, on the river's shores, that are normally dry, but flood from time to time, are called *ona* (or sometimes *rena*). They are said to be reserved for annual crops, but inspection reveals numerous fruit trees (though no rubber). The rolling hills predominant in the area are called *dare'* (or *tanah kasang*). Mountains are called *gunung*. The emphasis in this investigation is on *dare'* or *tanah kasang*, since a focus on the uplands has been part of our TropSoils mandate, and most Pulai lands fall into this category.

*Dare'* or *tanah kasang* is further subdivided according to stage of forest regeneration in this long-cycled, shifting-cultivation system. The impossibility of separating upland agricultural endeavour from forest regeneration in the classification system used by Pulai residents is perhaps one of the most interesting and useful findings (Figure 5). *Ladang* (upland rice field) represents the agricultural phase prior to this regeneration process. Also called *buga'an*, this is newly cleared and planted for the first time. The same land becomes *soso'* when it is in its second planting year after clearing, thus beginning the regeneration process. The next phase is called *semak*, and refers to the scrub-brush, bushy stage of forest regrowth. Next comes secondary forest (*belukau*) and then "primary" (or old secondary) forest (*imbo*). Further discussion of products obtainable from different kinds of forest will be provided in the next section of this project report. It is worthwhile noting that *kabun* (the orchard type of field, discussed below) can occur in *semak*, *belukau* and *imbo*.

The third kind of organization discovered relates to kinds of fields, though Colfer was never able to elicit a Minang word comparable to the English "field" (Figure 6). These are *pakarangan* (home garden), *sawah* (paddy rice field), *ladang* (upland rice field), and *kabun* (orchard/garden). *Kabun* can be subdivided by crop: citrus, coffee, rubber, chillie, rambutan, duku.

## Conclusions and Implications

There is a series of terms suitable for describing soils: *dingin* (lit. cold), *pane* (lit. hot)

*alui* (fine), *kasau* (coarse)

*baderai* (crumbly), *bagota* (lit. having sap, sticky, clayey)

*luna'* (soft), *kore* (hard)

*hitem* (black), *merah* (red), *kunieng* (yellow), *putieh* (white)

*baminyak* (lit. oily?)

*gocau* (muddy)

*masem* (lit. sour/acid)

*bapasiu* (sandy)

Certain of these terms, such as *putieh* (white), *baminyak* (oily?) and *gocau* (muddy), are most likely to be used in connection with *sawah* or wet rice cultivation. *Baminyak* sounds comparable to the concept reported in Sherman (1981) which a group of Northern Sumatrans considered most important for plant growth, but which differed from scientists' views of "fertility." We were unable to get a firm handle on what this term meant in the Pulai context. It seemed generally to be desirable. One group

| TANAH | | | |
|---|---|---|---|
| PAKARANGAN | SAWAH | LADANG | KABUN |

Figure 6. Taxonomy of fields, Pulai 1986.

maintained that it looks wet, but is not.

Distinctions like *alui-kasau* (fine-coarse), *bad-erai-bageta* (crumbly-sticky), *luna'-kore* (soft-hard) are not alien to soil scientists, corresponding as they do to English concepts of soil. *Gocau* (muddy), *bapasiu* (sandy) and color terms are similarly familiar to scientists.

From the TropSoils point of view, one of the most interesting of these descriptors is the word *masem*. Soil scientists use the word to refer to acid in soils, and decry such soils for their aluminum toxicity. Javanese similarly dislike soils that are *masem*. The Minang, on the other hand, say that fertilizers make a soil *masem*, and that after digging a hole to plant a fruit tree in newly cleared primary forest (*imbo*), one must wait three months to allow the soil to become *masem* (and *dingin*—cold). When the weeds have begun to grow in the hole, one knows the soil is *masem* there. Before planting in *sawah*, one must wait three or four days after the water buffalo have trampled the soil in land preparation, so that the soil will become *masem*. *Ona* (alluvial soil) is good because it becomes *masem* and receives fertilizer from the river water. In general, only rubber does not need *masem* soil, according to the Minang.

Understanding of this different meaning for the word *masem* is rather critical for extension efforts in the area, considering the primary focus on soil acidity in TropSoils' work and the negative implications of actual soil acidity for crop growth.

"Hot" and "cold" are not normally used by soil scientists to describe soil, but they are used among the Minang to describe upland and alluvial soils, apparently in the following manner: Soil in the forest is cold. When the forest is cut and burned, the soil becomes temporarily hot, but cools down in a relatively short amount of time. However, if it is cultivated for several years straight, exposed to the sun, it again becomes hot, and cannot grow crops until it is left to rest. One man said the soil "dies" and must be hoed to produce again. The red color of the soils the Minang consider the worst is said to come from too much heat (from exposure to the sun), and from loss of ashes.

The following are called "aspects" of soil, for want of a better term:

*lulua'* (mud)
*liye'* (clay)
*kabuik* (dust)
*pasiu* (sand)
*krekel* (gravel)
*tanogan* (iron-laden soil?)
*batu* (rock)

*Lulua'* (mud) is of course used in connection with *sawah* (wet rice fields), as is *tanogan*. The exact meaning of the latter remains unclear, but the term is sometimes paired with *baminyak* (lit. oily?), and seems generally not to be considered desirable. People say that if there is water nearby, *tanogan* has an oily yellowish-reddish film on it. This soil can only be identified during the hot season. It is unfortunate in the *sawah* because its mud will not break up into the fine aggregates desired for wet-rice cultivation.

The final portion of this study remains to be done. Some work has begun. Soil analyses were done in 22 locations in the Pulai area, and local descriptions of these same soils were obtained. Our intent is to compare the results of these analyses with the predictions that would follow from indigenous conceptions of soil.

## Forest Regeneration

The relevance of this small study emerged during the conduct of the study of soil classification, as we became aware of the important uses of the forest to the indigenous population. Such uses seemed to represent another potential resource for both Sitiung's people and agricultural experimentation. In many areas of Indonesia, the transmigrants' land is only partially cleared when they receive it. Often half or more of the land remains in forest. The following is designed to stimulate scientific thought about how we might best construct agroforestry systems (to maintain soil fertility, reduce erosion, reduce human labor inputs, etc.), building on indigenous knowledge and practice.

### Objective

The objective of this study was to document indigenous knowledge and utilization practices of partially cleared and forested areas to better under-

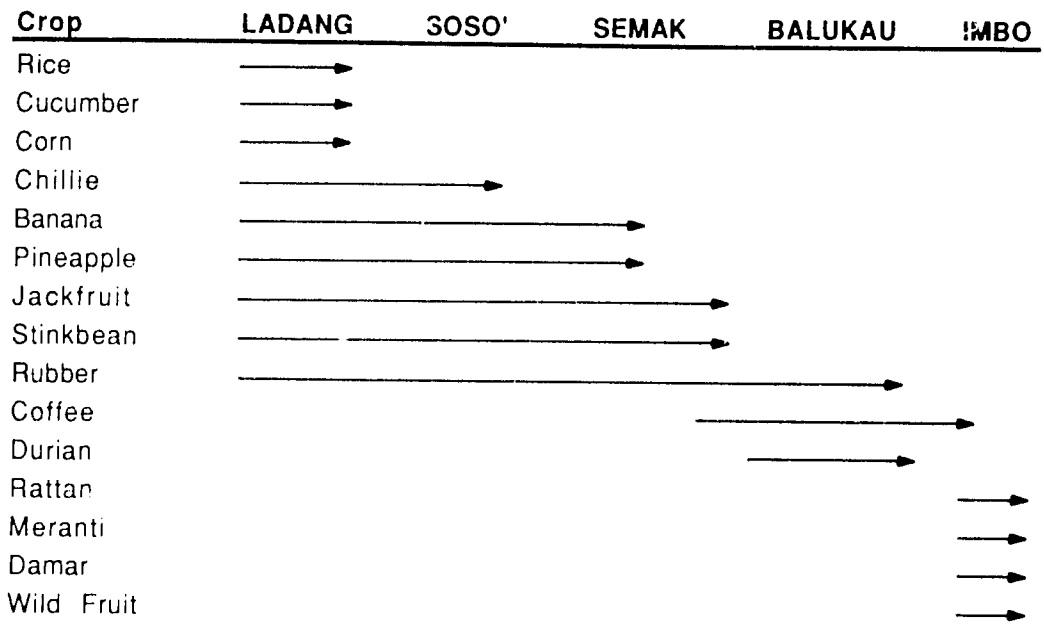


**Figure 7. Representative "Crops" by Stage of Forest Regeneration, Sitiung, West Sumatra 1986.**

stand concerns related to soil management in developing agroforestry systems.

### Procedures

The study was conducted in Pulai, with participant observation being the most basic method. Besides going into the forest with the people whenever possible, Colfer conducted many informal interviews with Minang farmers on the uses to which they put the forest in which they live. The results of this study are built on the general understanding gained from many more months of participant observation.

### Results

The most general finding of this study is that the forest supplies a variety of commodities that local people use. The forest resources vary with the stage of regrowth. Figure 7 shows some representative commodities that Pulai's people get from the forest, with a more complete account of our findings below.

From the point of view of TropSoils, an agricultural project, one main interest of this study lies in the possibility of transforming what is now essentially a minor forest product into a marketable agricultural commodity. The multiple soil advantages of keeping an adequate ground cover (such as a forest provides) are obvious in the Sitiung area. We have recognized the desirability of incorporating domesticated fruit trees (and possibly rubber or oil palm) into the normal transmigrant cropping patterns in the area. But there remains a nether region between forestry and agriculture which could provide valuable income at the same time that it preserves the remaining rainforest (as a soil cover) and draws on indigenous species with demonstrated adaptation to the local environment. This would be an agroforestry that utilized the forest rather than transforming it into agricultural land per se.

Across the top of Figure 7 are listed the stages through which the land passes in the forest-regeneration process as it occurs in the Pulai area. The following commentary summarizes findings that Colfer considered of potential use for TropSoils experimental research.

Colfer had hoped to participate in the village process of land/forest choice for making new ladangs, and still thinks her participation would provide extremely valuable information. However, when she left Sitiung in July 1986, the general consensus seemed to be that people would not be opening any significant ladang areas this year. The most common reason given was that the economic return did not justify the effort, though she would not want to rule out the possibility that the leader of the largest landholding clan felt uncomfortable with her

knowing the process. Reasons normally given verbally for selection of an area included proximity, sufficiently long interval since the last clearing, and (for the ladangs cultivated over the past two years) proximity to the road to Sitiung VI. It is probable that the Batang Hari River played a role comparable to the road in the past.

*1. Ladang*

Forest clearing is reported to begin with slashing of underbrush and small trees by women, followed by felling of large trees by the men (though Colfer did not see this process). The ladangs are cleared originally to plant upland rice. Rice is viewed strictly as a subsistence crop. The necessity to sell rice is cause for shame to Pulai residents. Yet it holds a very special place in that it is viewed as absolutely essential to normal human life. Men and women work together to plant the rice, using a dibble method (with men dibbling and women putting seed in the holes).

Contrary to earlier information, there is a variety of indigenous kinds of rice. Some farmers mix the kinds and plant them together; others keep them separate. Some also plant a variety of kinds, and some plant only one. It would seem worthwhile testing some of these indigenous varieties in experiments. Local names, with the anecdotal information available, include:

Upland rice. This includes examples of rice cultivated on *rena* (alluvial areas), *balukau* (upland, ex- secondary forest), and *imbo* (upland ex-primary forest):

*kumpai* - six months, upland rice
*saba'* - six months, upland rice
*pudung* - six months, upland
*mundun* - six months, upland
*kocie'* - six months, upland
*halui* - upland
*senda panjang* - upland
*godang putieh* - upland
*rotan kampai* - upland

Sticky rice. Local names include:

*pului' alui*
*sepului' Minang* - yellow, six months
*pului' suot* - upland, six months
*pului' putieh* - upland, six months
*pului' hitam* - upland, six months
*sapului' suto*

Paddy rice. Local names include:

*sese* - wet rice, 3.5 months
*keruing* - wet rice, 3.5 months

The list of names above is certainly not exhaustive, since this information was received "in passing." More detailed information on this topic would be easy to obtain, including particular strengths, weaknesses and descriptions (stalk height, shape, length and color of grain, etc.).

At some point during the rice-growing season (September to March, loosely), tree crops are planted in among the growing rice. The most common tree crop is rubber, but fields frequently have a few jackfruit and stinkbean. Other annuals frequently planted in small areas include *lado* (chillie), *gandum* (sorghum), *timun* (cucumbers), *jagung* (corn), *terong* (eggplant), *kacang panjang* (long beans), *kacang padi* (mung beans), *perio* (bittermelon) and *petulo* (similar to bittermelon, but not bitter tasting). Distances to market and small quantities mean that in practice these crops are generally used for subsistence.

Accompanying the women as they cared for the rice crop during the rainy season, Colfer was struck by the multiplicity of weeds growing among the rice stalks. The women had names for many different kinds of weeds, a few of which have uses. After eliciting some 15 names for weeds in a very short time, she decided to collect some samples and have them identified. She went to an apparently typical upland field and collected a "grab sample" of weeds in an area approximately 2 m by 3 m. The 19 weeds were later identified by Ir. Herwasono Soedjito at the Herbarium Bogoriense in Bogor.

Other local names elicited, but not identified, include *umpui' sarang bayo, umbui' umbui', sidukung anak, pago pago, galinggang lawi'* (medicinal uses), *daun sikatui', sawi yonggang, ndawang, sikadudue', naweang, capo, lalang* (*Imperata cylindrica*), *tolang tolang, sikuju, talote omban* and *sinduong*. Such names have little use alone, but the fact that women have so many names for weeds reflects the importance of weeding as an agricultural

activity, and proves that some sort of local knowledge exists that might well be used. These weeds are also, of course, the first stage of, or a prelude to, forest regeneration. They may make an important contribution as organic matter for the second cropping year, as well.

In March or April the upland rice is harvested, normally using a finger knife called *anuai*, and the rice stalk is left in the field, trampled to some extent during the harvesting process. The only man Colfer saw harvesting rice was a crippled man who could not do other work. However, men transport the rice back to the field hut and to the village.

We (Stacy Evensen, Dan Gill, and Colfer) measured the yields of six ladangs in Pulai, getting an average yield of 800 kg/ha(range: 480-1250 kg/ha). We used a 1 m wooden square, which we set down in ten places around each field, while the farmers were harvesting. These ten subsamples were combined to make five samples. Water content was measured on one sample per field, and applied to the rest.

Once harvest is completed, the field becomes *soso'*.

*2. Soso'*

The decision to plant or not to plant the same field a second year depends primarily on the harvest the first year, though factors such as labor availability and alternate sources of income certainly have an impact on the decision as well. If the rice was relatively abundant, a decision to plant again is more likely. The increase in weeding required the second year is also a consideration, as is the difficulty of clearing a new field.

Whether the field is planted to rice again or not, useful products are collected from *soso'*. The bananas and pineapples frequently planted the first year are bearing. Chillies often continue to be found in *soso'*. The need to check up occasionally on the rubber and other trees means that these fields continue to produce and be harvested periodically, on a small scale.

Since *soso'* provided a much more manageable environment in which to measure indigenous fields, and since we were very interested in getting a reasonable estimate of the average size of rubber gardens, we measured the eight second-year fields planted to rubber. Several Pulai residents agreed that such measurements should be reasonably representative of older rubber gardens.

We used very simple equipment—two sticks, a rope and a compass. Our selection criterion was simply second-year fields planted to rubber, and we were told we had measured all of these that Pulai people owned. The overall average field size was about 0.64 hectares, ranging from 0.16 ha to 1.60 ha. Rubber tree spacing averaged 4.9 m, ranging from 2.8 to 7.8 m. Tree spacing was measured in two ways. If there appeared to be something resembling rows, we measured the distances along two sides, and multiplied them together. If the planting pattern appeared quite hit-or-miss, we made two to four transects, measuring and averaging the distances among ten trees for each transect. Using an inclinometer, we got slopes ranging from 0 - 47 percent. Since we did not know the proper technique for estimating average slope, we simply periodically took inclinometer readings as we followed the boundary of each field. Out of a total of 34 readings, the mean was 17 percent. Though our methods are generally imprecise, they are adequate and practical for our purposes.

*3. Semak*

As bushes begin to take over, the area no longer looks like an agricultural field. Yet the jackfruit and stinkbean planted during the *ladang* phase begin to bear fruit. Bananas and pineapple continue into this phase. Near the village there are areas of *semak* that are planted to coffee, rambutan, duku, citrus; and there are many areas further away where rubber is growing to maturity surrounded by *semak*.

*4. Balukau*

By the time regrowth has become secondary forest (*balukau*), the rubber and other trees are bearing. The local rubber trees produce after about eight years. Jackfruit (*ceboda'*) and stinkbean (*petai*) are still bearing. Durian, a highly valued crop, and *cebodak hutan* (wild jackfruit) provide wild produce. Durian is not planted, Colfer was told, because there is a custom that durian are freely available to all, no matter who planted them, so people are not interested in trying to grow durian commercially.

Coffee trees are also frequently planted in *balukau*, needing shading as they do. Sometimes a special *kebun* (or orchard/garden) is set aside for coffee; other times coffee is planted in among the

rubber trees or in the backyard.

*Balukau* may also be cut down, left for a time, and then planted directly to fruit trees such as rambutan, duku, or citrus. These crops, like coffee, are often planted in the back yard, as are coconuts.

5. *Imbo*

Considering the length of time that this area is reported to have been occupied it seems probable that very little true "primary forest" remains. However, the people differentiate between *imbo* and *balukau*, the former being considered older, and providing different kinds of products. Below are listed some of the products Colfer observed or elicited from residents as coming from imbo. She suspects there are many more, since the forest is taken for granted by Pulai residents, and its utility has not been emphasized in development efforts in the area.

Saps

*Joneng*. This is a red dye from rattan fruit. The sap is shaken from the fruit, collected, flattened like a pancake and sold for Rp 9,000/kg. (US $9, 11/85).

*Julutueng*. Also called *geta putih*, this is a white sap, which is tapped like rubber, and used for export. It may be used in making bubble gum.

*Damau*. *Damar* is used for caulking canoes and, reportedly, for making glass. In the past it was a common fuel for lighting.

*Geta merah*, or "red sap". This is a product gathered by others (probably the forest-dwelling Kubu), but the Pulai people do not know what it is for. The tree must be cut down to yield the sap.

Fibers

*Rumbai*. This is obtained from the swampy areas in *imbo*, and is used for weaving seed bags.

Rattan. There are at least three kinds of rattan collected in the Pulai forests. These are *tabotabo*, *umbai* and *manau* (a big variety). Collectors received Rp 350 per "stick" ($0.35) and customers paid Rp 375/stick (($0.37), in November 1985. Rattan is reported to "belong to the forest, not to the village," so anyone can collect it freely.

*Lipai*. This is a fan shaped palm used for roofing (in Kalimantan, for hat making). It only grows on selected hills in the area, one called "Bukit Lipai".

Wood products

Commercial logs. *Meranti* (the favored export dipterocarp) is the most common type of tree that is logged. There is an important differentiation between export (red) and local quality (yellow). *Meranti kawang* is considered the best, then *meranti ambai*, then *meranti perang*. *Meranti sabuik* is another kind, of unknown quality. There are many other kinds of wood with commercial value (*kulin* or ironwood, *kapur*, another dipterocarp used for export, and so on). One of the problems with the common and desirable dipterocarps relates to the acquisition and planting of seeds on a large scale. However, on a small scale, such as individual households represent, seeds might be available naturally in sufficient quantity for a meaningful contribution to household income and maintenance of some forest cover.

*Balok* (beams). These are most frequently made from meranti. These beams are sawn with a chainsaw, in the forest, and dragged out to the road by water buffalo. Groups of Pulai men contract to sell such lumber at Rp. 25,000/cu m at roadside, or Rp. 30,000/cu m at sawmill (a bit less than US $25 and $30, respectively, 1/86). The transportation by road for such wood products is well established in the area.

*Tonam* (*Marsawa* in Indonesian). The buttresses of the tree are used for making the wooden "plates" used in gold panning. The tree itself is used for building.

*Garu*. This is a product found inside the *kare* tree (?), and costs Rp 100,000/kg if it is soft. It can be small as a pebble or big as a water glass. This description is reminiscent of a

product also collected in Kalimantan, called aloe wood, and found in genus *Aquilaria*, family Thymelaeaceae. The disadvantage to this product is that the tree must be destroyed to determine whether or not it has *garu* in it.

Fruit trees. Wild fruit trees are common in *imbo*. Colfer did not know the Latin names for any of the following, but they could be sought out and identified at the Herbarium Bogoriense without great difficulty or expense. Local names include:
*tampuai* (sometimes called *tampus*),
*gera'an*, *kulun tunjuk* and its "sister",
*buah sani*,
*kuduk biawa'* (similar to rambutan),
*lasau*,
*barangan*,
*dondan*, and
*tungao tungao*.

Medicinal plants. *Paku ban* (*Nephrolepis exaltata*), which also grows in the ladangs, is used medicinally (as a paste on the abdomen for intestinal problems). Medicinal plants abound, and the most knowledgeable person on this subject appears to be Pak Dukun (Kari). Colfer did not have the opportunity to pursue this topic in detail, but it may be of interest since rainforest areas are reputed to be a reserve of important medicinal plants. Some may have economic value.

Leaving the process of forest regeneration momentarily, it is worth noting the presence near the village of small areas devoted to crops sometimes considered forest products. These include:

*Pandan*, or *pandanus*, is an excellent fibre plant, and is used for weaving mats.

*Anau*, the sago palm, has many uses. Its "hair" serves as roofing material and string. Flour and candy can be made from its roots. Its fruits can be eaten, and an alcoholic beverage can be made from it. Its leaves are used for cigarette wrappings.

*Bulu*, or bamboo, is used for carrying liquids, cooking in, carrying poles, house construction, and so on. Its shoots are eaten.

*Rambio* is a material used for making roofs.

**Conclusions and Implications**

1. Test indigenous upland rice strains.
2. Utilize existing expertise on weeds, as needed.
3. Develop some experiments on minor forest products both within the forest, and in more conventional agricultural settings.

A tentative plan was made and permission obtained from Dr. Sudjadi to bring Ir. Herwasono Soedjito to Sitiung for a month-long, more focused botanical study of aspects of forest regeneration in spring 1986, but ultimately Colfer's own time did not allow it. Such input would be a valuable contribution, particularly if there is interest in following up on this agroforestry component.

## Land Ownership in Pulai

Unlike transmigrants, the Minang have a rather confusing system of land ownership. No land is formally registered. Some land is owned by matrilineal clans, and controlled by the head of the clan who distributes it among his aunts, sisters and their daughters. Some land belongs to nuclear families and can be sold or passed from a father to his own children. Some people say they have no land; others are sometimes reported to own the whole forest.

Complicating an already complicated picture is the sense on the part of Pulai inhabitants that outsiders' understanding their system may have adverse effects on them (most notably, taxation). Another factor is their perception that outsiders view their matrilineal inheritance system in a negative manner (though they themselves do not). In any event, this study was prompted by two needs: 1) a sense of confusion on the issue of land ownership, and 2) a sense that we needed to understand how much land was being used by Pulai residents to adequately evaluate the possibility of transmigrants' incorporating Minang practices into their own system. If each Minang family was using 10 ha of land, it was unlikely that the transmigrants could adopt that system (without substantial changes in transmigration policy).

**Objective**

The objective of this study was to describe land-

ownership patterns in Pulai relative to field size, animal ownership and wealth indicators.

**Procedures**

Pak Syarif and Colfer developed a form to be used in interviewing, which was pretested and revised according to our findings. It was administered to members of each household in Pulai (n=86), in June and July 1986. The form listed the kinds of agricultural fields extant in Pulai (with several lines for each kind); it listed kinds of animals; and it listed vehicles, fishing equipment, and modern household items such as TV. We also recorded the owner, within the household, of each of the above.

We did not have the resources to measure each field, so we had to rely on reports of field size. People had very fuzzy ideas of such measurements. For sawah and ladangs, Pak Syarif worked with the respondent to ascertain the best estimate of size. Fortunately he knew most of the land belonging to each resident of Pulai and had worked in land-clearing and other activities requiring some knowledge of measurement. This vastly improved results. For rubber gardens, the people had a better sense of how many trees they had than of how big their field was. A 5 m average spacing, found in the fields that were actually measured, was used to estimate hectarage in rubber gardens (or 400 trees per hectare).

**Results**

Data for only 20 families has been entered into the computer (23% of the total), and only descriptive analysis has been done on these results. However, some general observations are possible at this stage.

The most fundamental finding (deriving from the interview process rather than from the quantified results of the survey) is that the Pulai residents do not view the land as a finite and fixed entity to be divided among people in the same way that both Javanese and American soil scientists do. These Minang do not look at the total resource available to them and specify that this part belongs to this person and this part to that person. Instead, land seems generally to be thought of as it is relevant to human needs. There is no perceived sense of land scarcity among them.

It is true that clans (of which there are four main ones) are perceived to own land, but in another sense the head of the oldest clan in the community (Tigo Nenek) is viewed as owning all the land. In another sense, each household is perceived as owning land.

The sense of land ownership in which the people responded to this form relates to immediate household land use. Land was reported as owned if that family was actively cultivating it (e.g., a rice field) or could harvest it at any time (such as a rubber garden or a home garden). The remainder of the land which "belongs" to Pulai is not really owned by anyone, though all recognize the prior rights of the original clan. But that land is essential to their agricultural system. In effect, it is land in fallow; it is forest.

The following three sections provide preliminary descriptive information relating to field size, animal ownership and wealth indicators (based on the subsample of 20 families):

*Field size and ownership*

In evaluating land use for ladangs, rubber gardens and other tree gardens, it is important not to assume that the field size reported is sufficient for a family to subsist over time. The upland agricultural cycle is a long one, necessitating forest regrowth prior to reuse of the land for rice cultivation. The size of the field must be multiplied by the number of years it is necessary to wait until the land can be profitably used again, if we want a real estimate of land use under the existing system.

Home gardens, which all 20 families had, averaged 1700 $m^2$.

Of the 14 families who had sawah, the average size was 2200 $m^2$.

Of the five families working ladangs, the average field size was estimated at 5350 $m^2$.

Eight families reported owning rubber gardens, averaging 450 trees (or just over a hectare) per family.

Only two reported having other tree gardens, but their average size was over 4000 $m^2$.

Ownership was reported, in the majority of cases, to rest with the husband and wife (contrary to expressed ideals in the community). Oddly, this was particularly true of sawah, which is generally discussed as the most fundamental kind of clan land (again, in ideal terms). Women were listed as owners in two cases, but in 11 cases ownership was reported as joint. The five ladangs were all listed as jointly

owned. Home gardens also manifest this pattern, with 16 reporting joint ownership, two reporting male ownership, and one reporting female ownership.

Rubber gardens were far more likely to be listed as belonging to one or the other of the spouses. Of the 12 fields (owned by eight families), only two were considered jointly owned, with five owned by men and five owned by women. Of the two "other tree gardens," one was jointly owned and one was owned by a man.

*Animals in Pulai*

Pulai animal ownership, like land ownership, displays a markedly different pattern from the transmigrants'. The first difference is the predominance of taking care of other people's animals, in the Pulai system. Of the 15 water buffalo reported by these first 20 families, 14 were only being cared for by the respondent for someone else (five respondents); only one was owned by the respondent's family.

Cattle, extremely common among the transmigrants, are rare in Pulai. Only one family reported having any cows, and all three of the cows were being cared for for others. Similarly, the five goats reported in this subsample were being cared for by one family for another.

Almost all families (18) reported owning chickens, with an average flock of ten per family.

The importance of fishing in this community is evident from the number of boats and nets. Seventeen families owned 18 canoes. The 44 gill nets reported belonged to 15 families, yielding three each for the families which owned any. Ten families reported owning 11 cast nets in all (just over one each); and the "pana," or speargun, is owned by nine families (one each). Fishing is an almost exclusively male activity. No women were reported as owning nets, though one jointly shared ownership of the boat.

*Indicators of Wealth*

Turning to commonly accepted indicators of wealth, we asked about other modes of transportation and modern or electronic household items. Almost all families owned at least one bicycle (18 families had 20 bicycles); and two families had a motorcycle. In contrast to Koto Padang (Naim and Agus 1985), no one had a truck. No television sets were reported in this early subsample, and only two radios. However, tape recorders were quite common, with 19 families owning over 21 tape recorders. Six families reported owning sewing machines.

The men definitely had an edge on ownership of this sort of thing. Twelve of the bicycles were owned by men, two more were owned jointly, and three were owned exclusively by women (ownership in one family is not clear because of uncertainty of the sex of the respondent). The two motorcycles are owned jointly and by the man.

The two radios and 13 tape recorders were owned by men; though five women also owned tape recorders. Only with sewing machines did women have the advantage: All six sewing machines belonged to women.

**Conclusions and Implications**

At this stage, attention has been paid only to the size of fields. It will be important to look also at the overall averages for the entire community to get a real sense of land use. Coifer was hesitant to do this at this stage, since she does not know for certain how representative the subsample was, and time constraints preclude doing a complete analysis now.

But such calculations would better await the analysis of the full community data. The combination of these data with those found in the income study and in the time-allocation study should provide the necessary information for evaluating the indigenous system as it pertains to possible adoption and/or adaptation by transmigrants. Time use, land use and income derived for various activities can provide a kind of bottom line in agricultural decision-making, though such will of course be further influenced by such amorphous (yet real) matters as indigenous knowledge and perceptions of soil.

## Income in Pulai

As the research proceeded on indigenous knowledge, in Pulai, the systematic differences between the Minang way of life and that of the transmigrants became ever more glaring. Pulai residents were approaching the whole question of earning a living from a completely different point of view. And it seemed to be one that both provided them a higher

standard of living and had certain ecological advantages over the practices of the transmigrants. It was therefore deemed sensible to gather more information on this system.

### Objective

The objective of this study was to identify major sources and the amount of income available to residents or households.

### Procedures

A survey of every household in Pulai was planned, with interviews conducted either by Colfer or by Pak Syarif Lipati, her assistant. The questionnaire included one page devoted to agricultural sources of income, and a second page listing the other sources of income with which we were familiar (as well as space for adding sources previously unknown to us). The survey form was pre-tested by both Pak Syarif and Colfer, and revised accordingly. Differentiation was made on the form among family members, so that the contribution of each member could be ascertained. The respondents were asked to report their income over the previous year. The survey was conducted during the fasting month of Ramadan (May-June 1986). Colfer went over the completed interviews with Pak Syarif to clear up any inconsistencies or problems.

### Results

Time has not yet permitted the entry of these data into the computer or any kind of quantitative analysis. Qualitative perusal suggests the following:

1) Coffee cultivation was a much more important source of income this year than anticipated (perhaps partially because of the unusually high price).

2) Rice is virtually never sold, it being considered an act worthy of shame to sell one's rice.

3) Men gain income from fishing and logging.

4) Animal husbandry and rice and rubber cultivation are sources of income for both sexes.

5) Women appear dominant in the sale of produce from the home garden.

6) There is a sense that income belongs to the whole household, though most sources could be identified as belonging to one person or another, in the final analysis.

7) The people take care of water buffalo and goats for others, deriving income both from the caretaking (receiving one of every two offspring) and from renting out the water buffalo (for logging, land cultivation).

8) Gold panning provides another source of income.

### Conclusions

In a general sense, one of the most interesting findings was the diversity of sources of income available to any one household. The rubber trees are always standing and available if it is not raining. Someone who does not own bearing trees can tap someone else's gardens, receiving two-thirds of what he or she taps. There are rambutan and duku trees in December. The coffee provides a little all year, but really bears in April, May and June. In September, there is usually a run of fish, providing extra income. In the spring, when the waters are low in the Batang Hari, people pan for gold. Rattan can be gathered and sold. And there's always *"Rezeki tak diduga"* (or chance opportunities to earn money, such as helping someone get a truck unstuck, or guarding a bulldozer). There is even a bit of agricultural wage labor done.

Another interesting finding was the attitude of the Minang about income. Particularly Minang men, but both sexes to some degree, are always alert to opportunities to earn money. They profess interest in earning money with great enthusiasm. I repeatedly heard people say "I'm not ashamed to do anything to earn money." They show a very open, creative frame of mind about the whole question of surviving. They expect sources to be varied and they explore new possibilities that they think might be profitable. Two of the differences they mention between themselves and the nearby Javanese transmigrants are 1) the variety of Minang sources of income, and 2) the Minang sense that non-agricultural activities are fair game as well.

### Implications

Important items to investigate in forthcoming analyses include:

1) ratio of agricultural to non-agricultural sources of income;

2) comparative contribution of different family

members to the overall income; and

3) income derived from different agricultural products (e.g., rice vis-à-vis coffee or rubber, or wet rice vs. upland rice).

## Expert Systems—The Human Component

The activities on this subproject, to date, have been sporadic and processual—sporadic, because of unanticipated time constraints; and processual, because of our learning process, and changes in the expert systems programs themselves.

### Objective

The objective was to document human (heuristic) factors involved in crop selection for cultivation in two or more areas in Indonesia and identify "gaps" in our indigenous knowledge base for action and research.

### Results, Conclusions, Implications

Some of the difficult decisions that have been required include the following:

*1. Choices*

The final product of an expert system is a "choice," determined on the basis of hierarchical chains linking bits of knowledge in a logical fashion. In an expert system on fertilizer, the final product seems fairly straightforward: a particular level of the fertilizer. Considerable thought, however, had to be devoted to what the outcome should be in an expert system full of holistic anthropological information. We determined that our primary audience was to be agricultural scientists and Indonesian policymakers concerned with agricultural issues. This prompted us to include three kinds of choices: likelihood of a crop existing in people's fields; proportion of land likely to be devoted to such a crop; and possible development programs.

Although having three kinds of choices is somehow aesthetically unsatisfying, we have so far stuck with this decision because of the importance and interconnectedness of all three matters. It also seemed sensible to develop a system that would be usable by several categories of policymakers, since considerable effort must go into feeding in the variety of information of relevance in such "choices."

*2. Variables*

When we began working on this expert system in April 1985, the software did not include "variables." Variables (in the expert system terminology) allow us to incorporate a variety of quantitative data that had previously been unwieldy if not impossible to include. Using the new variables component, we were able to make some progress incorporating information from three time allocation studies into the logical, hierarchical chains leading to choices.

*3. Linearity in the entry of rules*

The fact that the computer must go through its paces in order necessitates decisions about the primacy of certain facts vis-à-vis other facts. There is no way to make two things equally important, though many times in human matters things probably are equally important. Thus a certain amount of arbitrariness enters the expert system. Considerable effort has been (and must be) devoted to minimize such arbitrariness, by making decisions about relative importance, in as careful a manner as possible.

*4. Frames*

We are now expecting to experiment with the incorporation of a frame approach into the "Farmsys" expert system. There are certain traits, characterizing ethnic groups (e.g., a hierarchical world view or viewing rice cultivation as a symbol of ethnic identity), that are more immutable than the usual "qualifiers" (such as size of land holding or family size). It seems possible to simplify the rule-based expert system, by incorporating these more immutable characteristics into a frame-based system, which can then be consolidated into a more elegant overall system.

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*Interpreting Existing Soil-Management Systems*

# Intra-Household Decision-Making

*Carol J. Pierce Colfer, University of Hawaii*
*Evi Martha, Andalas University, Padang*
*Vickie Sigman, University of Hawaii*
*Kathleen Wilson, University of Hawaii*
*Russell Yost, University of Hawaii*
*Marian Rauch, University of Hawaii*
*Michael K. Wade, North Carolina State University*

This sub-project evolved into two relatively autonomous activities. The Case Study, described later in this report, was originally conceived to focus on decision-making within farm families. Partly in response to this interest, and our need on-site for more information on this topic, we initiated some work on intrahousehold decision-making, reported in the *TropSoils Technical Report, 1985-1986*. Not fully satisfied with our information, we initiated a third small study in February 1986. On the basis of the 1985 study in Sitiung V as well as more general observational data, we were convinced that input from both sexes was important in agricultural decision-making among the Javanese. A main purpose of this study was to provide evidence to support (or contradict) these observations.

## Objective

The objective was to ascertain the patterns of intrahousehold decision-making among Sitiung farmers, particularly relating to soil and crop management.

## Procedures

Evi Martha, a student of sociology and anthropology at Andalas University in Padang, helped to plan and executed a study of decision-making among Javanese transmigrants, to complement her previous study of farmer decision-making among Minang women in the area. Having some familiarity with the area, she was able to use a combination of methods: modified participant observation (for qualitative understanding of the context), secondary sources and a survey. For the latter, she chose random samples of 15% of the households in Sitiung I Blok A (N=41) and Sitiung I Blok D (N=69), interviewing only married women. She pre-tested her survey instrument in both locations, and had other team members critique it for her prior to administration to the sample.

## Results

*Findings on women and agriculture in Sitiung*

We should begin this section with a statement of the Javanese ideal related to agricultural decision-making in Sitiung. The reader, however, is asked to remember that ideals provide us with a partial picture; for agricultural planning we need to know about actual practice, which often conflicts with ideals. Some Javanese ideals are somewhat akin to American ones: Men do the heavy agricultural work in the fields and make the important decisions. Women work at home, perhaps doing a bit of gardening on the side, and help their husbands from time to time, as needed. Men's role as heads of household is frequently mentioned, and the saying "Go along to heaven, follow to hell as well" (*suergo nunut, neroko katut*) is interpreted to mean that final decisions are in the hands of husbands. The fact that winding up in hell may not be the most desired outcome leads naturally to another Javanese value, which moderates the male supremacy implied in the above.

Javanese life includes a negative valuation of the use of force in human relations. People, including children, are persuaded, sometimes tricked, but rarely forced to do things. An elaborate system of supernatural sanctions complements the human sanctions, which discourage people from forcing or angering others. The Javanese are well known for their ideal of calm and balance in the universe, including the human component. Probably related to this is their emphasis in the decision-making realm on *musyawarah*, or discussion leading to consensus among all parties. This holds in marital and familial relationships as well. So, while words can be found to support the notion of male supremacy among the Javanese, the realities of everyday life are substantially modified by other Javanese values (including considerable emphasis on the importance of mothers) with the result being relatively high status and decision-making involvement for women.

We retain considerable skepticism about the degree to which people's reported decision-making activity corresponds to reality. People are influenced

by their own ideals, by their perception of the researcher's ideals, and by reality. We assume in this study that involvement in any activity necessitates some decision-making. This is particularly true among the Javanese, where instructions and orders are not so frequently given to other family members; people go about their work rather autonomously. Thus part of what follows deals with people's reported involvement in activities. In interpreting tables dealing with responses to specific questions such as "who decides x or y?," cultural ideals must be borne in mind. The degree to which these bias the answers cannot be known, but that they do bias the answers is almost certain.

*1. Self perceptions*

Sitiung women's own perception of themselves is as farmers. When asked their work, 78% considered their primary occupation to be "farmer," with 7% more considering farming a secondary occupation. The other two categories of work that were significant for women were "trader" and "laborer" (see Table 1), particularly so as secondary work. Table 2 provides comparable information on their work experience in Java. The move to Sitiung has surely involved some major changes, but the self-categorization as farmer does not appear to have changed much (81% considered themselves farmers in Java; with 6% reporting farming as a secondary occupation).

There appear to have been changes in women's trading activity with the move to Sitiung. In Java 2% considered themselves primarily traders, and 19% reported such activity as supplementary. But in Sitiung, none considered their primary occupation to be trading, yet 35% reported it as a secondary occupation.

The comparison in percentages between "farmers" and "farm laborers" before and after transmigration may be distressing to planners. According to these findings, the number of "farmers" hardly changed (81% in Java to 78% in Sitiung), but the number of "farm laborers" has doubled (10% in Java and 21% in Sitiung). This may be because increased land holdings of transmigrants in Sitiung yield increased wealth which in turn provides more

Table 1. Women's primary and secondary occupations in Sitiung I, Blok A and D.

| Occupation | Blok A, N=41 | | Blok D, N=69 | | Weighted Average | |
|---|---|---|---|---|---|---|
| | prim. | secon. | prim. | secon. | prim. | secon. |
| Farmer | 87.81 | 12.5 | 71.88 | 3.7 | 77.82 | 6.98 |
| Trader | 0.00 | 50 | 0.00 | 25.93 | 0.00 | 34.9 |
| Official | 2.44 | 0.00 | 0.00 | 0.00 | 0.91 | 0.00 |
| Ag. laborer | 9.75 | 12.5 | 28.12 | 7.41 | 21.27 | 9.31 |
| Laborer | 0.00 | 25 | 0.00 | 62.96 | 0.00 | 48.81 |

Table 2. Women's primary and secondary occupations in Java, before transmigration.

| Occupation | Blok A, N=41 | | Blok D, N=69 | | Weighted Average | |
|---|---|---|---|---|---|---|
| | prim. | secon. | prim. | secon. | prim. | secon. |
| Farmer | 82.86 | 0.00 | 79.31 | 10 | 80.63 | 6.27 |
| Trader | 2.86 | 33.33 | 1.72 | 10 | 2.14 | 18.7 |
| Official | 2.86 | 0.00 | 0.00 | 0.00 | 1.07 | 0.00 |
| Ag. laborer | 8.57 | 0.00 | 10.35 | 0.00 | 9.69 | 0.00 |
| Laborer | 2.86 | 66.67 | 8.62 | 80 | 6.47 | 75.03 |

opportunities for farm labor. The comparatively sparse population in West Sumatra also means less competition for existing agricultural jobs; and the recency of occupancy means that there is less diversity in occupational choices. The secondary occupation, "unskilled laborer," has taken another dramatic dive with the move to Sitiung (from 75% to 49%).

When queried on their reason for working (Table 3) most women (69%) said they wanted to, and 28% said "it's the usual thing to do." Less than 1% reported being told to work by their husbands, and just under 2% considered themselves forced to by economic conditions.

**Table 3. Reasons given by Sitiung women farmers for working (percents).**

| Reason | Blok A n=41 | Blok D n=69 | Weighted average |
|---|---|---|---|
| Usual | 36.59 | 23.19 | 28.18 |
| Wants to herself | 63.41 | 72.46 | 69.09 |
| Told to by husband | 0.00 | 1.45 | 0.91 |
| Forced to by economic circ. | 0.00 | 2.9 | 1.82 |

*2. Women in organizations*

In an attempt to find out about women's extra-familial activities, we asked them what organizations they belonged to. Table 4 provides the results of that inquiry. The interesting point, from an agricultural perspective, is the fact that the Agricultural Cooperative is the most commonly mentioned organization, with 92% of the women saying they belonged to it. Evi Martha notes that "Generally women have more connections with the Agricultural Cooperative than men/husbands..." (1986:7).

Table 5 provides the percentages of women reporting attending various kinds of meetings. Again the Agricultural Cooperative is, for all practical purposes, at the top (right next to family planning).

Women report selling produce to the Agricultural Cooperative more than twice as often as they report men doing so (43% vs. 17%), whereas men are almost twice as likely to be reported buying seeds (24% to 13%) and fertilizer (25% to 14%). Reported borrowing and saving activities appear to be very similar for men and women, although Evi noted that "It is usually women who engage in the borrowing and selling of small amounts (e.g., Rp. 15,000), whereas the men work the sawah, and only borrow large amounts from the Agricultural Cooperative (more than Rp. 100,000) using livestock/things which are easy to sell as collateral (1986:7).

Remembering the caveat about the reliability of answers to direct questions on decision-making, we turn to Table 7. The value on consensual decision-making is clear, in that 91% of the women reported making joint (husband-wife) decisions about the Agricultural Cooperative and 74% reported joint decisions about village activities in general. The value on male dominance in decision-making is also evident in this table. For the coop, only 14% of the women reported being the dominant decision-making, with 60% reporting their husbands as dominant or deciding alone. Interestingly, for village activities, women's reported decision-making involvement increased, with 26% reporting deciding alone or being the dominant decision-maker, and 40% reporting their husbands as dominant.

*3. Women at work*

In the earlier time-allocation studies, we looked at the broad range of activities in which Sitiung residents were involved (Colfer, Yost, Kasmini, and Kurdiana 1984). But the method we used was not sufficiently detailed to break down the steps in agricultural production by sex. Tables 5 and 6 provide that breakdown, as reported by Sitiung women.

Table 5 contains a great deal of information. In the steps to sawah production, from land preparation through control of money received, the following was reported:

1) Women report themselves to be dominant in planting, replanting, weeding, winnowing, drying, deciding to sell and controlling the money obtained from the crop

2) Men are reported to dominate in land preparation, choice of crops, fertilizing, water control and spraying. It is worth noting that though transmigrants in general recognize the value of fertilizers and pesticides, they frequently do not have the money to buy these inputs. Additionally water control appears to be more in the hands of the government than in the

Table 4. The involvement of Sitiung women farmers in various village activities (percents).

| Activity | Blok A, N=41 | | Blok D, N=69 | | Weighted Ave. | |
|---|---|---|---|---|---|---|
| | Inv. | Not inv. | Inv. | Not inv. | Inv. | Not inv. |
| Birth control | 65.85 | 34.15 | 68.12 | 31.88 | 67.27 | 32.73 |
| Gov't women's clubs | 31.71 | 68.29 | 24.64 | 75.36 | 27.28 | 72.72 |
| Agri. coop. | 92.68 | 7.32 | 91.3 | 8.7 | 91.81 | 8.18 |
| Revolving credit | 19.51 | 80.49 | 20.29 | 79.71 | 20.00 | 80.00 |
| Family pl. group | 41.46 | 58.54 | 50.72 | 49.28 | 47.27 | 52.73 |
| Religious study group | 14.63 | 85.37 | 42.03 | 57.97 | 31.82 | 68.18 |
| Village meetings | 73.17 | 26.83 | 52.17 | 47.83 | 60.00 | 40.00 |

Table 5. Division of labor and mode of payment in wet rice fields as reported by women farmers (percents).

| Steps | Blok A, N=41 | | | | | Blok D, N=69 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| lab | Wife | Husb | Fam mem | Lab exch | Paid lab | Wife | Husb | Fam mem | Lab exch | Paid |
| Hoeing | 36.10 | 97.60 | 36.59 | 0.00 | 12.20 | 60.87 | 81.16 | 37.68 | 0.00 | 5.80 |
| Flattening | 0.00 | 97.60 | 36.59 | 0.00 | 12.20 | 13.04 | 89.96 | 37.68 | 0.00 | 5.80 |
| Choosing crop* | 19.51 | 65.85 | 0.00 | 0.00 | 0.00 | 8.70 | 66.67 | 1.45 | 0.00 | 0.00 |
| Planting | 97.60 | 21.95 | 39.02 | 65.85 | 2.44 | 91.30 | 52.17 | 42.03 | 23.19 | 4.35 |
| Fertilizing | 36.59 | 97.60 | 41.46 | 0.00 | 0.00 | 50.72 | 76.81 | 40.58 | 0.00 | 5.80 |
| Replanting | 95.12 | 9.76 | 43.90 | 0.00 | 0.00 | 89.86 | 30.43 | 39.13 | 0.00 | 5.80 |
| Weeding | 95.12 | 58.54 | 48.78 | 0.00 | 0.00 | 91.30 | 36.23 | 47.83 | 0.00 | 7.25 |
| Water control | 0.00 | 97.60 | 0.00 | 0.00 | 0.00 | 0.00 | 88.41 | 36.23 | 0.00 | 5.80 |
| Spraying | 4.88 | 97.60 | 36.59 | 0.00 | 0.00 | 0.00 | 88.41 | 37.68 | 0.00 | 5.80 |
| Harvesting | 90.24 | 95.12 | 39.02 | 65.85 | 2.44 | 68.12 | 84.06 | 44.93 | 23.19 | 4.35 |
| Threshing | 95.12 | 95.12 | 41.46 | 65.85 | 2.44 | 85.51 | 81.16 | 44.93 | 23.19 | 0.00 |
| Winnowing | 87.80 | 9.76 | 39.02 | 75.61 | 0.00 | 66.96 | 20.29 | 43.48 | 23.19 | 7.25 |
| Carrying home | 78.05 | 95.12 | 41.46 | 0.00 | 0.00 | 62.32 | 78.26 | 42.03 | 0.00 | 1.45 |
| Drying | 97.60 | 0.00 | 48.78 | 0.00 | 0.00 | 92.75 | 20.29 | 49.28 | 0.00 | 0.00 |
| Carrying/hulling | 90.24 | 90.24 | 43.90 | 0.00 | 0.00 | 73.91 | 71.01 | 40.58 | 0.00 | 5.80 |
| Deciding/sell | 80.49 | 41.46 | 0.00 | 0.00 | 0.00 | 44.93 | 24.64 | 0.00 | 0.00 | 0.00 |
| Controlling $ | 82.93 | 14.63 | 0.00 | 0.00 | 0.00 | 52.17 | 11.59 | 0.00 | 0.00 | 0.00 |

*The figure under "lab exch" refers to a decision by the extension agent.
Note: 26.83% of women reported extension agent choosing crops in Blok A. 21.74% reported similarly in Blok D.

hands of individual farmers in the Sitiung area, since the irrigation system is fed by water pumped from river, at government expense and with government maintenance.

3) Women report the considerable involvement of both sexes in harvesting, threshing, carrying home and carrying to the rice huller.

In home gardens (Table 6), again we find male dominance reported in choosing crops, and female dominance reported in controlling money obtained from selling produce. Fencing emerges as an exclusively male activity, so efforts to encourage fencing on other fields (discussed frequently within the TropSoils team) would best be attempted via the men. Planting, weeding and harvesting are reported to be dominated by women in home gardens, though both sexes are actively involved.

**Table 6. Division of labor in home gardens as reported by women farmers.**

| Steps | Blok A, N=41 | | | Blok D, N=69 | | | Weighted Average | | |
|---|---|---|---|---|---|---|---|---|---|
| | Wife | Husb | Fam mem | Wife | Husb | Fam mem | Wife | Husb | Fam mem |
| Prepare sawah | 95.12 | 100.00 | 63.41 | 82.61 | 94.20 | 65.22 | 87.27 | 96.36 | 64.55 |
| Choosing crop | 41.46 | 97.56 | 7.32 | 15.94 | 88.41 | 2.90 | 25.45 | 91.82 | 4.55 |
| Planting | 97.56 | 95.12 | 63.41 | 94.20 | 71.01 | 65.22 | 95.45 | 80.00 | 64.55 |
| Weeding | 97.56 | 78.05 | 63.41 | 95.65 | 62.32 | 65.22 | 96.36 | 68.18 | 64.55 |
| Fencing | 0.00 | 100.00 | 63.41 | 0.00 | 97.10 | 65.22 | 0.00 | 98.18 | 64.55 |
| Harvesting | 100.00 | 97.56 | 63.41 | 95.65 | 84.06 | 63.77 | 97.27 | 89.09 | 63.64 |
| Selling | 14.63 | 7.32 | 2.44 | 10.14 | 2.90 | 0.00 | 11.81 | 4.55 | 0.91 |
| Controlling $ | 17.07 | 0.00 | 2.44 | 10.14 | 1.45 | 0.00 | 12.72 | 0.91 | 0.91 |
| Look for grass for livestock | 80.49 | 85.37 | 60.98 | 57.97 | 78.30 | 57.97 | 66.36 | 80.94 | 59.09 |

*4. Division of decision-making between women and their husbands*

In Table 7 we return to a question that asks about decision making directly: How are decisions made about education, family planning and household finances? The most interesting information in this table, from the standpoint of agricultural planning, is the reported preeminence of women in family finance. Sixty-seven percent maintain that they have sole control of family finances (a percentage that rises to 93% if the cases where the wife is dominant or equal are added); and 90% report doing the routine shopping without input from their husbands. This reported female dominance is particularly significant in an overall climate that idealizes male dominance in decision-making.

A general picture of women's perceptions of decision-making in Sitiung can be gleaned quickly by looking at the zeros in Table 8. In no cases, in either community, do women perceive their husbands deciding alone about the resolution of problems the wives have in the household, in agriculture, or in other work. Conversely, and to a greater degree, in no case do women report either deciding alone or serving as the dominant decision-maker in a joint decision involving the resolution of problems their husbands have in agriculture, in other work, with friends, or with family. Thus, although women report some degree of autonomy in the conduct of their own lives, their husbands are perceived to have greater autonomy. Even in joint decisions involving the wife's work, most women report their husbands having a greater voice than they (consistent with the ideal of male dominance discussed earlier). Similarly the majority of decisions in this realm are again seen as taken jointly, rather than individually, with the only exceptions being related to men's problems with their own friends and family.

*5. Collaborating with and extending to women*

The final section to be discussed here pertains directly to the question of involvement of women in research and extension of agricultural findings. In a previous report, Colfer has noted that TropSoils has had trouble involving women in our agricultural research. We failed utterly to persuade women cooperator farmers to attend meetings with their husbands in Sitiung V. Table 9 presents women's reports of their own participation in public meetings. This suggests that even had we been able to persuade women to attend our meetings, they would have made little or no input. Another strategy should be developed, since we have ample evidence from this study and several others that women are just about as involved in agriculture as are men.

With agreement that addressing extension questions is justifiable within our project, we can begin to look at ways to get our new technologies across. Use of the media may be important in such endeavors. Table 10 provides women's reported exposure to TV, radio, newspapers and magazines. There is a clear preference for the non-printed word among Sitiung's women.

**Table 7. Husband wife decision-making in Sitiung related to education, family planning and household finances (percents).**

| | Wife alone | Wife dom | Together equal | Hus dom | Husband alone | Other |
|---|---|---|---|---|---|---|
| **Blok A** | | | | | | |
| Children's education | 0.00 | 9.76 | 36.60 | 41.46 | 2.44 | 7.32 |
| Use of birth control | 9.76 | 14.63 | 12.20 | 17.07 | 2.44 | 0.00 |
| Control of family money | 68.30 | 2.44 | 21.95 | 2.44 | 4.88 | 0.00 |
| Shopping/necessities | 95.12 | 0.00 | 2.44 | 0.00 | 0.00 | 0.00 |
| Shopping/supplementary | 2.44 | 9.76 | 26.83 | 51.22 | 7.32 | 0.00 |
| **Blok D** | | | | | | |
| Children's education | 1.44 | 7.25 | 40.58 | 42.03 | 2.90 | 4.35 |
| Use of birth control | 2.90 | 23.19 | 7.25 | 31.86 | 0.00 | 1.44 |
| Control of family money | 66.67 | 4.35 | 21.74 | 10.14 | 1.44 | 0.00 |
| Shopping/necessities | 86.96 | 5.80 | 1.44 | 4.35 | 0.00 | 1.44 |
| Shopping/supplementary | 1.44 | 7.25 | 8.70 | 81.16 | 1.44 | 1.44 |
| **Weighted average** | | | | | | |
| Children's education | 0.90 | 8.19 | 39.10 | 41.82 | 2.73 | 5.46 |
| Use of birth control | 5.46 | 20.00 | 9.09 | 26.36 | 0.91 | 0.90 |
| Control of family money | 67.28 | 3.64 | 21.82 | 7.27 | 2.72 | 0.00 |
| Shoppingnecessities | 90.00 | 3.64 | 1.81 | 2.73 | 0.00 | 0.90 |
| Shopping/supplementary | 1.81 | 8.19 | 15.46 | 70.00 | 3.63 | 0.90 |

## Conclusions

This study, like many others we have done, documents women's involvement in agricultural activities. We feel that it can safely be assumed that some independent decision-making inevitably occurs in the conduct of such activity. However, when queried on family agricultural decision-making roles specifically, men are usually fingered as the responsible party.

To go from the above data to agricultural recommendations, some judgments must be made that necessarily involve values rather than science. We will clarify the reasoning that leads to the following recommendations to aid the reader in evaluating them.

1. In general the person who does work should be involved in decision-making related to that work. This reflects a value on individual freedom and autonomy.

2. Involvement in productive work is a prerequisite for status within the community (Sanday 1974) and self-respect for all people. Thus women's existing participation in agricultural work should not be marginalized by lack of training and opportunities,

relative to men, in projects such as TropSoils. This reflects a value on equality between the sexes.

3. There should be greater recognition of the value of the subsistence sphere and what is sometimes called the "reproductive" sphere (activities necessary for the maintenance of human life, such as cooking, child care, education). Women's activities particularly tend to revolve around these two undervalued spheres of work (though rural people of both sexes are storehouses of knowledge on the subsistence sphere). This reflects a more general value on equity, both between men and women and between rural and urban peoples.

4. Rural people's existing knowledge should be used in agricultural planning, and agricultural technologies should be tested for acceptability by rural people. This reflects a value on human beings and their potential contribution. It also reflects sincere skepticism about the possibilities for successful development without such participation.

### Implications

The following recommendations are based on two additional assumptions:

1. Collaborative work is most efficiently done with the sex that normally performs that function (avoiding attempting to change patterns that appear benign).

2. Patterns that appear discriminatory are not benign, and TropSoils should, in small ways, discourage them.

Attempts to work with women should be intensified, since information has accumulated at a steady rate showing that women consider themselves farmers (Tables 1 and 2), and do agricultural labor (Tables 5 and 6). The existing involvement of women in the Agricultural Cooperatives may be a good lead. Collaboration with the work parties organized for planting and harvesting (Table 5) would probably be the most innovative way to gain access to the women. This approach is further recommended by the apparent lack of success both observed and reported (Table 9) getting Sitiung women to participate in conventional village meetings. Colfer has argued elsewhere that the success of the family planning program in Bali was principally because of its use of existing grouping patterns (the "banjar system," Colfer 1979); and there is local evidence that

**Table 8. Women's decision-making in the solution of problems between husbands and wives (percents).**

| Kind of problem | Wife alone | Wife dom | Together equal | Hus dom | Hus alone |
|---|---|---|---|---|---|
| | | | **Blok A** | | |
| On wife's side | | | | | |
| Housework | 17.07 | 4.88 | 14.63 | 58.50 | 0.00 |
| Agriculture | 9.76 | 4.88 | 14.63 | 68.30 | 0.00 |
| Other work | 4.88 | 0.00 | 0.00 | 2.44 | 0.00 |
| On husband's side | | | | | |
| Agriculture | 0.00 | 0.00 | 9.76 | 73.17 | 14.63 |
| Other work | 0.00 | 0.00 | 0.00 | 7.32 | 21.95 |
| With friends | 0.00 | 0.00 | 2.44 | 19.51 | 73.17 |
| With family | 0.00 | 0.00 | 0.00 | 34.15 | 58.53 |
| | | | **Blok D** | | |
| | **Wife alone** | **Wife dom** | **Together equal** | **Hus dom** | **Hus alone** |
| On wife's side | | | | | |
| Housework | 11.59 | 4.35 | 15.94 | 66.66 | 0.00 |
| Agriculture | 8.70 | 4.35 | 17.39 | 65.22 | 0.00 |
| Other work | 1.45 | 0.00 | 0.00 | 2.90 | 0.00 |
| On husband's side | | | | | |
| Agriculture | 0.00 | 0.00 | 13.04 | 65.22 | 17.39 |
| Other work | 0.00 | 0.00 | 1.45 | 5.80 | 10.14 |
| With friends | 0.00 | 0.00 | 7.25 | 36.23 | 55.07 |
| With family | 0.00 | 0.00 | 7.25 | 43.48 | 46.38 |
| | | | **Weighted Average** | | |
| | **Wife alone** | **Wife dom** | **Together equal** | **Hus dom** | **Hus alone** |
| On wife's side | | | | | |
| Housework | 13.63 | 4.55 | 15.45 | 63.63 | 0.00 |
| Agriculture | 9.10 | 4.55 | 16.36 | 66.37 | 0.00 |
| Other work | 2.73 | 0.00 | 0.00 | 2.73 | 0.00 |
| On husband's side | | | | | |
| Agriculture | 0.00 | 0.00 | 11.82 | 68.18 | 16.36 |
| Other work | 0.00 | 0.00 | 0.91 | 6.37 | 14.54 |
| With friends | 0.00 | 0.00 | 5.46 | 30.00 | 61.82 |
| With family | 0.00 | 0.00 | 4.55 | 40.00 | 50.91 |

the use of the traditional Minang clan organization in the Abai Siat Rubber Replanting scheme has contributed to their success. Such collaborative work could easily fit into the project as it moves toward farmer testing of technologies viewed as having high potential by the scientists.

Collaborative work should be focused to match the existing division of labor. Since men dominate in land cultivation on sawah, studies of tillage in wet rice would best be done with them (Table 5). Women's dominance in planting and weed control suggests that experiments on plant spacing and pesticides should be planned with women. Since pesticides are not used extensively in Sitiung, the dominance of men in the area of spraying is probably a result of the fact that men have been exposed to extension activity rather than women. Since women are the weeders, they will probably have greater motivation to control the weeds and are thus potentially better collaborators. Crop selection in every kind of field is reported to be determined by men, thus their input should be important when deciding on experimental crops. Observation suggests, however, that considerable spontaneous planting of small plots of subsistence crops is done by both sexes, apparently without discussion or overt planning; and subsistence crops are, of course, very important in the Sitiung farming systems.

One important consideration in making such choices is that since both men and women consider themselves to be farmers, both should have opportunities to expand their level of skill and to contribute their experiential knowledge to TropSoils thinking. In this way the project can avoid displacing people from their traditional roles at the same time that these people's existing knowledge can be utilized and enhanced.

Experiments should be designed to respond to the differing needs of the differing kinds of fields of importance in the Sitiung farming system (Tables 5 and 6). Although one can argue that "soil is soil," the management of soil clearly differs from home garden to sawah to kebuns.

Table 9. Reported participation of Sitiung women in meetings that are held (percents).

| Kind of participation | Blok A | Blok D | Weighted average |
|---|---|---|---|
| Just listen | 84.62 | 72.22 | 76.84 |
| Sometimes ask questions and give opinions | 15.38 | 27.78 | 23.16 |
| Frequently ask questions and give opinions | 0.00 | 0.00 | 0.00 |

## A Case Study

The Case Study, undertaken in collaboration with the Population Council and the Farming Systems Support Project, is part of a Case Studies Project on Intra-Household Dynamics and Farming Systems Research and Extension. Its purpose is to document the methods, approaches, successes and failures of a number of farming systems projects, for use as instructional materials.

The case study developed under this project is called "Farm-Based Research in the TropSoils Project, Sitiung, Indonesia." Its writing was coordinated from the University of Hawaii by Vickie Sigman. Colfer, as well as other TropSoils team members, helped to conceptualize the case study, including choosing the most appropriate aspects of

Table 10. Sitiung women's reported exposure to the mass media (percents).

| Media | Blok A Often | Blok A Some | Blok A Never | Blok D Often | Blok D Some | Blok D Never | Weighted average Often | Weighted average Some | Weighted average Never |
|---|---|---|---|---|---|---|---|---|---|
| Television | 12 | 39 | 48 | 23 | 74 | 3 | 19 | 61 | 20 |
| Radio | 29 | 20 | 51 | 35 | 35 | 30 | 33 | 29 | 38 |
| Newspapers | 0 | 12 | 88 | 7 | 17 | 75 | 5 | 15 | 80 |
| Magazines | 0 | 7 | 93 | 3 | 17 | 80 | 2 | 14 | 85 |

the project to include (since much of TropSoils work is like conventional "component" research); and making suggestions and corrections in several drafts. Kathleen Wilson, Russell Yost, and Marian Rauch, as well as other faculty members at the UH campus were active in gleaning information from TropSoils reports and in further massaging data for inclusion in the case.

TropSoils activities that were highlighted in the case include the initial modified sondeo, the collaborative work with farmers in Sitiung VC, the CIAT pasture and legume trials, the nutrition/income study and the time-allocation study.

Two results of this case study appear to be of use to the project. The first pertains to the enhanced availability of TropSoils experience for other would-be farming-systems practitioners. These cases are to be published and made available through the existing networks maintained by the Population Council and the Farming Systems Support Project. The thought that went into synthesizing the experience of TropSoils/Indonesia in farming systems related matters into a small case study (84 pages overall) was helpful to the team in both conceptualizing what we were doing, and in conveying the process to others. It should also enhance the visibility of the project.

The second important result has been the increased interest and involvement of UH campus staff in TropSoils. In the process of writing the case, a number of faculty became quite knowledgeable about the project, and would thus now be in a much better position to collaborate effectively with the on-site team. The fact that faculty members from both the Human Resources and the Agriculture parts of the College of Tropical Agriculture and Human Resources were working together is another plus. There is general recognition in the College that closer collaboration between the social and natural sciences is desirable; yet working together more effectively has proven difficult. This case study has truly been a joint endeavor.

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*Interpreting Existing Soil-Management Systems*

# Farmer Resource Allocation In Sitiung, West Sumatra

*Stephenie Kan, University of Florida*
*Carol J. P. Colfer, University of Hawaii*

The presence of the household as an integrated and central part of the farm system complicates the process of technology generation for the farmer with limited resources. The inclusion of the household into the farm system adds another dimension to this allocation of resources—family welfare.

When the household is considered in the allocative process, risk and the valuation of activities must be looked at from the prospective of family welfare. It is difficult to put a value on crops used for consumption by the household. Putting a market value on these crops assumes that the household is able to buy these crops if the members do not grow them or sell all of them. The value of consumed crops is difficult to estimate, particularly if the household cannot afford to buy them in the market. Since the farm is involved with sustaining life rather than merely making a profit, the farmer with limited resources will be less willing to take on risks. Because of scarce resources, the farmer with limited resources is less able to absorb losses and the costs of failure are very high.

The household must, then, allocate its scarce resources among competing consumption and production needs in a way to ensure having at least the minimum necessities for survival. Profits from the farm business are not necessarily reinvested in the farm, but are directed to the household for allocation. Therefore, the acceptability of new technology to these farmers with limited resources will depend largely on how well the new technology can compete with other needs (including the traditional methods that the new technology is developed to replace) for resources and the amount of additional risk that the new technology is perceived to involve.

## Objectives

The objectives were 1) to identify amounts and sources of resources available to farmers and application of these resources to agricultural production, and 2) to identify factors influencing farmers to accept new technology.

## Procedure

In designing research aimed at small farmers, the available resources that a farmer has must be taken into consideration. The amount of resources a farmer makes available for agricultural production and the acceptability of new technology depends on many different factors. This research is aimed at understanding some of these factors.

In order to gain some understanding of the amounts of labor and capital farmers have available and the manner in which they allocate these resources among many competing needs, certain factors were considered: 1) farmers' perceived constraints to agriculture; 2) investment, savings and risk; 3) interaction between on- and off-farm work; 4) agricultural productivity and input use; 5) available credit; 6) availability of labor; 7) labor use, general and agricultural; 8) farmer goals; 9) spending hierarchy (what needs the farmer considers most important); and 10) major cash expenditures.

To obtain information on the preceding factors, the following sources were used: 1) direct observation and casual interviews; 2) information from scientists associated with TropSoils and CSR in Sitiung; and 3) existing data collected by TropSoils and the CSR staff, specifically the Sitiung V time allocation survey (Colfer et al. 1985), the nutrition income survey (Chapman 1984), the study of tree crop management in Koto Padang (Naim and Agus 1985), and the survey of small ruminant management (conducted in Sitiung by Ann Wade, reported in Pulungan et al. 1985).

A review of these sources led to the development and implementation of three activities to understand the factors affecting allocation of farmer resources.

### *1. Enterprise record-keeping study*

Daily survey forms were distributed in bound, one-month booklets, which were collected at the end of each month. For the first two months, the farmers were visited several times each month to make sure they understood how to fill out the form. The final record books were collected during the last week in November. The activities which were tracked were: 1) daily on-farm activities, 2) farm input use, 3) farm labor use, 4) amounts of harvests sold and saved,

5) some market information, and 6) off-farm work.

2. *Economic survey*

This survey was fairly long—five pages—and took from 20 minutes to one hour to complete, depending on the language ability of both farmer and interviewer (the Indonesian national language was not often understood well by all the farmers in Sitiung V). The survey covered: 1) farmer perceptions of farm production, 2) activities in the face of severe economic constraints, 3) perceptions of off-farm work, 4) farmer credit availability, 5) general goals, 6) spending hierarchy, 7) major cash expenditures, 8) investment and 9) some labor questions. Input and suggestions from the CSR staff in Sitiung proved to be very helpful.

3. *Production-constraints survey*

Questions pertaining to farm productivity were asked in terms of yield per unit of seed rather than per hectare. Spacing and seeds per hole were also asked in order to get some estimate of yield per hectare.

## Results and Conclusions

1. The majority of farmers surveyed indicated that they prefer to be farmers. It could be that the farm itself is looked on as an investment and source of security, where as a steady job, even though it brings a steady income (which farming often does not), does not offer the same amount of security for the future.

2. Animals (most notably chickens) play a very important role as a means of investment and as a hedge against bad times. The raising of chickens seems to fit in very well with the farmer's system, as chickens require a minimum amount of capital and labor.

3. Farmers showed a very strong interest in tree crops, particularly for coffee (which is fetching a good price currently because of problems Brazil is having with its coffee production). Twenty of 29 farmers surveyed indicated that they planned to grow coffee in their second upland field. Nine planned to grow only coffee, five planned to grow coffee in combination with rice (presumably they will intercrop rice with coffee until the trees shade out the rice), and six planned to grow coffee in combination with other crops (however, in these cases, coffee was mentioned as the first crop that they wanted to grow).

4. Most farmers surveyed acknowledged that by increasing fertilizer and pesticide use, their yields would increase. However, the farmers are not using more fertilizers and pesticides. In the hierarchy of spending, fertilizer ranked third and pesticide fourth, after food and seed. Increasing fertilizer and pesticide use ranked fourth in farmer goals. It seems that farmers perceive the benefits of higher fertilizer and pesticide use, but also perceive other needs and goals to be of more importance. Therefore, technology that recommends increasing yields by only increasing fertilizer use will not likely be readily adopted by the farmers.

## Implications

Technologies more likely to be adopted might be those aimed at increasing productivity while not increasing costs significantly (such as increasing the efficiency of fertilizers) or technologies that, though increasing cost, show such substantial increases in benefits that farmers will pull resources away from other activities in order to adopt the new technology. This is not to say that fertility experiments are useless. On the contrary, they are very important. However the adoption of technology for the farmer with limited resources must be done with his constraints and needs in mind. Also, it should be noted that the Sitiung transmigration area is continuously developing, and a sensitivity to the farmer's changing needs and concerns is very important.

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*Modification of Soil-Management Systems*

# Effects of Different Sources Of Fertilizer on Soil Properties

*Fahmuddin Agus, Centre for Soils Research*
*Carol J. Pierce Colfer, University of Hawaii*
*Stacy Evenson, University of Hawaii*
*Sholeh, Centre for Soils Research*
*Richard G. Dudley, University of Hawaii*

This experiment was initiated with 13 cooperator farmers in Sitiung V (Aur Jaya) and in Sitiung I (Piruko). Each farmer was considered to be a farmer-managed replication. The soil in Sitiung I is predominantly Inceptisol and in Sitiung V, Ultisol. The fertility of plots within each farmer's field and from one farmer to another was quite variable, due to the different methods of soil management and to the various crops that had been planted on any particular spot.

## Objectives

This project was expanded to include both inorganic and organic fertilizer sources and their effects on both the crop and farmer. The objectives were 1) to observe farmers' response to application of different sources of fertilizers (inorganic and organic); 2) to introduce other varieties of crops for home gardens, and 3) to compare crop response to fertilizer source relative to cost.

## Procedures

*1. Experimental design*

Treatments tested in this study were:

Treatment 1 = Control; no fertilizer application.

Treatment 2 = 10 t/ha of barnyard manure (broadcast)

Treatment 3 = 10 t/ha compost (broadcast)

Treatment 4 = (kg/ha) 100 Urea, 125 TSP, 125 KCl, and 80 kieserite ($MgSO_4$), (broadcast)

Treatment 5 = (five replications) = 25 t/ha fishpond sediment (averaging 73% water content on weight basis; broadcast)

These treatment were arranged in a Randomized Complete Block design with seven Javanese farmer-managed replications in Sitiung I and six in Sitiung V (all Sundanese).

*2. Crops*

Chili (*Capsicum annuum* L.) was planted in September 1985, and bambara groundnuts (*Voandzeia subterranea*) were planted in March 1986. Chili seedlings, bambara nut seeds and pesticide were distributed, in addition to inorganic fertilizers, compost, and in Sitiung V, barnyard manure. Any farmers' responses, complaints anad comments were recorded, in addition to a pre-planned set of parameters.

## Results

*1. Farmers' responses to the crops*

Chili

When the farmers were asked about what kind of crop they would like to grow for the experiment, their initial response was almost unanimous: "It's up to you." Since one of our main interests was farmer input, we tried again. We presented several crops such as chili, tomato, bambara groundnuts, spinach and wing bean to the farmers as possibilities, and asked them to choose again. This time they chose chili.

Chili is the most common spice, or appetizer, in Sitiung, and is normally eaten by the transmigrants with rice and vegetables. The amount of chili consumed is variable among individuals, families and ethnic groups, but from a global perspective is probably high for almost everyone in West Sumatra. Despite its ubiquity in the diet, it is not widely grown among transmigrants except for a few Sundanese who were growing lots of it in large plots in their home gardens in Sitiung V in 1983-84. Some simply preferred growing chili and hadn't thought of doing so. They were interested in trying it, given our provision of supplies and guidance.

From a nutritional viewpoint, chili contains mostly carbohydrates and vitamins (especially Vitamin A). Although its hot taste requires that it be eaten in fairly small amounts, it may provide small amounts of Vitamin A (important, since blindness caused by Vitamin A deficiency is a widely recognized Indonesian health problem). Its price fluctuates widely. In early 1984 its price was as high as Rp. 4,000/kg. This figure can also drop as low as Rp. 500/kg (in February 1986, US $ 1 = RP. 1126).

Bambara groundnuts

The method of choosing this crop was similar to the way we chose chili. Only after hearing some alternatives did the farmers spontaneously choose bambara nuts. Even though they said they liked the crop, few in Sitiung V planted it, because the seeds were difficult to find

Bambara groundnuts are normally planted only in home gardens, by a few Javanese and Sundanese transmigrants. Usually only small amounts of land are devoted to this crop, and its purpose is home consumption. The market for this crop is undeveloped in Sitiung, since most of the indigenous communities, where the markets are centered, are completely unfamiliar with it. This, as well as the difficulty in getting seeds, may be the reason that farmers don't grow it in large quantities.

Although the local market for bambara groundnuts is limited now, the nutritional benefits of its cultivation make it an excellent home garden crop. Bambara groundnuts are a rich source of protein, carbohydrates and iron, and can substantially enhance the family's diet. They are also easy to harvest and prepare.

*2. Farmers' responses to treatments*

Most cooperator farmers readily recognized the usefulness of inorganic fertilizers, compost and barnyard manure. Many of them were curious when we introduced the use of fishpond sediment. They anticipated that it would not be very different from soil, and would require a lot of work to apply. Furthermore, only half of the cooperator farmers had fish ponds on their home gardens. Many farmers even preferred the control treatment to the sediment treatment. The farmer's practice of neither feeding their fish nor fertilizing their ponds (see the report, "A Survey of Small Fish ponds in the Sitiung Area") meant that the pond sediments were usually low in nutrients. This low nutrient content was reflected in low crop yields (Table 1).

At the time of this study, inorganic fertilizer was the most common soil amendment in Sitiung VC. This was primarily because the farmers did not have enough ruminants to supply large amounts of manure. Another important factor was that government's fertilizer recommendations focused almost exclusively on inorganic fertilizers. Despite not having a good source of manure, the farmers recognized its value. Manure use is very common on Java, where these farmers learned to farm.

Compost requires some work prior to application, and the farmers considered this treatment to be time-consuming. However, most of the farmers also believed that this amendment would be good for crops, in general. A few farmers prepared compost in a garbage well. Separating plastic and other non-weatherable materials, the farmers dumped garbage from the kitchen and from the home garden into the well to rot, and used it whenever they wanted it. It is impossible to produce a large amount of compost this way, so only a limited kind and number of crops can benefit from it.

In Sitiung IA, manure was used almost as widely

**Table 1. Effects of different sources of nutrients on chili and bambara groundnut production.**

| Treatment | Average yield, kg/ha* | |
|---|---|---|
| | Chili | Bambara nuts |
| Control | 860 b | 2900 c |
| Compost | 1677 a | 3860 b |
| Manure | 1883 a | 3810 b |
| Fertilizer | 1682 a | 4180 a |
| Fishpond sediment | 875 b | 2960 c |

*Average of thirteen replications, execept for the fishpond sediment treatment which is average of seven treatments. Note: Any two means having a common letter are not significantly different at the 5% level of significance using DMRT.

**Table 2. Farmers' preference for different sources of fertilizers.**

| Rank: number farmers preferring various treatments | | | | | |
|---|---|---|---|---|---|
| Treatment | 1st | 2nd | 3rd | 4th | 5th |
| Control | 0 | 0 | 0 | 11 | 2 |
| Compost | 2 | 1 | 9 | 0 | 0 |
| Manure | 6 | 5 | 2 | 0 | 0 |
| Fertilizer | 5 | 7 | 1 | 0 | 0 |
| F. Sediment | 0 | 0 | 0 | 2 | 3 |

as inorganic fertilizers. Manure might even surpass the popularity of purchased fertilizers there. Almost every family in Sitiung I had ruminant livestock. Manure, along with inorganic fertilizers, was often applied, particularly to paddy rice.

There were more trees in Sitiung I home gardens, probably because of longer residence. Selected kinds of trees in Sitiung I had also been fertilized with manure, dependent on its availability. Farmers have less open space and have devoted less attention to annual crop production. Trees, such as coconut, clove, jackfruit and coffee, dominated these home gardens. Part of each farmer's home garden was devoted to a stable for cattle and goats and, on some, a fishpond or two. Almost every farmer raised chickens. Sitiung I farmers showed less interest in compost than did Sitiung V farmers, saying that since they had manure, there was no need to bother with making compost.

Even if there are more fish ponds in Sitiung I, farmers still think applying the fishpond sediment would require a great deal of work. Although they occasionally dig out the fish ponds, the sludge is simply piled along the edge of the ponds. Coconuts and other trees grew along the edges of many fish ponds. Table 2 shows the farmers' ranking of the various treatments.

**Table 3. Summary of partial budget calculation for chili.***

| Treatment | Ay(kg/ha) | GB(Rp) | NB(Rp) | TCV(Rp) | MRR(%) |
|---|---|---|---|---|---|
| Control | 731 | 913,750 | 913,750 | 0 | - |
| F. sediment | 744 | 930,000 | 870,000 | 60,000 | d |
| Fertilizer | 1,430 | 1,787,500 | 1,726,500 | 61,000 | 1,332 |
| Manure | 1,601 | 2,001,250 | 1,885,250 | 116,000 | 288 |
| Compost | 1,425 | 1,781,250 | 1,583,250 | 198,000 | d |

*"d" in the column of MRR means dominated. A treatment is dominated when its TCV is higher but its NB is lower then another treatment.
Note: US $ 1 = Rp. 1,126. Ay = Adjusted yield; GB = Gross benefit; NB = Net benefit; TCV = Total cost that vary; MRR = Marginal rate of return.

**Table 4. Summary of partial budget calculation for bambara nuts.***

| Treatment | AY(kg/ha) | GB(Rp) | NB(Rp) | TCV(Rp) | MRR(%) |
|---|---|---|---|---|---|
| Control | 2,465 | 616,250 | 616,250 | 0 | - |
| Fertilizer | 3,553 | 888,250 | 856,250 | 32,000 | 750 |
| F. sediment | 2,516 | 629,000 | 569,000 | 60,000 | d |
| Manure | 3,293 | 823,250 | 707,250 | 116,000 | d |
| Compost | 3,281 | 820,250 | 622,250 | 198,000 | d |

*"d" in the column of MRR means dominated. A treatment is dominated when its TCV is higher but its NB is lower then another treatment.
Note: US $ 1 = Rp. 1,126. Ay = Adjusted yield; GB = Gross benefit; NB = Net benefit; TCV = Total cost that vary; MRR = Marginal rate of return.

3. *Crop response to treatments*

Statistical analysis in Table 1 shows that, for chili, manure, inorganic fertilizers, and compost gave significantly higher yield than either the fishpond sediment or the control. (Note: The fishpond sediment treatment had fewer replications than the others.)

For bambara groundnuts, inorganic fertilizers produced the highest yield of nuts. Compost and manure were not significantly different from each other, but they were significantly lower than inorganic fertilizers, and significantly higher than either the control or the fish-pond sludge.

4. *Economic realities*

Since there were significant effects of treatments on yields, the data is more meaningful if economic analysis is done in addition to statistical analysis. Tables 3 and 4 show the summary of partial budget analysis. Table 3 shows that for chili, inorganic fertilizer applications, at the rate applied in this treatment, gave a very promising MRR (1332%). This means that when we invest an additional Rp. 61,000 to apply the inorganic fertilizer, we receive 1332% x Rp. 61,000 more in addition to the Rp. 61,000 we invested. And if more money (Rp. 55,000) is invested to change inorganic fertilizer treatment to manure treatment, we will receive 288% x Rp. 55,000 more in addition to the Rp. 55,000.

From Table 4, it can be seen that inorganic fertilizer application was the only economically viable treatment (with MRR of 750%). Other treatments were dominated by this treatment. This means that additional money invested for other treatments did not give an increase in net benefits. However, long-term effects of fertilizer use versus organic-matter use on soils has not been studied.

**Conclusions**

Chili and bamoara ground nuts seem to be promising crops for cultivation on home gardens. These two crops gave significant responses to barnyard manure, compost and inorganic fertilizers at the rates applied in this trial. The application of fishpond sediment (from ponds with such low levels of management and at the rates of sludges applied) did not significantly improve yields over no soil amendment at all (the control treatment). Farmers also preferred the first three treatments over the other two.

**Implications**

From the view point of production only, manure, inorganic fertilizers and compost produced good yields from chili and bambara nuts. However, if cost-benefit is taken into account, we would not recommend these treatments equally. For chili, manure application was the most economical (assuming the minimum rate of return of 100%). Inorganic fertilizer application is still recommendable in cases of capital/labor shortage for manure. For bambara nuts inorganic fertilizers application was the most economical. Statistically, manure and compost treatments were significantly higher than control and fishpond-sediment treatments. However, since they required higher input and resulted in less net benefit than inorganic fertilizer application, these two treatments were not economical.

*Modification of Soil-Management Systems*

# Farmer Practice and Production

*Stacy Evensen, University of Hawaii*
*Carol J. P. Colfer, University of Hawaii*

Sitiung V is one of the newer settled areas within the 60,000 ha transmigration area of Sitiung. When this study began in April 1986, the village of Aur Jaya (Sitiung VC), chosen as site of this study, was three-and-a-half years old. Aur Jaya is an ethnically mixed village consisting of 255 households: 124 Sundanese (49%), 126 East Javanese (49%) and five Minang (2%).

The research conducted during this reporting period has been altered. Instead of three study sites, research has been conducted in one major location, Aur Jaya (Sitiung VC). The work plan was broadened to investigate farmer practices on their upland fields as well as on home gardens. This allowed for a more thorough study of the overall farming system.

## Objectives

The objectives of this study were 1) to characterize specifically the use and composition of crops grown in Aur Jaya home gardens; 2) to determine farmers' practices regarding use of crop residues, preparation of soil, use and application of fertilizer on both their home garden and upland field, and 3) to learn farmers' perceptions and beliefs regarding soil fertility and improvements.

## Procedures

Two aspects of this on-going study will be reported here: the characterization of home gardens, and soil and crop management practices. Using a purposive random sampling technique, eight families in Aur Jaya representing the three ethnic groups in the community were chosen for this study. Direct observation, structured interviews and drop-in visits were used to gather data. In addition, an inventory of perennial and annual (food) crops was compiled for each home garden and the garden areas specifically devoted to food crops were measured.

## Results

*1. Characterization of the home garden*

All Sitiung transmigrants received from the government a house on a 1/4 hectare lot to be used for a home garden in addition to a one hectare upland field parcel. The home gardens are, in most cases, fairly flat and, three-and-a-half years after clearing when this study began, still contain some large stumps and logs.

Previous researchers' observations indicate that, when the transmigrants first arrived their home gardens were the first areas to be cultivated. The government provided planting material for certain tree crops such as rambutan, coconut, jackfruit and citrus. These, along with government-provided vegetables such as eggplant, spinach ("bayem" and "kangkong"), longbeans and chili, were planted immediately to supplement families' diets during the initial settling-in period. Coffee, stinkbean and cloves were planted for economic benefit as soon as planting material became available. The first food crops to be planted in the home garden were maize, soybean, cassava and peanuts.

During the first two years food crops dominated home-garden plantings, and farmers relied heavily on this production for their family food (along with government subsidies of rice, oil and dried fish) (Colfer et al. 1985). Tree crops were still young and unproductive and farmers needed as much land as possible planted to food crops for sale and subsistence. Now, while the amount of home garden area still planted to food crops is considerable (see Table 1), perennial tree crops are becoming more important. Crops of economic importance are now, or soon will be, bearing: coffee, rambutan, citrus and sugarcane. In addition, pineapple, papaya, banana, guava, jackfruit and starfruit provide a continuous supply of food for home consumption and trade.

Generally, Aur Jaya home gardens are bordered by pineapple, jackfruit, silk-cotton tree, coconut and banana. Some leguminous trees (calliandra, gliricidia and sesbania) were observed along the borders but were by no means predominant. Aur Jaya is near a forest where firewood is plentiful, and farmers there have not yet received cattle or goats from the government. Farmers are quite aware of the usefulness of

legume tree crops as a green manure but their limited plantings have not been managed to produce in quantity. Farmers have also reported difficulty in obtaining planting material and are unfamiliar with some of the species of legume trees provided to them by the government. Therefore, while observed in most home gardens, leguminous trees appear to be under-utilized, except for leucaena, the pod of which is consumed.

Traditional home gardens may contain between 50-60 species of mostly fruit tree and vegetable crops (Brownrigg 1985). A census of the home gardens surveyed (Table 2) shows that a total of 46 species were represented, with no one garden containing more than 28 species. This crop census may slightly underestimate total species since census-takers were primarily concerned with annual food and perennial tree crops and may have overlooked spice or medicinal plants unless prominent. However, this lower diversity of plantings when compared to traditional home gardens was also pointed out by earlier research (Chapman 1984). Reasons for this might be the relatively short development period for these gardens, the scarcity of planting material for familiar crops or crops that do especially well in the Sitiung environment, and the need to concentrate efforts and space on food crops for sale.

Table 3 lists the composition of home-garden crops by the food group they represent. Looking at this from a nutritionist's perspective, it appears that the Aur Jaya home gardens should provide an adequate supply of major nutrients to the family diet. A variety of pulses such as peanut and soybean are planted which could supplement family protein, calcium and B vitamin intake. Vegetable crops and fruits are planted in what seem to be adequate amounts for providing a good supply of Vitamin A and Vitamin C. The presence of root crops (especially cassava) should supply a good, regular source of carbohydrate, an important nutrient for all people, but an especially important nutrient for these hard-working farmers. Unfortunately, due to the lack of

**Table 1. Home garden area planted to food crops (April 1986).**

| | Crop area, m² | | | | | | |
|---|---|---|---|---|---|---|---|
| Farmer | Soy | Peanut | Corn | Cassava | Mung | % Area unused* | Total area*** |
| A | 2104 | 443 | *** | *** | — | 30 | 1783 |
| B | 1488 | — | *** | *** | — | 10 | 1339 |
| C | 945 | — | *** | 260 | — | 20 | 965 |
| D | 1800 | — | *** | *** | — | 10 | 1620 |
| E | 1456 | — | 288 | *** | — | 10 | 1570 |
| F | 157 | — | 1823 | — | — | 10 | 1782 |
| G | no food crops grown | | | | | | |
| H | 258 | — | 70 | — | 630 | 5 | 910 |

* Estimate of the area within the measured food crop plots unplanted due to the presence of stumps or trees.

** Estimation of the amount of home garden space planted to food crops. With the exception of Farmer A, who has 3200 m², all remaining farmers have a total of 2500 m² available to them on their home garden lot. Of this total, an estimated 400 m² is taken up by the family house, bathing area and entrance/children's play area.

***Crop was intercropped with soy or peanut; no individual measurements were taken of its area.

**Table 2. Crop census of selected home gardens in Aur Jaya.**

| Crop | Number of specific crops/trees planted per family* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | E. Javanese | | | | Sundanese | | | Min. | No. of | Avg. |
| | A | B | C | D | E | F | G | H | plants | |
| Avocado | — | — | — | — | — | — | — | 1 | 1 | — |
| Basil | — | — | — | — | — | 1 | — | | 1 | — |
| Banana | 17 | 2 | 10 | 20 | 5 | 8 | 16 | 15 | 93 | 12 |
| Calliandra | | | 6 | | | 1 | — | — | 7 | 1 |
| Cassava | • | • | • | • | • | • | • | • | • | — |
| Chayote | 1 | — | — | — | — | — | — | — | 1 | — |
| Chili | — | 3 | 3 | — | — | — | — | 10 | 19 | 2 |
| Citrus | 6 | 5 | 5 | — | 3 | 3 | 5 | 3 | 30 | 4 |
| Clove | 6 | 9 | 10 | — | 3 | 9 | 11 | 2 | 60 | 8 |
| Coconut | 11 | 6 | 8 | 6 | 6 | 12 | 13 | 8 | 70 | 9 |
| Coffee | 79 | 69 | 54 | 42 | 18 | 76 | 14 | 150 | 502 | 63 |
| Corn | • | — | • | • | • | • | — | • | • | — |
| Crotolaria | — | — | — | — | • | — | — | — | • | — |
| Duku | — | — | — | — | — | — | — | 3 | 3 | — |
| Durian | — | — | — | — | 1 | — | 4 | — | 5 | — |
| Eggplant | — | 5 | — | — | — | — | — | 8 | 13 | 2 |
| Embacang | — | — | — | — | — | — | — | 4 | 4 | — |
| Ginger | 1 | — | — | 1 | — | — | 1 | 2 | 5 | — |
| Guava | 3 | 2 | 13 | — | 3 | 7 | 7 | 2 | 37 | 5 |
| Hyacinth bean | — | — | — | 1 | — | — | — | — | 1 | — |
| Jackfruit | 16 | 16 | 25 | 20 | 17 | 28 | 28 | 32 | 182 | 23 |
| Katuk | — | — | 6 | — | — | 12 | — | — | 18 | 2 |
| Kunyit | 1 | — | — | — | — | — | — | — | 1 | — |
| Laos | 1 | — | — | 2 | — | — | — | 1 | 4 | — |
| Lemongrass | 1 | — | — | 1 | — | 1 | — | 1 | 4 | — |
| Leucaena | — | 1 | 15 | 21 | 5 | 9 | — | — | 51 | 6 |
| Long bean | • | — | — | — | — | — | — | — | • | — |
| Mango | — | — | — | — | 2 | 3 | 4 | — | 9 | 1 |
| Mung bean | — | — | — | — | — | — | — | • | • | — |
| Papaya | 16 | 2 | 16 | 7 | 6 | 17 | 7 | 6 | 77 | 10 |
| Peanut | • | — | — | — | — | • | — | — | • | — |
| Pigeon pea | — | — | — | — | • | — | — | — | • | — |
| Pineapple | • | • | • | • | • | • | • | • | • | — |
| Rambutan | 5 | 17 | 7 | — | 14 | 5 | 23 | 12 | 83 | 10 |
| Sesbania | 2 | — | — | — | — | — | — | — | 2 | — |
| Silkcotton tree | 2 | 3 | 2 | 4 | 1 | — | 4 | — | 16 | 2 |
| Soursop | 4 | 2 | 5 | 2 | — | 4 | — | — | 17 | 2 |
| Soybean | • | • | • | • | • | • | — | • | • | — |
| Spanish plum | — | — | — | — | — | 1 | — | — | 1 | — |
| Starfruit | — | — | — | — | 1 | — | 4 | — | 5 | — |
| Stinkbean | 8 | 7 | 16 | — | 3 | 1 | 8 | 20 | 63 | 8 |
| Sugarcane | 15 | — | — | 4 | 3 | 1 | 1 | >100 | NA | — |
| Swamp cabbage | — | — | • | — | — | • | — | — | • | — |
| Sweet potato | • | • | • | — | — | — | — | • | • | — |
| Tamarind | 1 | — | — | — | — | — | — | — | 1 | — |
| Taro | 3 | — | — | — | — | — | — | — | 3 | — |
| Species/farmer | 28 | 19 | 22 | 17 | 22 | 25 | 19 | 24 | 22 | |

* An area planted; individual plants not counted.
— No data collected.
NA = Not applicable.

productivity of some of the fruit trees (with the exception of nutrient-rich papaya), the choice (eggplant versus a green leafy vegetable), quantity (a few plants versus enough for daily consumption), and the fact that home-garden produce may be sold rather than consumed, the home garden may not be meeting the nutritional needs of the Aur Jaya families.

Most of the fruit produced in the home garden is eaten, often by children, or traded with neighbors. Most of the food crops, however, are sold or saved for seed. Very little is consumed by the family. This observation is contrary to what has been observed by other researchers and warrants additional investigation. In order to more closely observe home-garden production, a record-keeping system has begun.

Vegetable production in Aur Jaya seems remarkably limited. Aside from the ever-present cassava leaves and jackfruit, only scattered small patches of swamp cabbage, eggplant, long bean and other "traditional" home-garden crops were seen. The fact that nutrient contribution from vegetables, especially green leafy vegetables, is important for family health, coupled with the fact that their production appears limited, indicates that a more intensive investigation of family food production and consumption should be pursued.

**Conclusions**

Home gardens in Aur Jaya have less diversity of plantings than do traditional home gardens. This may be understandable given the short time they've had to develop. These gardens are still in transition. The earlier home gardens consisted primarily of food crops and young fruit trees. Over time fruit and other tree crops (coffee, rambutan, jackfruit, citrus, papaya) have become more important in terms of providing food and cash income to the farm family. As these trees grow, space available for planting food crops is becoming more limited. Even so, farmers still depend heavily on home-garden food crops for cash income. The "traditional" use of home gardens as chiefly for family consumption and secondarily for sale or barter is not borne out by observations of Aur Jaya home gardens. The opposite seems true. Except in the case of fruit and some vegetables, the remainder of home-garden produce is sold or saved for seed. Even crops such as cassava root and jackfruit will be sold when a market is available. When asked to identify the role of each farmer's home garden, the most frequent responses were "for the future," "for my grandchildren" and "for perennial tree crops," all indicating an economic benefit rather than a subsistence role. The nature of home

**Table 3. Composition of home garden crops by food group or use.**

| Farmer/Ethnic. | Number of species of each type of crop | | | | | | |
|---|---|---|---|---|---|---|---|
| | Tree* | Condiment** | Coffee | Oil | Fruit | Pulse & veg | Root crop*** |
| A - E. Java | 2 | 6 | 1 | 1 | 8 | 6 | 3 |
| B - E. Java | 2 | 2 | 1 | 1 | 8 | 3 | 2 |
| C - E. Java | 3 | 2 | 1 | 1 | 7 | 5 | 2 |
| D - E. Java | 2 | 4 | 1 | 1 | 5 | 3 | 1 |
| E - Sundanese | 3 | 2 | 1 | 1 | 10 | 4 | 1 |
| F - Sundanese | 2 | 5 | 1 | 1 | 10 | 5 | 1 |
| G - Sundanese | 1 | 3 | 1 | 1 | 10 | 2 | 1 |
| H - Minang | — | 6 | 1 | 1 | 10 | 5 | 1 |

* Fuel/border trees = calliandra, leucaena, sesbania grandiflora, crotolaria, gliricidia and silk-cotton tree.
** Condiments = clove, tamarind, laos, lemongrass, basil, ginger, and sugarcane.
*** Root crops = cassava, sweet potato, and taro.
— No data available.

gardens in Aur Jaya seems to reflect the community's transition from a subsistence to a cash economy.

*2. Soil-management practices*

In a separate study, soil-management practices were documented. The methods of soil preparation used by farmers in Aur Jaya seem to be quite similar, differing only in frequency and intensity. Farmers begin their field preparation for planting by removing existing weeds and grasses. These are scraped away at the root level using a hoe and are either tossed to one side to rot, dried and burned or, in a few cases, allowed to dry on the soil surface, where they are then incorporated as a soil amendment.

After the soil has been cleared of weeds farmers may broadcast fertilizer depending on their perceptions of the soil's fertility and the time of the year. Farmers often determine soil fertility by looking at the color of the soil--"yellow" or "red" soil is infertile and may warrant an application of fertilizer. The previous yield is also an indicator of soil fertility. Farmers also observe weed growth throughout their fields--sparse weed growth may indicate an infertile patch and often farmers will give a spot application of fertilizer to these small areas.

Farmers view consistent rain as a key factor in increasing the availability of fertilizer. All farmers interviewed during the end of the dry season reported that, although they had already planted their crop, they would wait until the rains came before adding fertilizer. Farmers feel that the rains are necessary to "bring down" the fertilizer so it is available to the roots. Without the rain, farmers said the fertilizer would just be "evaporated" from the surface by the sun. The most commonly used fertilizers are TSP and urea, usually mixed and applied together. Lime is usually applied in larger quantities every one to two years, and is broadcast sparingly at other times.

Another reason mentioned for adding fertilizer after planting rather than before is that, if given after crops are well established (after four to six weeks), their roots will be large enough to absorb and utilize the nutrients from the fertilizer. Before that time roots are too small to take advantage of the fertilizer application and fertilizer given at that time would be wasted. These perceptions may indicate that farmers feel fertilizers have only a short-term benefit and that, due to the limited access to inputs in Aur Jaya, wise farmers are those who can maximize fertilization by effective timing of application. This is borne out by the observed high frequency (although not necessarily high rate) of fertilizer use among these farmers. Fertilizer is given at least once during each planting cycle--either before hoeing or after sprouting to be incorporated into the soil during weeding--and sometimes more often if, for instance, a farmer feels the crop is lacking in a specific nutrient as suggested by crop growth or leaf color.

If fertilizer is applied after the field is cleared of weeds it is generally incorporated into the soil during hoeing. There are no cows or plows in Aur Jaya so hoeing is the only method of soil cultivation used there. The depth of hoeing varies among farmers, averaging 15 cm deep, with a range of 10 - 30 cm. A few farmers said they hoed two times, describing a process that resembles "double digging." This involves hoeing once to hoe-depth, pulling back the soil. The area is then hoed a second time, enabling the farmer to reach much farther down and, if adding fertilizer at this time, to incorporate it at a much greater depth. Since this is a very labor-intensive process, and labor is a major constraint for these farmers, it must be assumed that farmers who practice deep digging are really quite rare.

Crop residues, and other organic matter such as ash, compost and leaf matter, are also incorporated into the soil during hoeing. All farmers use their crop residues in some way. Soybean and peanut residue is usually allowed to rot on the soil surface and is incorporated into the soil during hoeing. Sometimes the soybean residue will be burned first and the ash incorporated instead. Corn and rice residue are too dense to be buried easily and are generally burned first. Some farmers bring residues home from their upland fields and compost this with other material such as kitchen waste. This usually entails piling crop residue, leaf litter and kitchen waste into a hole. This mixture is allowed to rot and is infrequently turned if at all. While most farmers recognize the benefits of compost, many view it as too labor-intensive. It is the rare farmer who will haul crop residue to the home, make compost and haul it back to the family upland field. If compost is made at home it is generally used in the home garden, especially around fruit trees of economic value, as a mulch and soil amendment. It is also incorporated into the areas in the home garden to

be used for food crops.

After the soil has been cleared of weeds, the desired soil amendments added and the field hoed, plots are formed.

Most of the upland fields in Aur Jaya are sloping, some steeply. Farmers, therefore, fashion large terraced plots with drainage canals on these sloping fields to accommodate rain run-off and prevent erosion. A few farmers, in anticipation of the government promise to provide them with cows, have planted forage grasses along the contours of their sloping fields.

Farmers rarely plant just one crop in their field or home garden during any given planting season. Usually two to four crops such as soybean, peanut, cassava, corn and rice (in the wet season) will be planted. These will be arranged in a checkerboard fashion, with corn and cassava always planted along contours or terraces at a spacing of between 50 - 100 cm between plants and 2 - 5 m between rows.

The timing of planting is seen by farmers as critical and they are very much in tune with what their immediate neighbors are planting. Farmers feel that if they lag too far behind their neighbors in planting soybean and rice they will likely have problems with insects and disease. The planting of peanuts seems to be less time-dependent although, in order to capture a better market price, farmers try to be among the first to plant this crop if possible.

The common way to plant crops is to use a dibble stick to make evenly spaced holes (20 - 25 cm apart) into which seeds are planted. The rate of seeds per hole varies depending on the crop, and the quantity and quality of seed available. Generally, two to three soybeans per hole, one to two peanut seeds, two to three corn seeds and between four and ten rice seeds are planted per hole. If the seed is small and/or of poor quality more seeds will be used. Sometimes farmers will add fertilizer (usually TSP) to the seed container so that it is mixed together with the seed and added during planting.This has been observed during rice and corn planting.

Once seeds are planted farmers will often cover the seeds with a small amount of soil by hand or by "sweeping" the newly planted area with a cassava branch causing soil to fall into the hole. The prevalence of free-roaming chickens in the area, especially around the home garden, makes this practice necessary. The only instance observed where seeds were not covered immediately by soil occurred during rice planting in the upland field. If the farmer thought rain would fall shortly, the holes were left uncovered to be filled in later by rain.

Approximately four to six weeks after planting (or longer depending on the availability of labor) these newly planted fields are weeded. This is done with a small hoe known as a *koret* (Javanese term). Fertilizer is often broadcast at this time and is incorporated into the soil as the koret scrapes the weeds from the surface.

When a crop is ready for harvest, the whole family gathers to assist. Soybeans are cut at their base and gathered into piles to be transported one to two kilometers home for processing. The leaves and stalks that remain after the grain is removed are either used in the home garden or returned to the upland field to rot on the field and be incorporated later. Peanuts, however, are generally pulled up, the peanuts removed in the field and the peanut residue left to rot on the soil surface. The peanuts are transported home by the sackfuls for processing. Corn is similarly cut down and the ripe ears removed in the field. Only the ears are brought home for processing. Rice is harvested and the grain removed in the field. The final cleaning and drying occurs at home.

**Conclusions**

The soil-management practices and perceptions reported here apply to both the home garden and upland field with one exception: Farmers tend to use more inputs in the upland field than in their home garden. The use of fertilizers and lime in the upland field is greater than that in the home garden whereas compost is used more frequently in the home garden. This greater use of inputs corresponds to the greater economic benefit farmers feel they derive from food crops in their upland fields. Indeed, the only crops in the home garden given fertilizer and lime seem to be the food crops that will be sold. Fruit trees and vegetables are given fertilizer infrequently, if at all. It is more likely that compost will be used on these crops.

The farming practices mentioned here apply to one village in Sitiung and, therefore, cannot at this time be considered representative of practices adhered to throughout Sitiung. However, since farmers tend to consult one another regarding best practices, and perform certain activities similarly,

these soil-management practices may represent a good general picture of farming activities in the Sitiung area.

### Implications

By identifying current farmer practices researchers can better tailor experimental design and specific technology development to the farmers' actual capabilities and constraints. Home gardens represent 20% of a farmers' total agricultural system but have not as yet been well characterized. Knowledge of the nature and management of this system will better enable researchers to develop technologies pertinent to the whole agricultural system.

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*Modification of Soil-Management Systems*

## A Survey of Small Fish Ponds

*Richard G. Dudley, University of Hawaii*
*Lizdang Hidayat, Centre for Soils Research*
*Carol J. Pierce Colfer, University of Hawaii*

Fish culture is widely practiced and popular throughout Indonesia. Almost 400,000 Indonesian households produce about 100,000 tons of fish from freshwater fish ponds.

In West Sumatra over 40,000 tons of fish are caught but most of this is from the ocean. However, about 6,000 tons (15 percent) are from freshwater aquaculture. In the inland areas, such as Sitiung, the importance of the freshwater captured or cultured fishes is considerable. Although marine fishes (mostly from Padang) are marketed near Sitiung, they are relatively expensive.

Statistics for the district of Sawahlunto-Sijunjung list a total fish catch of about 560 tons of which only 106 tons (18%) are from fish ponds or rice-field fish culture. The provincial fisheries service reports a gross estimate of per capita fish consumption at 9.6 kg per year or about half the national goal of 18 kg per year. Undoubtedly the consumption of fish in the Sitiung area is much lower. A recent report (Chapman 1984) indicated that slightly less than 50% of the survey households in Sitiung had "low" (less than 34 grams per day) protein consumption. Chapman suggested that increased fish consumption (among other things) could help to alleviate some potential nutritional problems.

Although fish production is relatively unimportant in the area, many small fish ponds have been built as a result of traditions brought from Java (especially among the Sundanese) and government programs. Most of these ponds are located near the house in the home garden, and as a consequence may become an integral part of the gardening/farming system. Often leftover food is thrown into the pond, wash water runs into the pond and pond water can be used for watering garden crops during dry periods. Pond mud is used by some as a soil additive as well.

This survey was undertaken to discover the relationship between current pond management practices

and the home farming system, and, in particular, to determine ways in which management of the home garden fishpond and sediment taken from it could be improved to optimize benefits to the farmers and their families. In general potential benefits are threefold: increased yields of fish to be eaten or sold, improved recycling of waste products from the garden and household, and use of pond water and mud (pond sediment) in the home garden.

### Objectives

The objectives of this study were 1) to determine the optimal uses of fish ponds and fishpond sediments in improving soils and crop production in home gardens, and 2) to determine realistic techniques for enhancing the integration of fish raising and other pond activities into the overall management of the home garden.

### Procedures

Ponds in Sitiung V and Sitiung I were surveyed. Included in the questionnaire were questions about the types of fish grown, fish feeds used, fertilizers used, size of the pond, age of the pond, uses of pond muds, and harvest patterns, amounts and uses. In addition, a sample of pond mud was taken from each pond. This sample was obtained by dragging a small can over the bottom of the pond in two or three places. In taking these samples we attempted to sample the surface sediment rather than the underlying soil. It would be this sediment ("lumpur") which would be removed from the ponds periodically. These grab samples were placed in a bucket and mixed. A sample of the resulting mixture was placed in a labeled soil sample bag. The samples were air dried and tested for extractable K, Ca, Mg, P and Al+H.

### Results

*1. Raising Fish*

General considerations:

Fish ponds can be managed in a multitude of ways. In general we can categorize pond management by the amounts of food and fertilizer added. Extensively managed ponds rely to a large extent on the natural productivity of the pond waters. At the other extreme, intensively managed ponds might receive many kilograms of fish food and fertilizer.

The complexity of pond management increases as food and fertilizer inputs increase, although usually fish output and profit also increase. With very intensive management, there is the potential for depleted oxygen and disease. Increased water flow can alleviate some of the problems by removing toxic substances (ammonia for example) and by bringing in oxygenated water. In situations where many fish are grown together in crowded tanks or raceways (or ponds), increased water flows are usually necessary. Thus, very intensive fish culture is generally carried out in flowing water. This requires substantial supplies of good water. Virtually all ponds in the Sitiung area would fall into the extensive category, but possibilities for intensification exist.

Most of the fishes grown in other parts of Indonesia can be grown in Sitiung, assuming fingerlings are available. The most common fishes found in Sitiung fish ponds are members of the introduced (from Africa) genus *Oreochromis* (formerly included in the genus *Tilapia*). The Mossambique tilapia (*Oreochromis mossambicus*), known locally as *mujair*, is very common both in natural waters and in ponds and it is likely that even if they were not stocked in the ponds they are present, having been introduced with the water or with other fingerlings. Mujair are rather prolific mouthbreeders (the female parent carries the eggs in her mouth and the young will take refuge there when frightened). In many ways mujair are a good pond fish. They reproduce readily, they eat algae of various sorts, especially planktonic and mud-surface diatoms, but will eat artificial foods too. In general they do not require high-protein foods, but will grow faster if given them. On the negative side, mujair will breed at a very small size and age (as little as six months) and can overpopulate a pond very rapidly with small fish. In the Sitiung area this may be more acceptable than in other places since small fish are eaten.

A close relative of mujair is the Nile tilapia (*Oreochromis niloticus*) locally called *nila*. This fish has been introduced by the fisheries department to improve the prospects of tilapia culture. Research has shown that nila will grow larger before it spawns compared to mujair, and it has a better growth rate as well. Otherwise the two fishes are very similar and are easily grown under adverse circumstances. The two species are not easy to tell apart (although the

farmers may believe they can) and they interbreed readily. If true nila are available, they would be the tilapia of choice for pond culture. Unfortunately it is likely that the nila in this area are not a pure strain. This reduces the benefits of using nila rather than mujair. The crossbreeding of these two species is an item of concern in the Philippines as well (Marcarianas et al. 1985).

Although widespread, these two species are not particularly popular in Indonesia. However, they are probably the most easily grown, especially in the type of ponds found in Sitiung, and are very popular in other parts of the world. In fact the Pond Management CRSP selected *Oreochromis niloticus* as the species to work with at all its locations around the world.

*Ikan mas* (*Cyprinus carpio* or common carp) seem to be the species which most residents of Sitiung would like to grow. Ikan mas is easily grown but the techniques for spawning the fish and raising the young are a bit more complicated than that for mujair or nila. Also ponds are somewhat more successful if there is some water flow. Ikan mas can be grown in ponds if the fry (seed) are available.

At present ikan mas seed are obtained from areas distant from Sitiung. Ikan mas eats a variety of bottom fauna and occasional plant material. It can be grown on artificial feed as well. Although ikan mas can be grown in Sitiung ponds, it is not the best fish for this purpose.

*Ikan lele* (*Clarius batrachus*, walking catfish) is not very common in Sitiung fish ponds at present, but may be growing in importance. Ikan lele is both popular and suited to the conditions in Sitiung fish ponds. Because of special modifications of the gill arches, ikan Lele is able to breathe air and is not dependent on good water quality for oxygen. In fact, ikan lele can live out of water for up to eight hours. Ikan lele is a bit harder to breed in ponds than mujair and nila, but the techniques are well within the abilities of most Sitiung pond owners. Reasonably cheap and simple manuals describing these methods in Indonesian are available (for example: Mudjiman 1984). It is likely that as initial seed stocks of ikan lele become available in the Sitiung area this species will be grown in more ponds.

Like the above species, ikan lele can be grown using naturally occurring foods, but also responds well to added foods and fertilizers.

Another fish which is not present in Sitiung, but is often referred to in popular fish-culture articles around the world, is the grass carp (*Ctenopharyngodon idella*). This fish is a fast-growing herbivore that reaches 40 kg and could be grown in areas where abundant vegetation is available. It would not be recommended for Sitiung ponds, but would be ideal for controlling vegetation in local irrigation canals. The grass carp is relatively hard to breed and would require a hatchery source for fingerlings (seed).

The local situation and fish culture practices:

Fish ponds examined within the transmigration areas had an average size of about 75 square meters but ranged from 12 to 600 m$^2$. While the average size is small by western standards, and by commercial fish culture standards, they are large enough to successfully grow fishes, particularly tilapia (mujair or nila) and walking catfish (lele). However, the amount of fish produced under average to good conditions will not exceed 0.3 kg per m$^2$ per year. Thus a 10 m x 10 m pond can only produce 30 kg at best, or about 6 kg per capita per year (for a family of five). Sales from such a fish harvest could conceivably bring the family 45,000 rupiah if all the fish were sold and the marketing problems were overcome (both unlikely). Nevertheless, that would be a substantial amount of money, given the nominal costs of most of the pond operations.

In many ponds in Sitiung limited water availability is a serious barrier to fish-pond construction. Many fish ponds built there rely on rain for the water supply. Because our survey was directed at "successful" fish ponds the data do not reveal a number of dry "more or less" fish ponds in the area. Some farmers were attempting to grow fish in ponds that had water for only part of the year.

In very few cases did the pond owners have an accurate idea of what was added to the pond or what amount of fish was taken out. Reported harvests ranged from 530 to 15000 kg/ha/year. The upper end of this reported range is clearly impossible under pond conditions in Sitiung. Values in excess of 3000 kg/ha/yr (30 kg/100 m$^2$/yr) would be very unusual. However, most information for Sitiung ponds falls within a more realistic range (Figure 1). Under ideal conditions perhaps 4000 kg/ha/year would be a

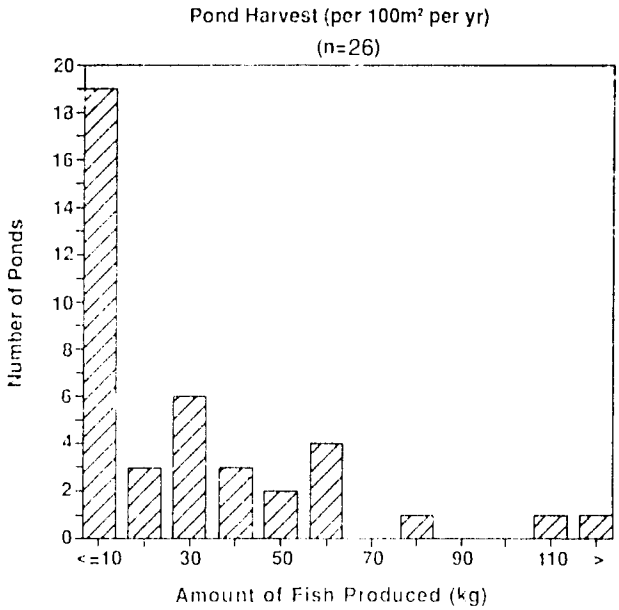


**Figure 1. Pond harvest per 100 m² per year. Estimation from farmers. Number of ponds vs. kg of harvest. Numbers on the X axis indicate the upper**

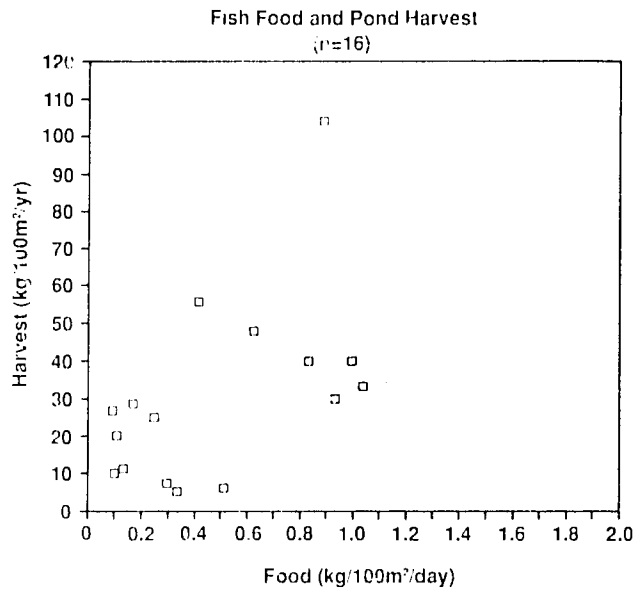


**Figure 2. Fish food and pond harvest. Y-axis: harvest per 100 m² per year. X-axis: fish food added**

realistic target if the pond were well managed. Special techniques and better water supplies might allow higher harvests, but will not be available.

About two-thirds of Sitiung pond owners fed some sort of food to their fish. The most common foods were rice bran (dedak) and leftover food from the house. Rates of addition of food to the ponds ranged from zero to almost 7 kg/day/100 m². The relation of the feeding rate to reported harvest, for 22 ponds where both feeding rate and harvest information were given by the farmer, are shown in Figure 2. (Two outlying points were omitted: one at a feeding rate of 4 kg/100 m²/day and another at a harvest rate of 150 kg/100m²). The relationship between feeding rate and harvest is not a strong one for several reasons. The data for both variables is approximate at best. Also other factors affect the harvest, but are only imperfectly known from these ponds. For example some ponds are built on what was previously flooded rice (sawah) while others are built on upland areas. Previous agricultural treatments may affect later pond production. Also agricultural practices on surrounding lands are likely to affect fish production.

Surprisingly, very few of the ponds surveyed received fertilizer. Urea has been applied to five of the ponds, and only two received manure as fish food (a few others received an initial application of manure when the pond was new). This is unusual in that manure is readily available and is a useful additive for this type of pond. A partial explanation for this is that farmers in Sitiung V, where most of the ponds were surveyed, did not yet have cattle. Manure has been found to be extremely useful for growing tilapia, and several appropriate technologies are available for using livestock wastes in fish ponds (e.g. Pullin and Shehadeh 1980). These include the growing of chickens in pens over fish ponds which is already practiced in parts of West Sumatra. While Sitiung pond owners do not have the financial resources to grow chickens in pens (which requires that the chickens be fed,) they could build the night roosting pens over one side of the fish pond.

*2. Pond Soils*

In Sitiung V, only five of 26 pond-owners had not used pond soils as a soil additive on crops (especially trees). Owners in Sitiung I seemed less likely to do so but the sample was small (only one of four had even tried using sediment). This difference, if it is real

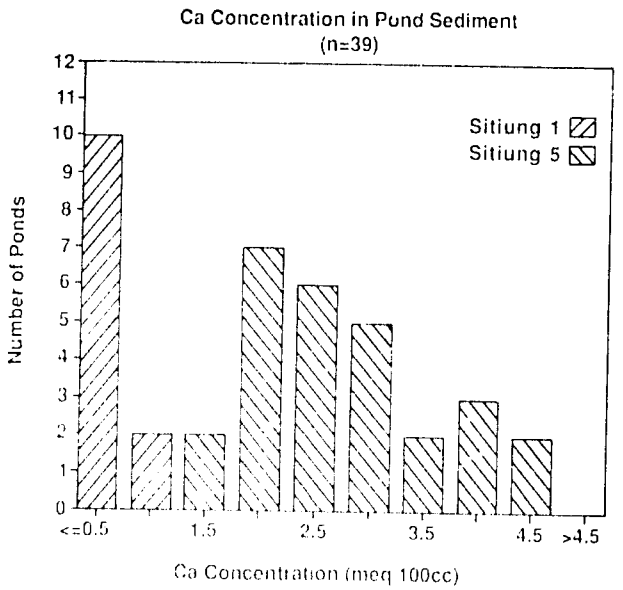


**Figure 3. Concentration of Ca in pond mud. Each bar shows the number of ponds which had mud**

may be due to the higher availability of animal manure in Sitiung I or could be due to the fact that more Sundanese live in Sitiung V and are familiar with the use of pond mud as a soil additive.

A summary of the analysis of sediments from 39 ponds is given in Table 1. Several factors may be expected to affect the sediment nutrient levels. Some of these are: age of the pond, amount of fertilizer and food added to the pond, growth and sedimentation of nitrogen-fixing algae. In our survey, the amount of food added to each pond did not seem to have any bearing on the amount of Ca, K or P in the pond sediment (Figures 3, 4 nd 5). Presumably at higher food inputs over longer periods a positive relationship would be apparent. The span of pond ages in our survey is insufficient to examine the effect of this variable. The ponds in Sitiung V were less than two-and-one-half years old, and most in Sitiung I were less than five years old.

While several contributions to the chemistry of submerged (especially sawah) soils are available (De Datta 1981), these are of limited use when discussing the use of fish-pond sediment. This is because the reactions taking place in the reduced environment of

**Table 1. Summary of pond sediment data from 39 small fishponds in Sitiung V and Sitiung I. P concentration in ppm, others in meq/100 cc.**

| | Al+H | Ca | Mg | K | P | Al sat |
|---|---|---|---|---|---|---|
| Sitiung V | | | | | | |
| | 0.13 | 4.31 | 0.94 | 0.65 | 27 | 0.02 |
| | 0.18 | 3.14 | 0.93 | 0.39 | 11 | 0.04 |
| | 0.58 | 1.57 | 0.39 | 0.24 | 7 | 0.21 |
| | 0.31 | 2.57 | 0.43 | 0.39 | 9 | 0.08 |
| | 0.58 | 2.00 | 0.41 | 0.30 | 13 | 0.18 |
| | 0.27 | 3.00 | 0.47 | 0.33 | 13 | 0.07 |
| | 0.27 | 1.86 | 0.50 | 0.43 | 10 | 0.09 |
| | 0.18 | 3.00 | 0.75 | 0.41 | 9 | 0.04 |
| | 0.40 | 2.29 | 0.67 | 0.33 | 19 | 0.11 |
| | 0.22 | 2.57 | 0.68 | 0.56 | 9 | 0.05 |
| | 0.62 | 2.14 | 0.53 | 0.19 | 9 | 0.18 |
| | 0.67 | 2.43 | 0.54 | 0.22 | 9 | 0.17 |
| | 0.67 | 1.57 | 0.45 | 0.23 | 9 | 0.23 |
| | 0.13 | 3.86 | 1.03 | 0.79 | 25 | 0.02 |
| | 0.13 | 3.29 | 0.83 | 0.56 | 25 | 0.03 |
| | 0.71 | 1.43 | 0.34 | 0.28 | 28 | 0.26 |
| | 0.18 | 1.86 | 0.45 | 0.33 | 4 | 0.06 |
| | 0.18 | 1.43 | 0.78 | 0.65 | 17 | 0.06 |
| | 0.18 | 2.29 | 0.86 | 0.39 | 14 | 0.05 |
| | 0.18 | 4.00 | 0.75 | 0.52 | 34 | 0.03 |
| | 0.13 | 2.71 | 0.65 | 0.45 | 7 | 0.03 |
| | 0.13 | 2.29 | 0.49 | 0.62 | 12 | 0.04 |
| | 0.13 | 2.43 | 0.45 | 0.43 | 6 | 0.04 |
| | 0.13 | 1.86 | 0.83 | 0.70 | 12 | 0.04 |
| | 0.09 | 4.05 | 0.43 | 0.54 | 31 | 0.02 |
| | 0.13 | 3.71 | 0.74 | 0.56 | 24 | 0.03 |
| | 0.13 | 1.71 | 0.60 | 0.59 | 12 | 0.04 |
| Sitiung I | | | | | | |
| | 0.73 | 0.24 | 0.74 | 0.37 | 5 | 0.35 |
| | 0.13 | 0.66 | 0.75 | 0.55 | 82 | 0.06 |
| | 0.69 | 0.29 | 1.01 | 0.62 | 18 | 0.26 |
| | 0.52 | 0.27 | 0.95 | 0.56 | 11 | 0.23 |
| | 0.22 | 0.49 | 0.97 | 0.36 | 9 | 0.11 |
| | 0.60 | 0.50 | 0.96 | 0.41 | 4 | 0.24 |
| | 0.65 | 0.33 | 0.75 | 0.24 | 8 | 0.33 |
| | 0.34 | 0.30 | 1.06 | 0.67 | 30 | 0.14 |
| | 0.77 | 0.25 | 0.90 | 0.45 | 13 | 0.32 |
| | 0.65 | 0.39 | 1.09 | 0.39 | 5 | 0.26 |
| | 0.52 | 0.55 | 1.18 | 0.34 | 14 | 0.20 |
| | 1.81 | 0.25 | 0.92 | 0.27 | 5 | 0.56 |
| n | 39 | 39 | 39 | 39 | 39 | 39 |
| sum | 15.27 | 73.89 | 28.20 | 17.31 | 609 | 5.28 |
| mean | 0.39 | 1.89 | 0.72 | 0.44 | 16 | 0.14 |
| var | 0.105 | 1.519 | 0.052 | 0.023 | 181.8 | 0.015 |
| Sitiung V Only | | | | | | |
| n | 27 | 27 | 27 | 27 | 27 | 27 |
| sum | 7.64 | 69.37 | 16.92 | 12.08 | 405 | 2.21 |
| mean | 0.28 | 2.57 | 0.63 | 0.45 | 15 | 0.08 |
| var | 0.041 | 0.707 | 0.037 | 0.025 | 68.7 | 0.005 |
| Sitiung I Only | | | | | | |
| n | 12 | 12 | 12 | 12 | 12 | 12 |
| sum | 7.63 | 4.52 | 11.28 | 5.23 | 204 | 3.07 |
| mean | 0.64 | 0.38 | 0.94 | 0.44 | 17 | 0.26 |
| var | 0.163 | 0.018 | 0.018 | 0.017 | 433.5 | 0.016 |

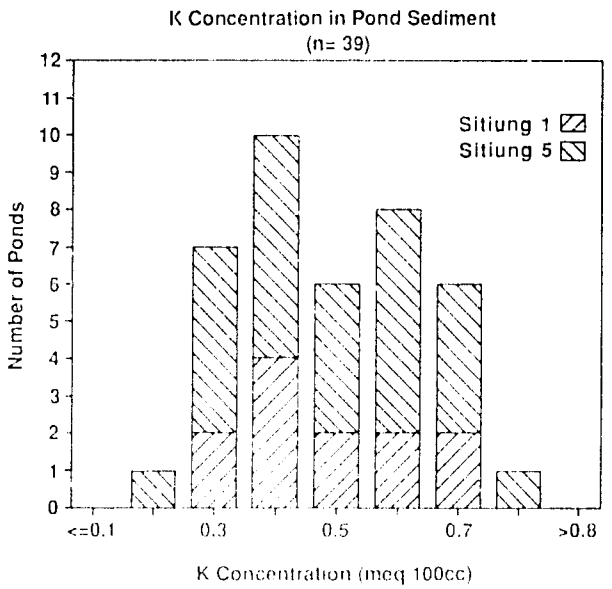


**Figure 4. Concentration of K in pond mud. Each bar shows the number of ponds which had mud with the indicated concentration of K.**

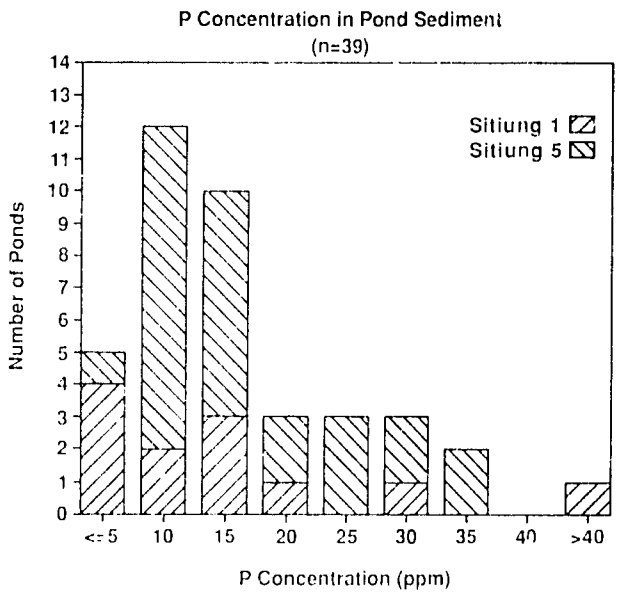


**Figure 5. Concentration of P in pond mud. Each bar shows the number of ponds which had mud with the indicated concentration of P.**

the bottom muds are all reversible when the muds are exposed to an oxidizing environment. A remaining question is if and how nutrients might accumulate in pond sediments other than through the addition of allochthonous material to the pond.

## Conclusions and Implications

If additional information on the origins of nutrients in pond sediments is desired, then additional data will have to be collected. It seems reasonable that pond sediments can be of some use at present, and would be of more use on crops if pond-management practices were intensified and additional foreign matter (food and fertilizer) were added to the ponds. It would be useful to have information about nitrogen (if it were lost through denitrification for example) and about micronutrients that may be needed on crops. It is unlikely that pond sediments will replace other fertilizer sources, or that pond fishes will become a major food item, but their integration into the home farming system may provide needed assistance to the small pond owner.

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# Improving and Sustaining Productivity in Farmers' Fields

One goal of soil science is to enable users of land resources to predict soil behavior and crop performance at any location, at any moment, for a wide range of agroclimatic conditions. This implies that soil behavior and, therefore, crop performance vary from place to place and from moment to moment. Soils behave in this way because the attributes that cause them to behave in a particular way vary simultaneously over space and time. It is this elusive and ever-changing quality of behavior-determining land qualities that has prevented soil scientists from applying their knowledge to predict soil behavior and crop performance.

Prediction of crop performance cannot be made on soil information alone. Prediction requires integration of soil, microbial, plant and atmospheric processes in a coherent fashion. This section provides examples of research on microbial (mycorrhizae) and chemical (phosphorus) processes, and prediction of crop performance based on crop-climate interactions.

The ultimate objective of these efforts is to enable users to predict the impact of soil-management practice on productivity and sustainability many years into the future.

# Matching Crop Requirements Of Rice, Maize, Soybean and Peanut to Soil Characteristics With Crop Simulation Models

*Goro Uehara, University of Hawaii*
*Li-Ling Lin, University of Hawaii*

As reported last year, crop models for rice and two grain legumes, soybean and peanut, will be used with data sets obtained in both Hawaii and Sitiung. However, due to personnel changes on site in Sitiung, data sets for rice were not available. Experiments with peanut and soybean to collect the standard minimum data sets were delayed. Data sets for rice from experiments planted in Hawaii are reported herein.

## Objectives

The objectives of this study were 1) to identify the minimum soil, crop, and weather data needed to predict the performance of rice, maize, soybean and peanut cultivars in the humid tropics; 2) to test, validate and modify existing rice, maize, soybean and peanut simulation models using the minimum data set; and 3) to use rice, maize, soybean and peanut simulation models as screening devices for varietal testing.

## Procedures

The minimum data set identified in the previous annual report (*TropSoils Technical Report, 1985-1986*) was used for the experiments with rice. Tables 1 and 2 list the growth stages and component harvest codes that are used to complete the minimum data set for crop phenology. Dates of 50% emergence, 50% of main tillers with three collared leaves, 50% anthesis, and physiological maturity are recorded as part of the minimum data set.

Experiments with five rice cultivars grown in both lowland and upland conditions were planted over two seasons at the Wailua Experiment Station on the island of Kauai. The upland experiment was planted by direct seeding while the lowland was planted with transplanted rice seedlings. The seedlings were planted at the same time as the direct seeded upland trial.

## Results

The number of days after planting to emergence, panicle initiation, heading and physiological maturity for five rice varieties are shown in Table 1. It is evident from the data that soil-management practices, such as nitrogen fertilization, that depend on timing with phenological events for best results will be affected by cultivar and date of planting. Through trial and error, a farmer will eventually find the optimum time to fertilize, irrigate or prepare for the next crop. The farmer may be reluctant to give up a familiar cultivar for a promising new one because his trial-and-error knowledge is not likely to apply to the new cultivar. A crop model that predicts phenological events for different cultivars, dates of planting and location can assist farmers in their soil- and crop-management practices to the phenological characteristics of a new cultivar.

The minimum soil, weather and crop data to simulate the results in Table 1 also have been collected. Comparison of the observed and simulated results will be completed soon.

The grain yield and straw weight expressed in

**Table 1. Observed phenological events of five rice varieties planted in two seasons.**

| Variety | Days after planting: Emergence | Panicle initiation | Heading | Physiolog. maturity |
|---|---|---|---|---|
| | | (1985 Winter) | | |
| Bellemont | 5 | 43 | 79 | 118 |
| IR-36 | 5 | 52 | 89 | 129 |
| K-C-A | 5 | 48 | 85 | 122 |
| Labelle | 5 | 42 | 78 | 117 |
| Starbonnet | 5 | 61 | 103 | 142 |
| | | (1986 Summer) | | |
| Bellemont | 4 | 45 | 76 | 105 |
| IR-36 | 5 | 59 | 91 | 121 |
| K-C-A | 5 | 53 | 85 | 113 |
| Labelle | 4 | 43 | 75 | 104 |
| Starbonnet | 4 | 61 | 94 | 123 |

Planting date: 09/05/85
Planting date: 06/10/86

gm/m for five rice cultivars grown under upland and lowland (flooded) conditions in the winter of 1985 and summer of 1986 are shown in Table 2. The genotype by environment interaction is even more pronounced when grain yields rather than phenological events are used as an index. Although soil-management inputs were kept high for this experiment, it is clear that the economic optimum would vary with cultivar, date of planting and location.

The soil, weather and genetic information needed to simulate the results shown in Table 2 has been collected. A comparison of observed and simulated results will be available soon.

## Conclusions

The model has been calibrated and validated for simulating and predicting the date of emergence, panicle initiation and physiological maturity after planting. It can do so for any location where maximum and minimum air temperature and solar radiation data are available. The model is sensitive to day length, and this information can be obtained from latitude and day of the year.

## Implications

In West Sumatra, where rice is grown from warm lowlands as in Sitiung to high uplands as in Sukarami, the development rate of rice varies considerably over short distances. This research enables users to predict important phenological events of rice cultivars at any location and date of planting without benefit of trial-and-error field experiments, so that rice cultivars suited to each location can be identified with relative ease.

Table 2. Final harvest of five rice varieties in Wailus Rice.

| | | Experimental field | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Grain yield | | Straw weight | | Total above biomass | | Grain/straw ratio | |
| | | gm/m² | | | | | | | |
| Variety | Year | Upland | Lowland | Upland | Lowland | Upland | Lowland | Upland | Lowland |
| Bellemont | 1985 | 351.3 | 301.3 | 568.8 | 794.4 | 920.1 | 1098.7 | 0.6 | 0.4 |
| | 1986 | 360.0 | 835.9 | 471.9 | 728.0 | 832.0 | 1563.9 | 0.8 | 1.2 |
| Labelle | 1985 | 174.2 | 128.9 | 743.3 | 995.9 | 917.4 | 1124.8 | 0.2 | 0.1 |
| | 1986 | 315.3 | 1048.7 | 532.2 | 1389.2 | 847.5 | 2438.0 | 0.6 | 0.8 |
| IR-36 | 1985 | 325.5 | 159.5 | 1073.8 | 1269.9 | 1399.4 | 1429.5 | 0.3 | 0.1 |
| | 1986 | 546.6 | 1006.3 | 635.2 | 1111.2 | 1181.8 | 2117.5 | 0.9 | 0.9 |
| K-C-A | 1985 | 496.3 | 306.8 | 904.8 | 892.6 | 1401.1 | 1199.4 | 0.6 | 0.3 |
| | 1986 | 667.0 | 1351.9 | 693.4 | 1312.7 | 1360.4 | 2664.6 | 1.0 | 1.0 |
| Starbonnet | 1985 | 11.5 | 11.4 | 1530.9 | 1975.1 | 1542.4 | 1986.5 | 0.0 | 0.0 |
| | 1986 | 227.2 | 1070.4 | 721.5 | 1301.5 | 948.7 | 2371.9 | 0.3 | 0.8 |

# Assessing Field Inoculation With Introduced and Indigenous VA Mycorrhizal Inocula by Crop Growth and Yield on Soil Cleared Of Tropical Rain Forest

## *Effect of VA Mycorrhizal Species On Tolerance to Soil Acidity*

*Ruey S. Huang, University of Hawaii*
*Russell S. Yost, University of Hawaii*
*Nguyen V. Hue, University of Hawaii*
*Chung Shih Tang, University of Hawaii*

Growth-limiting factors in tropical agricultural systems that have been associated with the "acid soil infertility" complex include toxicities of Al and Mn and deficiencies of certain essential elements such as P, K, Ca, Mg and Mo (Adams 1984). The correction of these Al and Mn toxicities by liming the soil is not always economically feasible in the high-leaching tropical soils. Plant species and varieties within species are known to differ widely in their tolerance to these factors, and some of these differences are genetically controlled, particularly in the tropical-pasture legumes. Differential tolerance of tropical legumes to aluminum and manganese has been demonstrated by Andrew (1978).

The genus *Desmodium* provides a number of species and cultivars that are being used for improving pastures in both wet and semiarid tropical regions (Burt et al. 1983). For instance, there has been recent interest in *D. ovalifolium* because of its good adaptation to the highly weathered acid soils of the tropics and its persistence under grazing (Grof 1982 and 1984). Hence, a viable approach to the problem of acid soil infertility is to select plants with greater tolerance to excess Al and/or Mn in acid tropical soils.

Nutrient deficiencies in infertile soils can be overcome by use of fertilizers or VA mycorrhizal inoculation. It is now well established that many plants form mycorrhizal associations that result in increased uptake of phosphorus from soils low in this element, and uptakes of other nutrients also have been reported to be enhanced (Harley and Smith 1983). However, little work has been done on the assessment of possible interactions through systematic multiple-variable studies on a range of representative combinations of liming, P fertilization, soil, VA mycorrhizal fungus and plant type.

### Objectives

The objectives were 1) to examine the liming, P fertilization and VA mycorrhizae effects on growth responses of *Desmodium* species in a Al-toxic soil; 2) to evaluate the beneficial effects of VA mycorrhizae interactions with soil liming on two *Desmodium* species on two acidic soils; 3) to compare the acquisition of Mn from soils between two *Desmodium* species.

### Procedures

The Paaloa soils are upland soils between the Schofield Plateau and Koolau Range on Oahu Island, Hawaii. These soils are found at altitudes of 300 to 520 m and with an annual rainfall of 1750 to 2250 mm/year. The annual rainfall is so high that Mn apparently leaches from topsoils because total soil Mn content only 0.10%. Because the soil pH is also low (about 4.2), Paaloa soils have greater Al solubility, extracted by 0.02 M $CaCl_2$ solution (Hoyt and Webber 1974), than Wahiawa soils (Table 1). In contrast, the moisture regime of the Wahiawa soils is characterized by alternate wet (November to April) and dry (May to October) periods. This alternation facilitates remobilization and reprecipitation of Mn. Manganiferous soil concretions have been located in the Wahiawa soils (Sherman et al. 1949; Glasby et al. 1979), and their total Mn content is as high as 1.5%.

In the first experiment four factors (*Desmodium* species, mycorrhizae, soil types and soil pH) were compared. Seedlings of two *Desmodium* species were transplanted into plastic pots which contained 4.7 kg of soil per pot. Samples of Paaloa (Humoxic Tropohumult) and Wahiawa (Tropeptic Eutrustox) soils, used in this experiment, were collected, sieved and fumigated. Powdered reagent-grade $CaCO_3$ was added in increments (0, 2, 4 and 6 meq per 100 g of soil) so that soil pH was raised to the level suggested for reducing soil toxicities of Al and Mn. Soil P was amended with $KH_2PO_4$ to provide 0.06 mg/L P in solution, extracted with 0.01 M $CaCl_2$ solution. There were three replications of the treatments, which were arranged in a split-plot design. Plants were harvested

42 days after transplanting.

In the second experiment four factors (*Desmodium* species, mycorrhizae, soil pH and soil P) were compared. *Desmodium intortum* and *D. ovalifolium* seedlings with or without mycorrhizal treatments (inoculated with live or killed spores of *Glomus aggregatum* were transplanted into plastic pots which contained 1.9 kg of fumigated Paaloa soil per pot. Soil pH was adjusted with $CaCO_3$ to soil pH (1:1) of 4.25 and 5.42. Soil P was amended with $KH_2PO_4$ to provide 0.008, 0.052 and 0.840 mg/L P in solution, extracted with 0.01 M $CaCl_2$ solution. Potassium, sulfur, magnesium, boron, zinc, copper and molybdenum were added in amounts considered adequate for the plant requirements. There were three replications of the treatments, which were arranged in a split-plot design. Whole plot treatments, were mycorrhizae treatments in order to minimize cross-contamination. Plants were harvested 42 days after transplanting.

In the third experiment, seedlings of two *Desmodium* species were grown in plastic pots which contained 0.5 kg of soil with eight combinations of Paaloa and Wahiawa soils. By mixing these two soils with various ratios, ranges of total soil Mn content and Mn in soil solution were obtained. This approach was useful to compare Mn acquisition of two *Desmodium* species. There were four replications of the treatments, which were arranged in a randomized complete block design. Plants were harvested 36 days after transplanting.

Observation of the rhizospheric pH changes: *Desmodium* seedling roots were embedded into the bromocresol purple pH indicator-stained (0.06% agar medium had originally been adjusted to pH 7.2 (red color) for 15 hours.

Plant measurements: Shoot and root dry weights were determined at harvest. Mycorrhizae infection was determined at harvest by the Phillips and Hayman (1971) method. Nutrient concentration of plant shoot tissues was determined in ball-milled plant samples with an X-ray quantometer (Applied Research Laboratory Model 7-000).

## Results

### 1. *First experiment*

Chemical properties of the two soils are given in Table 1. The Paaloa soil contained higher Al and lower Mn than the Wahiawa soil. In contrast, the Wahiawa soil contained high levels of Mn and relatively low levels of Al. As expected application of lime reduced the levels of both Al and Mn in 0.02M $CaCl_2$ solution.

Plant growth was strongly influenced by both the

**Table 1. Soil chemical properties of samples of Paaloa and Wahiawa soils.**

| Soil | $CaCO_3$ added | Soil pH | Al in solution | Mn in solution |
|---|---|---|---|---|
| meq/100g of soil | | | ——mg/kg—— | |
| Wahiawa | 0 | 5.23 | 0.4 | 55.7 |
| | 2 | 5.49 | 0.2 | 20.4 |
| | 4 | 6.05 | 0.1 | 7.8 |
| | 6 | 6.45 | 0.1 | 1.2 |
| Paaloa | 0 | 4.27 | 5.7 | 1.6 |
| | 2 | 4.44 | 1.3 | 1.3 |
| | 4 | 4.78 | 0.4 | 0.1 |
| | 6 | 5.60 | 1.1 | 0.4 |

**Table 2. Shoot P concentrations of two *Desmodium* species grown in potted Wahiawa and Paaloa soils.**

| | | *Desmodium intortum* | | *Desmodium ovalifolium* | |
|---|---|---|---|---|---|
| Soil | Soil pH | Mycorrhizal inoculation | | | |
| | | + | - | + | - |
| | | Shoot P concentration (%) | | | |
| Paaloa | 4.27 | 0.14 | 0.06 | 0.11 | 0.04 |
| | 4.44 | 0.16 | 0.06 | 0.16 | 0.04 |
| | 4.78 | 0.16 | 0.07 | 0.16 | 0.04 |
| | 5.60 | 0.15 | 0.08 | 0.14 | 0.04 |
| | | Shoot P concentration (%) | | | |
| | 5.23 | 0.18 | 0.09 | 0.21 | 0.06 |
| | 5.49 | 0.21 | 0.13 | 0.23 | 0.06 |
| | 6.05 | 0.25 | 0.11 | 0.28 | 0.05 |
| | 6.45 | 0.27 | 0.10 | 0.25 | 0.05 |

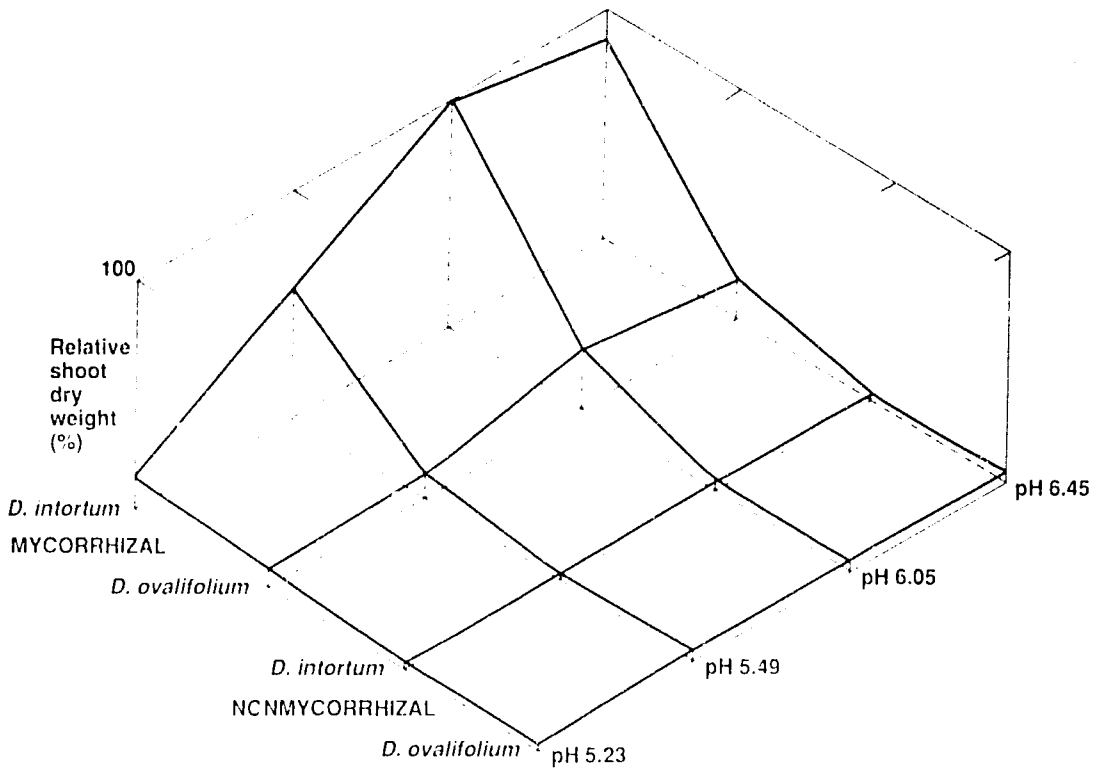


**Figure 1. Relative shoot growth response of two *Desmodium* species to mycorrhizal inoculation and soil pH in potted Wahiawa soil, where 100% = 19.54 g.**

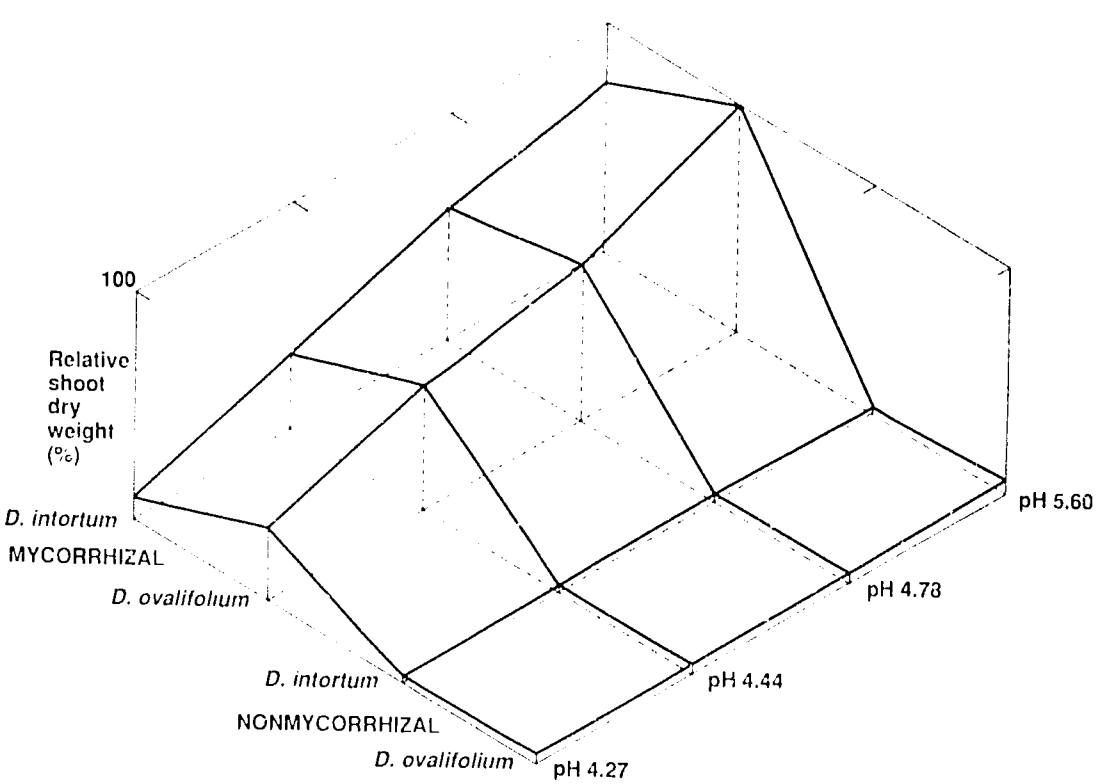


**Figure 2. Relative shoot growth response of two *Desmodium* species to mycorrhizal inoculation and soil pH in potted Paaloa soil, where 100% = 5.67 g.**

presence of mycorrhizae and soil acidity. As indicated in Figures 1 and 2, plants without mycorrhizal associations grew very poorly. Where mycorrhizae were absent, increasing levels of lime did not increase plant growth. This seems to be due to extreme P stress (Table 2).

Where mycorrhizae were present, plants responded 6 to 70 fold to application of lime depending on both soil and plant species. On the Wahiawa soil *D. intortum* grew larger than *D. ovalifolium*. As indicated in Table 3, response to lime on the Wahiawa soil is probably due to reduced Mn toxicity. Levels of Mn in foliar tissue ranged from 500 to 3000 mg/kg in *D. intortum* and from 1900 to 4800 in *D. ovalifolium*. Levels of Ca in tissue were also higher in *D. ovalifolium* than in *D. intortum*. Symptoms of Mn toxicity (leaf crinkling and chlorosis) disappeared in *D. intortum* at concentrations lower than 1000 mg/kg and at soil pH greater than 5.49. However, Mn toxicity symptoms were observed at all soil pH's (even at pH 6.45) in *D. ovalifolium*. Foliar concentrations of Mn remained high (1900 mg/kg) at this pH on Wahiawa soil.

In Paaloa soil, by contrast, growth of both plants increased as lime was applied and increased soil pH from 4.27 to 5.60. *D. ovalifolium*, however, grew larger than did *D. intortum* (Figure 2). Where soil pH was lowest (pH 4.27 and 4.44) *D. intortum* plants died four weeks after transplanting. Poor growth of this species was associated with lower shoot Ca concentration (Table 3)—a common symptom of Al toxicity.

*2. Second Experiment*

The two *Desmodium* legume species differed markedly in their growth responses to liming and P fertilization in Al-toxic Paaloa soil. Under low to medium soil P conditions, growth of both mycorrhizal *Desmodium* species greatly increased as soil pH was raised from 4.25 to 5.42. Without liming the soil, however, the use of heavy dressings of P fertilizer (up to 0.75 g $KH_2PO_4$/kg soil partially alleviated Al toxicity in *D. ovalifolium* (Figure 3), but not for non-Al tolerant *D. intortum* plants (Figure 4). In contrast, there were no responses to lime in nonmycorrhizal plants that grew in soils with low to medium P levels. Shoot P concentrations of nonmycorrhizal plants were equal or less than 0.11% and indicative of P deficiency (Table 4). Both *D. ovalifolium* and *D. intortum* plants studied here were highly mycorrhizal-dependent. When solution P concentration was 0.008 and 0.052 P mg/l and soils were limed, seedlings of *D. ovalifolium* and *D. intortum* with mycorrhizal associations grew larger (Figures 3

**Table 3. Shoot Ca and Mn concentrations of two *Desmodium* species grown in potted Wahiawa and Paaloa soils.**

| Soil | Soil pH | Plant Species DI* | DO | DI | DO |
|---|---|---|---|---|---|
| | | Shoot Ca conc. % | | Shoot Mn conc. mg/kg | |
| Wahiawa | 5.23 | 1.11 | 1.28 | 3149 | 4827 |
| | 5.49 | 1.16 | 1.56 | 1068 | 3413 |
| | 6.05 | 1.29 | 1.86 | 558 | 2441 |
| | 6.45 | 1.35 | 1.99 | 496 | 1904 |
| Paaloa | 4.27 | 0.51 | 0.91 | 89 | 286 |
| | 4.44 | 0.79 | 1.14 | 141 | 245 |
| | 4.78 | 1.07 | 1.29 | 142 | 198 |
| | 5.60 | 1.19 | 1.32 | 122 | 179 |

* DI = *Desmodium intortum*,
DO = *Desmodium ovalifolium*.

**Table 4. Shoot P concentrations of two *Desmodium* species with and without mycorrhizal inoculation grown in potted Paaloa soil.**

| Soil pH | Solution P g/kg soil | *Desmodium intortum* Mycorrhizal Inoculation * | - | *Desmodium ovalifolium* * | - |
|---|---|---|---|---|---|
| | | Shoot P concentration (%) | | | |
| 4.25 | 0.008 | 0.14 | 0.06 | 0.11 | 0.10 |
| | 0.052 | 0.15 | 0.08 | 0.13 | 0.10 |
| | 0.840 | 0.28 | 0.17 | 0.23 | 0.14 |
| 5.54 | 0.008 | 0.15 | 0.06 | 0.13 | 0.09 |
| | 0.052 | 0.18 | 0.08 | 0.22 | 0.11 |
| | 0.840 | 0.34 | 0.18 | 0.32 | 0.16 |

and 4) and had higher shoot P concentration (Table 4) than those of nonmycorrhizal *Desmodium* seedlings. There was no significant growth difference between mycorrhizal and nonmycorrhizal plants when soils were limed and solution P was as high as 0.840 P mg/l. Mosse et al. (1973) inferred that the threshold concentration at which plants can take up P may be lowered when they are infected with mycorrhizae. The field results of Yost and Fox (1979) for some plants would support this viewpoint.

*3. Third experiment*

Total soil Mn was varied in this experiment by varying the amount of Mn containing soil in the soil mixture (Table 5). Total soil Mn ranged from 0.10 to 1.50% and soil pH ranged from 4.12 to 5.00. Resultant level of Mn in soil solution ranged from 0.3 mg/kg with 100% Paaloa soil to as high as 34.9 mg/kg with the mixture of 60% Wahiawa soil and 40% Paaloa soil, and again decreased to 6.8 mg/kg with 100% Wahiawa soil.

Growth of *D. intortum* was at a minimum where Mn in soil solution was greater than 30 mg/kg. Minimum growth corresponded to foliar levels of Mn greater than 1000 mg/kg. Growth of *D. ovalifolium*, however, did not follow levels of Mn in soil solution as closely (Table 6). Rather, growth was reduced where less than 20% of the soil mixture was Wahiawa soil. This corresponds to less than 0.39% total soil Mn. The growth of *D. ovalifolium* was negatively correlated with total soil Mn (-0.89 **). In contrast, shoot dry weight of *D. intortum* was negatively correlated with Mn in soil solution (-0.86 **) but not correlated with total soil Mn.

Within 15 hours, *D. ovalifolium* strongly acidified the bromocresol purple, whose color changed from red (pH 7.2) to yellow (pH < 5.2), while *D. intortum* did not. This observation strongly suggested

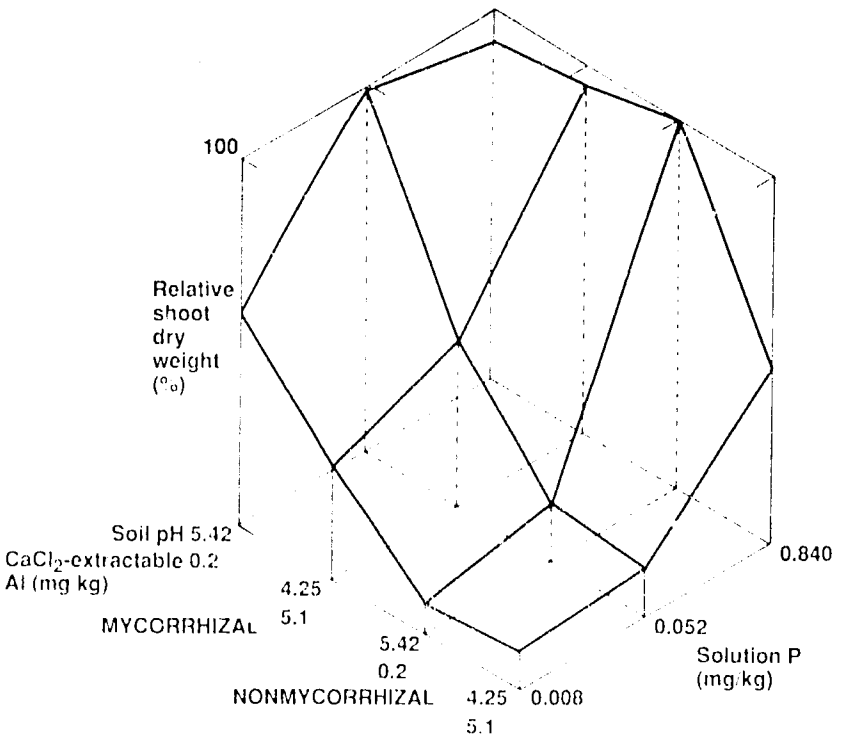


**Figure 3. Relative shoot growth of *D. ovalifolium* to mycorrhizal inoculation, soil P and soil pH in potted Paaloa soil, where 100% = 3.34 g.**

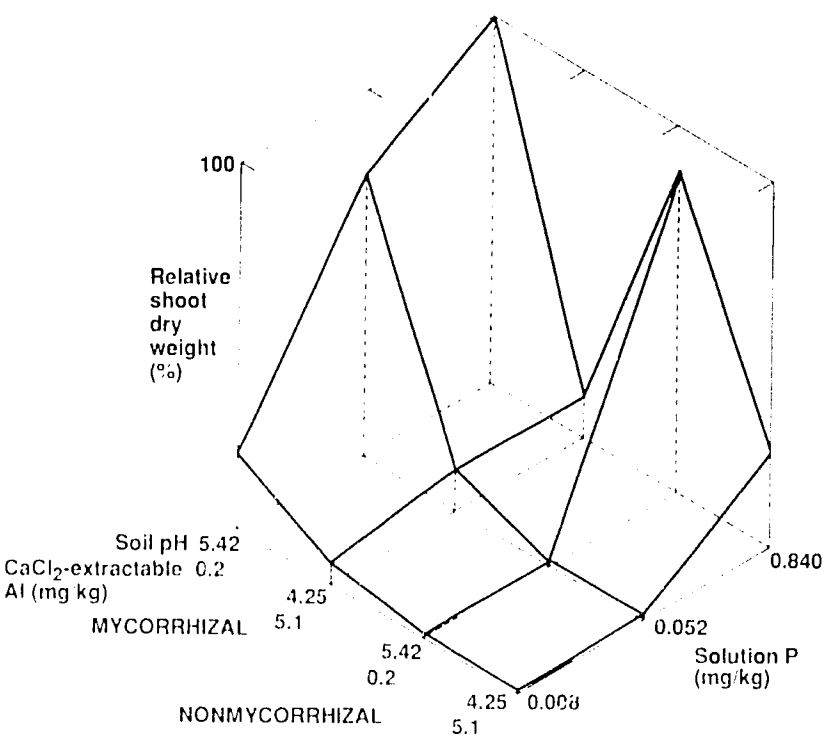


**Figure 4. Relative shoot growth of *D. intortum* to mycorrhizal inoculation, soil P and soil pH in potted Paaloa soil, where 100% = 7.07 g.**

**Table 5. Soil pH, Mn in soil solution, total soil Mn, shoot dry weight, and shoot Mn concentrations of two *Desmodium* species in mixtures of Wahiawa and Paaloa soils.**

| Soil combination | | Soil pH | Mn in soil solution | Total soil Mn | Shoot dry* weight | | Shoot Mn conc. | |
|---|---|---|---|---|---|---|---|---|
| Wahiawa | Paaloa | | | | DI** | DO | DI | DO |
| % | | | mg/kg | % | g | | mg/L | |
| 100 | 0 | 5.00 | 6.8 | 1.50 | 2.04 | 0.37 | 385 | 1040 |
| 80 | 20 | 4.80 | 11.0 | 1.22 | 1.74 | 0.40 | 520 | 1088 |
| 60 | 40 | 4.70 | 34.9 | 0.94 | 0.62 | 0.38 | 1253 | 1403 |
| 40 | 60 | 4.78 | 33.2 | 0.67 | 0.78 | 0.64 | 1413 | 1439 |
| 20 | 80 | 4.50 | 32.7 | 0.50 | 1.00 | 1.15 | 1793 | 1800 |
| 10 | 90 | 4.28 | 22.3 | 0.25 | 1.73 | 1.27 | 107[illegible] | 1042 |
| 5 | 95 | 4.17 | 21.6 | 0.18 | 1.69 | 1.05 | -- | -- |
| 0 | 100 | 4.12 | 0.3 | 0.10 | 1.75 | 1.38 | -- | -- |

* Average of 4 replicates (10 seedlings per replicate).
**DI=*Desmodium intortum*, DO=*Desmodium ovalifolium*.
-- Data not determined.

that the *D. ovalifolium* plant roots produced chemicals which could lower rhizospheric pH and thus increase Mn solubilizing capability. This might explicate previous experiments in which *D. ovalifolium* and *D. intortum* were shown to respond differently in a manganiferous soil; the former Al-tolerant species was more susceptible to Mn toxicity even at pH 7.0.

## Conclusions

In summary, there are two main reasons for poor plant growth in acid soils: 1) the presence of toxic elements and 2) deficiencies of plant essential nutrients. In these experiments we attempted to compare the physiological responses on acid soils in two *Desmodium* species and assess the possible adaptive mechanisms in the plants.

The improved growth responses of both *D. ovalifolium* and *D. intortum* plants associated with VA mycorrhizal inoculation clearly demonstrated that they are highly mycorrhizal dependent. The beneficial influences of mycorrhizal associations are particularly important, for these *Desmodium* species are grown on tropical P-fixing soils. As indicated in these experiments, however, plant tolerance to toxic elements in acidic soils may not be improved by colonization with mycorrhizae. Thus mycorrhizae appear to aid in alleviating nutrient deficiencies but not in eliminating element toxicities. Inherent tolerance to Al and Mn toxicities is just as important as ensuring the plants have a vigorous mycorrhizae association.

**Table 6. Linear correlation coefficients between shoot dry weight of *Desmodium* species and soil Mn.**

| | | Mn in soil solution | Total soil Mn |
|---|---|---|---|
| | | mg/kg | % |
| Shoot dry weight (g) | *Desmodium intortum* | -0.86 ** | 0.07 NS |
| | *Desmodium ovalifolium* | -0.12 NS | -0.89 ** |

** 1% level of significance,
NS not significant.

The feature distinguishing *D. ovalifolium* from *D. intortum* is that in a variety of situations *D. ovalifolium* accumulates more Mn in plant tissues and is more tolerant to Al toxicity. A possible explanation for these difference is that the roots of *D. ovalifolium* produce organic exudates and lower the rhizospheric pH. Organic acids (e.g., oxalic, tartaric, salicylic) have been demonstrated to be effective in detoxifying Al (Hue et al., 1985). The same principles of complexation with organic acids (from root exudates) apparently leads to an opposite consequence by increasing the solubility of Mn in manganiferous soil, even in limed soil. This apparently causes Mn toxicity in *D. ovalifolium* grown in the manganiferous Wahiawa soil of Hawaii. This hypothesis, however, requires further evaluation.

The differential ability of *Desmodium* species to survive in soils high in Al or Mn affects the distribution of its species. On the basis of these experiments it is suggested that these *Desmodium* species have evolved and become adapted to specific soil chemical niches.

## Implications

The establishment of plants in acid soils is difficult unless the associations of mycorrhizal plants, fertilization and liming are critically matched to the specific "acid soil infertility" complex.

Mechanisms responsible for the successful growth of certain plant species in unusual nutritional environments, for example, Al- or Mn-toxic soils, are of interest to both ecologists and physiologists. Better understanding of organic complexation reactions in soils is expected to yield needed insights into the biochemistry of the rhizosphere. The role of organic acid complexation in the rhizosphere in plant tolerance to Al and Mn has potential to improve acid-soil management. Such knowledge seems useful in identifying adapted species and possibly in the development of a genetic program for the selection of superior plant species or varieties that will thrive under adverse conditions.

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# Modeling Phosphorus-Lime Interactions

*Gero Uehara, University of Hawaii*
*Douglas Godwin, International Fertilizer Development Center*
*Nacanieli Tuivavalagi, University of Hawaii*
*James Silva, University of Hawaii*
*I Putu Gedher Widjaja-Adhi, Centre for Soils Research*

An extensive introduction and review of this project was presented by objectives in the *TropSoils Technical Report, 1985-1986*.

Experiments conducted in Situng during the dry season of this reporting period were hampered by staff and budget reductions affecting both Indonesian and U.S. programs. Complete data sets to test and validate the phosphorus-lime model as stated in Objective 2 were not compiled at the end of the reporting period.

The following report covers work carried out in Hawaii to backstop the Indonesian activities relative to Objective 3.

As reported in the plan of work, a phosphorus by-nitrogen experiment with maize was planted at Poamoho Experiment Station, Oahu to test the response of the IBSNAT-CERES maize model to varying rates of N and P. Nitrogen was selected because an operational soil nitrogen model is available for comparative development of the phosphorus-lime model.

The overall structure for coupling the P model to crop models such as those for rice and corn is being developed at the International Fertilizer Development Center. The P model must necessarily and will eventually be coupled to the existing nitrogen model. The model will simulate the daily transformations among fertilizer, labile, active inorganic and stable inorganic phosphorus pools. Capability of handling fertilizers of differing dissolution rates will be built into the phosphorus chemistry routine.

The model will simulate P uptake as a function of root length density, ion concentration and prevailing moisture condition.

## Objectives

The objectives of this study were 1) to quantify model coefficients and couple model to existing crop models that simulate crop growth and development; 2) to test and validate the phosphorus-lime model in the field using observed and simulated pH, soil P, plant uptake, and crop performance as indices for comparison; and 3) to develop and test a phosphorus-lime model that simulates changes in extractable phosphorus concentration and soil pH over time.

## Procedures

Procedures for activities related to Objectives 1 and 2 were reported extensively in the previous technical report (*TropSoils Technical Report, 1985-1986*) and will not be repeated here.

An experiment to evaluate applied treatment effects of nitrogen and phosphorus on crop growth and development of maize was installed by N. Tuivavalagi and J. Silva at the Poamoho Experiment Station. Levels of P application were based on soil test P determined by the modified-Truog P method (Ayers and Hagihara, 1952). Data obtained from the experiment will be used to validate the IBSNAT-CERES maize model and to develop the phosphorus-lime sub-model.

## Results

Outputs related to Objectives 1 and 2 were reported in the previous technical report and will not be presented here.

Results from a field trial in Hawaii are presented in the following paragraphs. These results are from research conducted as part of the M.S. thesis of Mr. Nacanieli Tuivavalagi under the supervision of Dr. James Silva of the Department of Agronomy and Soil Science.

A phosphorus-factor routine calculates a critical concentration of P in the plant tissue for plant growth processes. Critical concentration curves and stress indices will have to be defined for each crop. This is necessary because P deficiency not only reduces yield but affects the rate of development of a crop. In this regard the P model is a useful device for aiding researchers to collect useful additional data from conventional soil fertility experiments.

Figure 1 shows the response of maize to nitrogen and P on an Oxisol with an average extractable soil-P as determined by a modified Truog method of 32 ppm. Owing to the high residual level of soil P, the yield response to applied P was low, as indicated by

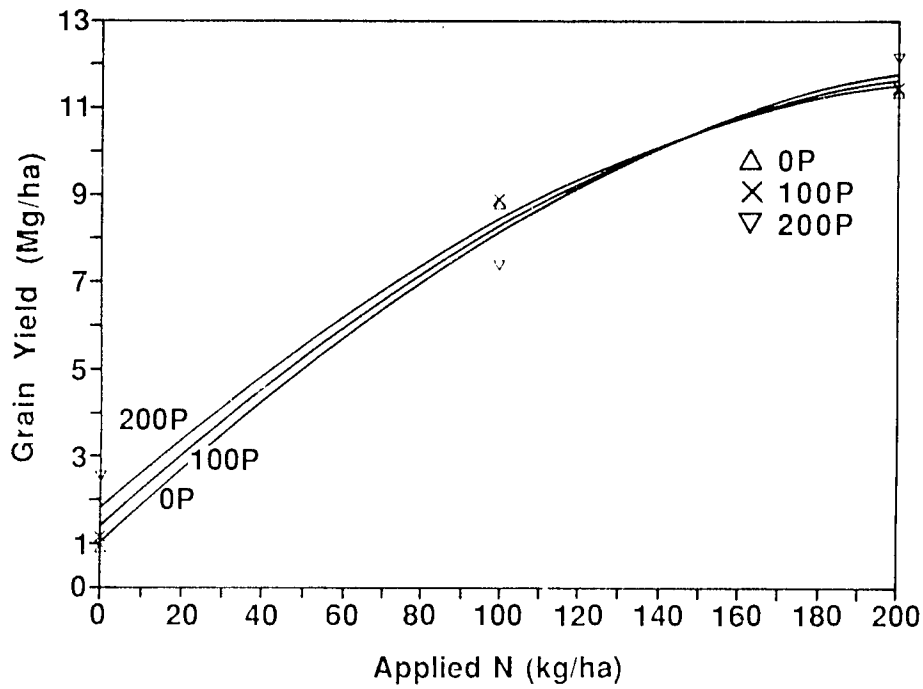


**Figure 1. The effect of applied N and P on maize grain yield. (R2 = 0.96)**

the results. While there was no statistically significant response to P, the effect of P rates on crop development was significant, as shown in Figures 2 and 3 which show the effects of P and N rates on days from planting to 50% tasselling and silking, respectively. These results provide strong indications that even mild P deficiencies will have marked effects on the development and rate of maturity of maize. Similar experiments have been conducted in Sitiung where soil P levels are low. These data are currently being collected.

## Conclusions

The results reported above provide strong indications that even mild P deficiencies will have marked effects on the development and rate of maturity of maize. The P component of the phosphorous-lime model must be able to predict these effects for any site and soil.

Similar types of experiments have been conducted in Sitiung and results from them will need to be evaluated to further develop and test the phosphorous-lime model.

## Implications

With adequate site and climate data sets, crop models for maize and soybean can eventually be used to approximate potential production in areas where the crops have not been grown before. When the phosphorus-lime model is operational, it should become part of these crop models to more adequately describe soil and site constraints to crop production.

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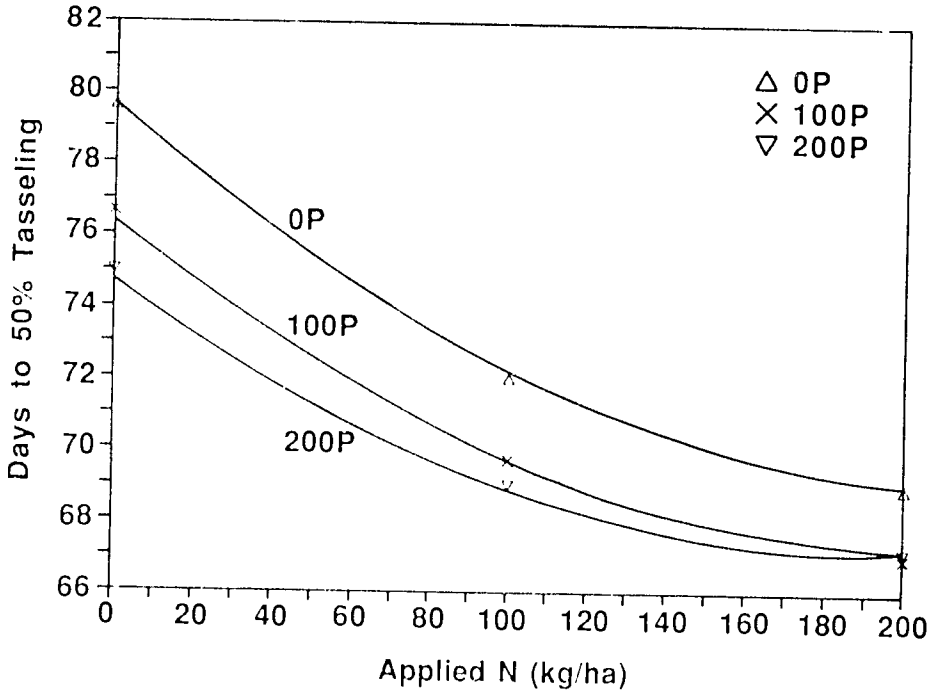


Figure 2. The effect of applied N and P on the number of days to 50% tasselling of maize. (R2 = 0.87)

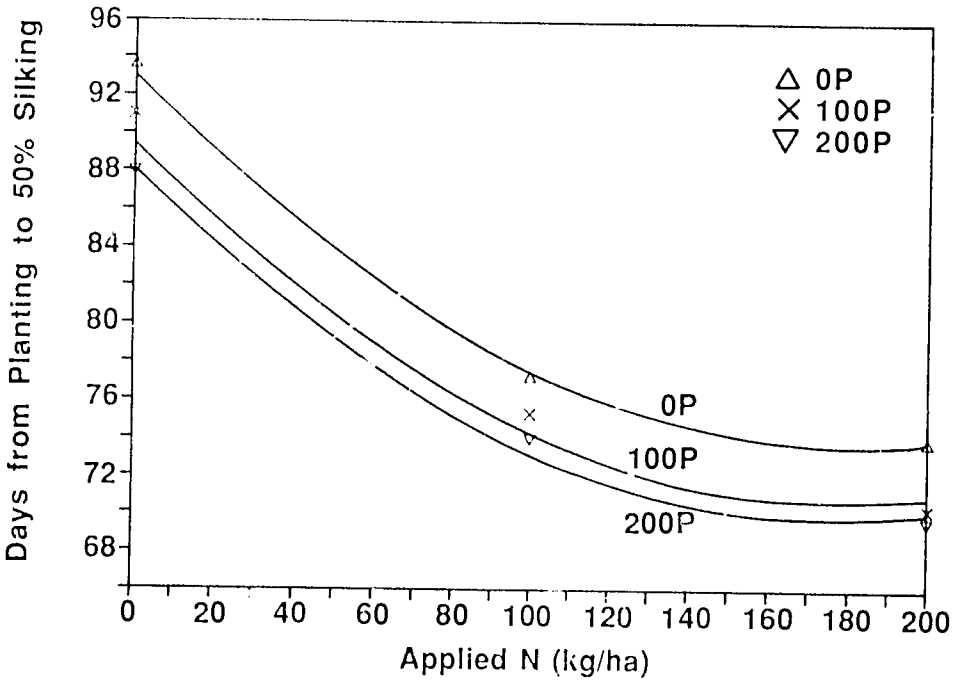


Figure 3. The effect of applied N and P on the number of days to 50% silking of maize. (R2 = 0.95)

# Land Reclamation: Soil Physics And Soil Conservation

Increases in crop yields from fertilizer application have not been as high as anticipated. Soil physical problems appear to be limiting further increases in crop yields. The farmers' inability to obtain profitable yields from fertilizer application leads to rejection of inputs and acquiescence to extremely low yields. Low yields in turn lead to neglect and soil loss through erosion.

The purpose of the research described in this section is to enable crops to respond fully to fertilizer inputs by eliminating microbial and soil physical constraints and soil loss.

# Role of Soil Physical Properties On Land Quality for Sustained Agricultural Production in Land Cleared by Heavy Equipment

*Goro Uehara, University of Hawaii*
*Lalit Arya, University of Hawaii*
*Keith Cassel, North Carolina State University*
*Graduate students, Andalas University*

The soil scientist hired to take responsibility for this project arrived on site late in the reporting year. Prior to his arrival, the project ascertained that his talents would be better served by redirecting the project objectives into the area of soil and water conservation. These objectives are stated in the work plan for next year.

## New Project Update

*This project has not been under way long enough to yield a substantive report, but should be mentioned because of its importance to the program.*

In readiness for this new thrust, equipment is being purchased to measure in site soil water. Power supply for the laboratory has been upgraded and instruments for soil and plant analysis for this work have been refurbished.

Two faculty members from Andalas University have joined the project to assist the project scientist. These faculty will use data collected by them to fulfill requirements for advanced degrees in soil science.

### Objectives

The objectives of this study are 1) to identify the soil physical parameters that are adversely modified by mechanized land-clearing; 2) to be able to recommend safe, inexpensive and acceptable post-land-clearing soil-management practices to reclaim soils damaged by mechanized land-clearing; and 3) to develop an economic model to identify the best combination of land-clearing and post level clearing method.

### Procedures

Soil physical properties associated with water infiltration and retention characterization will be determined by standard mechanical analysis for soil texture. Several sites were sampled by the Soil Conservation Service and data sets are available for several experimental sites in Sitiung.

*In situ* water content determinations with depth and time will be made with a neutron probe. Calibration of the probe will require gravimetric determination of soil samples in the field laboratory. The range of moisture content will be narrow unless the calibration can be made in the dry season or under a field shelter.

Several of these determinations will be made to complement on-going experiments such as those on phosphorus and lime. Solute movement and distribution in the profile and root distribution studies also will be considered to better understand field observa-

# Pasture Grass and Legumes For the Humid Tropics

*Carl Evensen, University of Hawaii*
*Russell Yost, University of Hawaii*
*Yoshinori Kanehiro, University of Hawaii*
*Ronald Guyton, University of Hawaii*

The importance of livestock and the difficulties in finding adequate feed in the Sitiung area have suggested the need to assess more productive forage systems. Forage species are also useful as green manures and cover crops and in plantings for soil and water conservation. The experiments and the demonstration reported here are designed to select promising forage and cover-crop species and to determine their fertilizer requirements and acceptance by farmers.

## Objectives

The objectives of this study were 1) to evaluate germ plasm of pasture legumes and grasses, managed with low fertilizer inputs, under Sitiung edaphaic and climatic conditions; 2) to determine the most productive forages and to consider applications as green manures and cover crops on small farms; 3) to quantify the yield response of four tropical forage legumes to different rates of lime, molybdenum and calcium sulfate; and 4) to assess Al and Mn toxicities on this soil using forage species with well characterized tolerances. This project has been expanded to include as additional objectives: 5) to quantify the yield response of four tropical forage legumes to different rates of lime, molybdenum, and calcium sulfate, and 6) to assess Al and Mn toxicities on Sitiung soils using forage species with well characterized tolerances. These objectives (5 and 6) have been accomplished in an experiment (Calcium and Molybdenum Response of Forage Legumes) which was supported by a USDA/University of Hawaii collaborative agreement (TL406).

## Procedures

### *I. CIAT Regional Trial B*

This experiment is planted on a Typic Haplorthox in Sitiung I and is arranged in a RCB design with four replications. The treatments consist of the following forage accessions, planted on December 26, 1984, except treatment 23, which was planted on March 15, 1985 to replace a dead accession:

| Trt. | Species | Abbreviation No. | CIAT |
|---|---|---|---|
| 1) | *Aeschynomene histrix* | AHIS | 9690 |
| 2) | *Centrosema arenarium* | CAREN | 5236 |
| 3) | *C. brasilianum* | CBRA1 | 5234 |
| 4) | *C. brasilianum* | CBRA2 | 5712 |
| 5) | *C. macrocarpum* | CMAC1 | 5062 |
| 6) | *C. macrocarpum* | CMAC2 | 5065 |
| 7) | *C. pubescens* | CPUB1 | 438 |
| 8) | *C. pubescens* | CPUB2 | 5189 |
| 9) | *C. sp.* | CSP1 | 5112 |
| 10) | *C. sp.* | CSP2 | 5568 |
| 11) | *Desmodium ovalifolium* | DOVA1 | 350 |
| 12) | *D. ovalifolium* | DOVA2 | 3784 |
| 13) | *Pueraria phaseoloides* | PPHAS | 9900 |
| 14) | *Stylosanthes capitata* | SCAP1 | 2252 |
| 15) | *S. capitata* | SCAP2 | 10280 |
| 16) | *S. guianensis* | SGUI1 | 136 |
| 17) | *S. guianensis* | SGUI2 | 184 |
| 18) | *Zornia latifolia* | ZLAT | 728 |
| 19) | *Z. sp.* | ZSP | 7847 |
| 20) | *Andropogon gayanus* | AGUY | 621 |
| 21) | *Brachiaria decumbens* | BDEC | 606 |
| 22) | *B. dictyoneura* | BDICT | 6133 |
| 23) | *Setaria ancepts* | SANC | - |
| 24) | *Calopogonium coeruleum* | CCOER | - |
| 25) | *C. muconoides* | CMUC | - |
| 26) | *Macroptilium atropurpureum* | MATRO | - |

The first 22 accessions were sent from CIAT, while the last four were added locally. Lime was broadcast over all plots at a rate of 375 kg/ha to give about 0.5 cmol Ca/kg soil to a 15cm depth. TSP was banded at 40 kg P/ha and the seed were planted in rows 50cm apart. Plot dimensions were 2m x 5m. Harvests were made during minimum and maximum rainfall periods, at which time 1 $m^2$ subplots were cut at three-, six-, nine- and 12-week intervals. Aside from these intensive harvesting periods, cuttings were made about every three months on 4 $m^2$ harvest areas. No additional fertilizer was applied until April 11, 1986, when, in response to reduced plant vigor, 25 kg N/ha was applied only on the grasses, and on all plots, 25 kg K/ha and 20 kg P/ha were applied. N and K were again applied at these rates on June 6,

1986 and thereafter approximately every three months.

*2. Calcium and molybdenum response of forage legumes*

This experiment is planted on a field adjoining the CIAT Trial and is laid out in a randomized complete block design with a complete factorial arrangement of the following forage species x fertility factors.

Species:

1) *Desmodium intortum* (Al sensitive, Mn tolerant)
2) *D. ovalifolium* (Al tolerant, Mn sensitive)
3) *Centrosema pubescens* (standard species)
4) *C. macrocarpum* (promising on acid soils)

Fertility Levels:

1) Check - no added Ca or Mo
2) Calcium sulfate - 680 kg/ha (to provide 200 kg Ca/ha)
3) Lime - 3.0 T/ha (to 25 % Al+H saturation)
4) Mo - 1 kg Mo/ha + 500 kg lime/ha (200 kg Ca/ha)
5) Mo - 2 kg Mo/ha + 500 kg lime/ha (200 kg Ca/ha)
6) Mo - 4 kg Mo/ha + 500 kg lime/ha (200 kg Ca/ha)
7) Lime - 10 T/ha (to 0 % Al+H saturation and pH > 6)

This report covers the establishment period of the trial (five and one half months) and the subsequent five forage harvests. The following blanket fertilizer applications were made to all plots at planting: P (TSP) at 100 kg P/ha; K (KCl) at 33.3 kg K/ha (1/3 of the annual application); and Mg (Kieserite) at 6.9 kg Mg/ha. The lime and calcium sulfate treatments were broadcast and the Mo (supplied as Ammonium heptamolybdate tetrahydrate) was dissolved in water and applied with a watering can. All fertilizers and amendments were incorporated to a depth of 15 cm with hoes.

Seed of *D. ovalifolium* (CIAT No. 350) was obtained from CIAT, while seed of *D. intortum* and *C. pubescens* w... obtained from the University of Hawaii. *Centrosema macrocarpum* (CIAT No. 5062) was planted by cuttings obtained from a CIAT trial in Sitiung II. Seed was coated and the cuttings were drenched after planting with rhizobial inoculum obtained from NiFTAL in Hawaii. All seed and cuttings were planted on April 16, 1985. The species were planted in four rows, 5 m long and 50 cm apart. The total plot size was 12.5 $m^2$ (5 m x 2.5 m).

Establishment of the trial was quite slow due to prolonged dry periods. Some irrigation with watering cans was necessary for the survival of the cuttings. Replanting of all the species were done as needed in mid-June 1985.

The *Centrosema pubescens* established very quickly and required almost no replanting. The two *Desmodium* species established very slowly, particularly *D. intortum*, which began to show chlorosis and mortality on the check and calcium sulfate treatments within the first month from planting. The month of June was extremely dry (51 mm of rainfall), so growth then was minimal. However, in July and August, well distributed rainfall caused a strong flush of growth and the plots began to fill in well.

The first harvest was made on October 3, 1985, and subsequent harvests on December 21, 1985, March 18, 1986, June 19, 1986, and September 25, 1986. For all harvests, the harvested area was the central 4 $m^2$ of the plots. Potassium was reapplied at the rate of 33.3 kg K/ha on October 10, 1985 and on April 5, 1986. Before the third harvest March 18, 1986, nodulation of the legumes was assessed by subjectively rating small samples of surface soil (0-5 cm depth). All plots contained nodulated roots except some of the 0 lime and $CaSO_4$ treatments. No other fertilizer treatment or species differences in nodulation were noticed.

*3. Forage demonstration*

The forage demonstration is located in a home garden borrowed from transmigration authorities in the center of the transmigrant village Sitiung Ve. The demonstration plots consist of four grass species (*Setaria ancepts, Brachiaria dictyoneura, Andropogon gayanus*, and a *Pennisetum sp.*), two legumes (*Centrosema macrocarpum* and *Desmodium ovalifolium*), and two grass-legume mixtures (*Brachiaria* + *Desmodium* and *Setaria* + *Albizia falcataria*). All these species have proven to be productive and well adapted to Sitiung conditions in previous TropSoils experiments. Low levels of lime (375 kg/ha) and phosphorous fertilizer (200 kg TSP/ha) had been applied at planting of the demonstration on April 24,

1986. The first cutting took place at a field day on September 18, 1986.

The intent of the forage demonstration is to introduce some productive forage species into the area and gain farmers' perceptions about their value in local farming systems. This is an especially timely demonstration since farmers in Sitiung Ve are expecting government-supplied cattle in the near future. Since Sitiung Ve is in the middle of recently cleared forest with no nearby grasslands, farmers will have to produce their own forages. One village official said that the lack of forages has delayed the arrival of the cattle.

**Table 1. Forage yields (oven dry weight basis) at 3-, 6-, 9-, and 12-week harvest intervals during the wet season 1985/86 from the CIAT Regional Trial B.**

| Species* | Harvest Date 28Dec85 | 18Jan86 | 8Feb86 | 1Mar86 |
|---|---|---|---|---|
| | kg/ha | | | |
| BDICT | 999 a | 2178 a | 2630 a | 4452 b |
| AGUY | 623 b | 1193 bc | 2569 a | 6185 a |
| SANC | 526 bc | 1255 bc | 1201 bc | 1960 cde |
| BDEC | 524 bc | 1423 b | 2315 a | 2967 c |
| CMAC1 | 371 cd | 864 cd | 1429 b | 1937 cde |
| CMAC2 | 356 cde | 714 de | 1120 bc | 1907 cde |
| CSP2 | 329 cdef | 603 defg | 687 cdefgh | 1426 defg |
| ZSP | 325 cdef | 597 defg | 879 bcde | 1204 defgh |
| SCAP1 | 266 defg | 357 efgh | 449 defgh | 828 efgh |
| CBRA2 | 249 defg | 517 defgh | 806 cdef | 1077 defgh |
| CBRA1 | 244 defg | 653 def | 1226 bc | 1516 defg |
| ZLAT | 216 defg | 453 defgh | 1131 bc | 1905 cde |
| SCAP2 | 198 defg | 217 fgh | 179 gh | 552 fgh |
| SGUI1 | 194 defg | 653 def | 905 bcde | 1606 def |
| CSP1 | 170 defg | 472 defgh | 685 cdefgh | 774 efgh |
| AHIS | 159 defg | 310 efgh | 311 efgh | 456 fgh |
| CPUB2 | 147 defg | 155 gh | 256 fgh | 395 gh |
| SGUI2 | 146 defg | 612 defg | 976 bcd | 1277 defgh |
| CAREN | 132 defg | 428 defgh | 778 cdefg | 1408 defgh |
| DOVA2 | 126 efg | 625 def | 1066 bc | 1929 cde |
| DOVA1 | 123 efg | 647 def | 1075 bc | 2099 cd |
| PPHAS | 111 fg | 255 efgh | 651 cdefgh | 892 efgh |
| CPUB1 | 106 fg | 120 h | 201 fgh | 468 fgh |
| CMUC | 76 g | 225 fgh | 339 efgh | 510 fgh |
| MATRO | 58 g | 89 h | 107 h | 228 h |

*Corresponding species name for these abbreviations can be found under the "Procedures" section of this report.
Note: Means followed by the same letter do not differ significantly at the 0.05 level according to Duncan's Multiple Range Test.

## Results

### *1. CIAT Regional Trial B*

This report covers intensive (every three weeks) forage harvests during the wet season (beginning December 28, 1985) and during the dry season (beginning June 26, 1986) and regular harvests on December 7, 1985 and June 5, 1986. The forages grew well during the first few harvests but began to display chlorotic leaves and decline in vigor in early 1986.

Since no additional fertilizer had been applied since planting and all clippings were removed from the plots, these were undoubtedly nutrient-deficiency symptoms. It was useful to determine how long the

**Table 2. Forage Yields (oven dry weight basis) at 3-, 6-, 9-, and 12-week harvest intervals during the dry season 1985/86 from the CIAT Regional Trial B.**

| Species* | Harvest Date 26Jun86 | 17Jul86 | 7Aug86 | 28Aug86 |
|---|---|---|---|---|
| | kg/ha | | | |
| BDICT | 1285 a | 1464 a | 3137 a | 3860 a |
| SANC | 655 b | 1065 abc | 1489 cd | 1651 defghi |
| BDEC | 562 b | 918 bcdef | 1943 bc | 3423 ab |
| CSP2 | 341 c | 521 defgh | 1140 defg | 1369 efghij |
| CMAC1 | 338 cd | 1016 abcd | 1278 cde | 2298 cd |
| AGUY | 333 cd | 1281 ab | 2263 b | 3607 a |
| CMAC2 | 242 cde | 454 efgh | 1017 defgh | 2077 cdef |
| CBRA1 | 220 cdef | 470 efgh | 1247 def | 1438defghij |
| CBRA2 | 199 cdefg | 502 defgh | 607 efghijk | 1172 ghijk |
| ZSP | 199 cdefg | 606 cdefgh | 1058 defg | 1533defghij |
| SCAP2 | 196 cdefg | 330 gh | 422 ghijk | 748 ijklm |
| DOVA1 | 195 cdefg | 949 bcde | 2498 b | 2737 bc |
| ZLAT | 185 cdefg | 526 defgh | 1277 cde | 1806 defgh |
| DOVA2 | 164 defg | 721 cdefg | 1952 bc | 2220 cde |
| CSP1 | 154 efg | 401 fgh | 480 ghijk | 862 ijklm |
| CPUB1 | 141 efg | 325 gh | 570 efghijk | 1113 ghijkl |
| CAREN | 124 efg | 271 gh | 947 defghi | 1437defghij |
| CPUB2 | 111 efg | 253 gh | 457 ghijk | 780 ijklm |
| SCAP1 | 109 efg | 213 gh | 298 hijk | 725 jklm |
| PPHAS | 102 efg | 267 gh | 859 defghij | 1225 fghij |
| SGUI1 | 79 efg | 323 gh | 852 defghijk | 1986 cdefg |
| CCOER | 52 fg | 161 gh | 123 jk | 318 lm |
| AHIS | 51 fg | 107 h | 235 ijk | 266 lm |
| MATRO | 32 g | 428 efgh | 126 jk | 275 lm |
| CMUC | 26 g | 57 h | 109 k | 131 m |
| SGUI2 | 24 g | 214 gh | 528 fghijk | 1068 hijkl |

*Corresponding species name for these abbreviations can be found under the "Procedures" section of this report.
Note: Means followed by the same letter do not differ significantly at the 0.05 level according to Duncan's Multiple Range Test.

forages could be productive without fertilizing since local farmers probably would not apply fertilizers, but to continue the species comparisons, a low-input fertilization schedule was begun in April 1986. The forages greened-up after regular NPK applications.

During the 1985/86 season the species *A. histrix*, *M. atropurpureum*, *S. capitata*, and *Z. latifolia* had high mortality rates (up to 50%) of older plants. However, *A. histrix*, *S. capitata* and *Z. latifolia* as well as *A. gayanus* and *S. guianensis* flowered and reseeded themselves heavily, reestablishing their stands. Table 1 shows the forage yields during the intensive harvests in the wet season, Table 2, the yields during the intensive harvests in the dry season, and Table 3, the regular harvests after approximately three-month growth periods. Generally, the grasses out-yielded the legumes with *Brachiaria dictyoneura* and *Andropogon gayanus* being the highest yielders. However, *Andropogon* tends to go to seed and get very fibrous after about nine weeks making it a less desirable forage. Of the legumes, the *Centrosema macrocarpum* and *Desmodium ovalifolium* were consistently high yielding, especially at the longer growth intervals. Other legumes which yielded well included *Centrosema brasilianum*, *Zornia latifolia*, *Z. sp.*, and on the longer growth intervals, *Stylosanthes guianensis*. There were no consistent differences between wet- and dry-season yields.

**Table 3. Forage yields (oven dry weight basis) for regular harvests at three month intervals during 1985/86 from the CIAT Regional Trial B.**

| | Harvest Date | |
|---|---|---|
| Species* | 7Dec85 | 5Jun86 |
| | kg/ha | |
| BDICT | 4533 a | 5942 a |
| AGUY | 3421 b | 6314 a |
| BDEC | 3166 bc | 5848 a |
| SGUI1 | 2563 cd | 2994 bc |
| DOVA1 | 2493 de | 3486 b |
| CMAC1 | 2431 de | 2627 bcd |
| DOVA2 | 2413 de | 3410 b |
| SGUI2 | 2388 de | 3504 b |
| SANC | 2051 def | 2190 cde |
| ZSP | 1824 efg | 2171 cde |
| CBRA1 | 1790 efgh | 1641 def |
| CMAC2 | 1584 fghi | 2122 cde |
| CBRA2 | 1414 fghij | 1465 ef |
| CSP2 | 1365 fghij | 1250 ef |
| CSP1 | 1309 ghijk | 942 fg |
| AHIS | 1262 ghijk | 1037 fg |
| PPHAS | 1202 ghijkl | 1312 ef |
| SCAP1 | 1074 hijklm | 984 fg |
| ZLAT | 1009 ijklm | 2699 bc |
| CAREN | 970 ijklm | 1625 def |
| CCOER | 685 jklmn | 772 fg |
| CPUB1 | 622 klmn | 717 fg |
| CPUB2 | 594 klmn | 549 g |
| SCAP2 | 504 lmn | 1129 efg |
| CMUC | 395 mn | 571 fg |
| MATRO | 235 n | 112 g |

*Corresponding species name for these abbreviations can be found under the "Procedures" section of this report

Note: Means followed by the same letter do not differ significantly at the 0.05 level according to Duncan's Multiple Range Test.

*2. Calcium and molybdenum response of forage legumes*

The forages had become well established by the first harvest, with the exception of the *Desmodium intortum*, which showed a very strong response to lime application. The unlimed plots of this species had very sparse stands due to seedling mortality, while the plots with calcium sulfate applied lacked vigor. Unlimed and low-limed plots of this species gradually died off during the successive harvests. The other three species showed no clear, visible response to the fertility treatments, except at the 0 lime level, which in all species appeared somewhat chlorotic. An analysis of variance for forage yields indicated that species and fertility factors caused highly significant yield differences at all harvests while the interaction of species with fertility level was non-significant.

In Table 4, the mean sun dry yields of each of the species at each of the fertilizer levels is presented for three of the harvests. For all five harvests *Centrosema macrocarpum* and *Desmodium ovalifolium* were very productive at all fertility levels, but did respond slightly to lime applications. The *Desmodium intortum* and to a lesser extent the *Centrosema pubescens* responded strongly to lime applications, indicating problems with Al toxicity and/or Ca deficiency. Three tons of lime per hectare produced maximum yields with all the species. The highest rate of lime (10 T/ha) produced lower yields in most cases, although these differences were not significant. None of the species responded to

**Table 4. Treatment means for forage yields on a sun dry weight basis from the Ca and Mo response of forage legumes trial. (Values in parentheses are percentage of maximum species, species means or fertilizer means yields.)**

a. Harvest on October 3, 1985.

| | *Desmodium intortum* | *Desmodium valifolium* | *Centrosema pubescens* | *Centrosema macrocarpum* | Fertilizer means |
|---|---|---|---|---|---|
| | kg/ha (%) | | | | |
| Check | 308 (7) | 4682 (75) | 3557 (67) | 5218 (81) | 3441 (63) |
| CaSO4 | 860 (20) | 4864 (78) | 2964 (56) | 5190 (80) | 3470 (63) |
| 3 T Lime | 4329 (100) | 6230 (100) | 5321 (100) | 6083 (94) | 5491 (100) |
| 1 kg Mo | 2392 (55) | 5815 (93) | 4146 (78) | 5716 (88) | 4517 (82) |
| 2 kg Mo | 2769 (64) | 6104 (98) | 4436 (83) | 5779 (89) | 4772 (87) |
| 4 kg Mo | 2866 (66) | 5544 (89) | 4200 (79) | 5766 (89) | 4594 (84) |
| 10 T Lime | 4152 (96) | 6196 (99) | 4792 (90) | 6481 (100) | 5405 (98) |
| Species means | 2525 (44) | 5634 (98) | 4202 (73) | 5747 (100) | |

LSD (0.05): Species = 462; Fertilizers = 611; Spp.xFert. = 1220

b. Harvest on March 18, 1986.

| | *Desmodium intortum* | *Desmodium ovalifolium* | *Centrosema pubescens* | *Centrosema macrocarpum* | Fertilizer means |
|---|---|---|---|---|---|
| | kg/ha (%) | | | | |
| Check | 0 (0) | 2604 (67) | 215 (11) | 1976 (55) | 1199 (49) |
| CaSO | 441 (7) | 2980 (76) | 619 (33) | 2483 (69) | 1530 (63) |
| 3 T Lime | 593 (100) | 3902 (100) | 1890 (100) | 3345 (93) | 2433 (100) |
| 1 kg Mo | 203 (34) | 3386 (87) | 887 (47) | 2559 (71) | 1759 (72) |
| 2 kg Mo | 122 (21) | 3850 (99) | 877 (46) | 2399 (67) | 1812 (74) |
| 4 kg Mo | 550 (93) | 3315 (85) | 925 (49) | 2669 (74) | 1865 (77) |
| 10 T Lime | 274 (46) | 3389 (87) | 1584 (84) | 3602 (100) | 2212 (91) |
| Species means | 255 (8) | 3346 (100) | 1000 (30) | 2719 (81) | |

LSD (0.05): Species = 493; Fertilizers = 653; Spp.xFert. = 1305

**c. Harvest on September 25, 1986.**

| | *Desmodium intortum* | *Desmodium ovalifolium* | *Centrosema pubescens* | *Centrosema macrocarpum* | Fertilizer means |
|---|---|---|---|---|---|
| | kg/ha (%) | | | | |
| Check | 0 | 2070 (56) | 607 (27) | 2006 (53) | 1171 (48) |
| CaSO4 | 0 | 2377 (64) | 884 (39) | 1732 (46) | 1243 (51) |
| 3 T Lime | 648 | 3689 (100) | 2269 (100) | 3108 (82) | 2428 (100) |
| 1 kg Mo | 0 | 2652 (71) | 1268 (56) | 2971 (79) | 1723 (71) |
| 2 kg Mo | 0 | 1865 (50) | 1079 (48) | 2753 (73) | 1424 (59) |
| 4 kg Mo | 0 | 2766 (75) | 1268 (56) | 2364 (63) | 1560 (64) |
| 10 T Lime | 0 | 3112 (84) | 2143 (94) | 3770 (100) | 2256 (93) |
| Species means | 93 (3) | 2647 (99) | 1360 (51) | 2672 (100) | |

LSD (0.05): Species = 297; Fertilizers = 393; Spp.xFert. = 786

increasing levels of Mo, and there was no evidence of increased N fixation (such as greener leaves or increased nodulation) due to Mo application.

Soil analysis of samples taken before the experiment and during the growth of the forages is shown in Table 5. The soil is quite acidic with a high extractable Al and low base content. These soil nutrient levels are quite representative of those commonly found in the Sitiung area.

*3. Forage demonstration*

The field day, which was organized by Suwandi (a CSR field technician) and Carl Evensen, was attended by about 30 farmers as well as various TropSoils team members and staff. The village secretary, representing the headman, and two village unit heads (*kepala jorong*) assisted in organizing the farmers and calling the meeting to order. Local extension agents were invited but unfortunately could not attend.

During the field day, each species was described as to methods of planting and harvest, value as animal forage, and soil fertility requirements. Possible uses were suggested, such as planting on terrace risers and on steeply sloping land to control erosion and in under-utilized spots in home gardens, such as under trees. But it was stressed that we are interested in farmers' ideas about whether these

**Table 5. Soil analyses before and during the experiment, sampled to a depth of 0-15cm.**

| Lime rate | pH | Al+H* | Ca+Mg* | K** | P** | % Acid Sat. |
|---|---|---|---|---|---|---|
| t/ha | cmol/kg | | | | ppm | |
| **April 6, 1985*** ** | | | | | | |
| 0 | 4.2 | 3.97 | 0.60 | 0.10 | N/A | 85 |
| **October 10, 1985** | | | | | | |
| 0 | 4.2 | 3.83 | 1.18 | 0.16 | 51 | 74 |
| 0.5 | 4.4 | 3.28 | 1.86 | 0.12 | 38 | 63 |
| 3 | 4.8 | 1.41 | 4.62 | 0.10 | 35 | 23 |
| 10 | 6.2 | 0.05 | 10.72 | 0.10 | 46 | 0.5 |

*Extracted with 1 N KCl.
**Extracted with Mehlich I (double acid).
***Composite sample before treatment application.

species would be useful and how they could best be utilized in the farmer's system. We then allowed farmers to collect planting materials of their choice and noted their names and the species they took. Twenty farmers took planting material and all agreed to allow us to monitor their progress. The *Setaria* and the *Pennisetum* species, which are upright, bunch-type grasses, were in greatest demand along with the *Desmodium*. Follow-up has involved visiting the farmers to see how they are using the forages, observing forage growth under farmer's conditions, and seeking farmer perceptions of the usefulness of the forages. Generally, farmers have preferred the bunch-type grasses, and plant them almost exclusively as borders along their home gardens and upland fields. Pastures or blocks of forages for cut-and-carry use are not popular.

### Conclusions and Implications

Of the four grass and 15 legume species tested in the CIAT Trial, the grasses produced about two to three times as much biomass as the legumes, and were preferred by farmers. The most productive grass was *Brachiaria dictyoneura*, although *Andropogon gayanus*, at harvest intervals less than nine weeks (to avoid steminess), was also attractive. However, local farmers almost all prefer *Setaria ancepts* because of its upright, non-spreading growth habit and high palatability. Even though this species was not as productive, *Setaria* should probably be considered for most future forage plantings in Sitiung since it seems to fit well into existing farming systems. Of the legumes, the most productive were *Centrosema macrocarpum* and *Desmodium ovalifolium*, which, since they combine well with grasses, should be considered for mixed grass-legume pastures, if these are appropriate. Pastures would have particular relevance for soil erosion control.

All four legume species tested in the calcium and molybdenum response experiment responded to liming, even the "Al tolerant" legumes, *Centrosema macrocarpum* and *Desmodium ovalifolium*. However, none of the species tested showed a yield increase or evidence of higher N fixation due to Mo application. *Desmodium ovalifolium* and *Centrosema macrocarpum* were fairly equivalent in yields, except in the second and third harvests, when the former produced higher yields. Either species would be productive at low liming levels in Sitiung. Clearly, on this Sitiung soil, Al toxicity is the main problem (as shown by poor growth of *Desmodium intortum*) while Mn toxicity is not a problem (as shown by the good growth of *Desmodium ovalifolium*).

# Management of Organic Materials In Indonesian Farming Systems

*Carl Evensen, University of Hawaii*
*Russell Yost, University of Hawaii*
*James Hansen, University of Hawaii*
*Michael Wade, North Carolina State University*

The marked response of some crops to green manure in previous experiments in Sitiung has suggested that the proper management of organic materials might reduce the need for lime and fertilizers on Sitiung farms. A series of experiments has been initiated in Sitiung to 1) quantify the influence of green manures on crop yields, 2) evaluate tree and herbaceous legumes for use in Sitiung farms, and 3) to incorporate information from Sitiung transmigrants in the selection and design of green-manuring systems. Findings from these studies should contribute to better management of organic materials on similar soils in Indonesia and elsewhere in the humid tropics. An especially important contribution is the identification of useful tree and cover-crop species for use in intercropping or relay-cropping with food crops.

Studies of organic matter decomposition and Al complexing are also under way at the University of Hawaii to elucidate mechanisms involved in the reduction of Al toxicity by organic matter additions. A survey of the literature concerning the ability of certain organic materials to reduce Al toxicity showed that organic ligands may modify Al phytotoxicity by: 1) forming soluble complexes with Al that are non-toxic, 2) reducing the concentration of toxic, soluble Al by forming insoluble complexes, and 3) preventing hydrolysis and precipitation of Al, and possibly maintaining toxic levels in the soil solution at near neutral pH.

Little is known about how the effects of organic materials on Al toxicity change as the organic material decomposes or whether application of organic materials can protect a crop through its life cycle. Research on these issues has recently begun at the University of Hawaii in a series of laboratory and greenhouse studies which will help to backstop and explain observations from the field research in Sitiung.

## Objectives

The objectives of this study are 1) to quantify yield increases of crops grown subsequent to green manures (from alley-cropped trees and herbaceous cover crop legumes); 2) to quantify the reduction in lime requirement and the amelioration of Al toxicity associated with organic matter additions; 3) to determine the adaptability (including Al tolerance) of selected tree and herbaceous legume species for use in transmigrant farming systems, and 4) to incorporate farm-family information from Sitiung transmigrants in the selection and design of legume management systems that provide N and soil protection.

## Procedures

*1. Alley-cropping experiment*

The experiment is planted on a Typic Paleudult site in Sitiung Vc and is laid out in a split-plot design with four replications. The treatments are as follows:

Main plots: tree species
1) *Albizia falcataria* (grown from seed)
2) *Calliandra calothyrsus* (grown from seed)
3) *Gliricidia sepium* (grown from hardwood cuttings)
4) No trees (control)

Subplot: liming levels
1) No lime
2) Low lime (Ca supplied as a nutrient at 375 kg lime/ha/year to provide 0.5 cmol Ca/kg soil to 15 cm depth)
3) High liming rate to reduce Al saturation to 25 % (2 t lime/ha applied first year; about 1/2 t lime/ha applied second year)

This report covers the crops grown during the 1985-86 rainy season, including upland rice, cowpea, and the growth of the tree hedges themselves. The tree hedges were planted 4 m apart in December 1984. Subplot size is 5.5 m x 12 m (consisting of three hedges 5.5 m long and 4 m between hedges) for the alley-cropped plots without trees. The harvested portion of the subplots consists of the central 3 m of the center tree hedge and 2 m to either side of the hedge for food-crop yields.

The trees were first pruned on September 17, 1985, nine months after planting. They were sampled to determine leaf fraction, wood fraction and dry

matter content, and the prunings were spread in the alleys to dry. After four days, leaves were shaken off branches and wood removed from the plots. Lime was reapplied on the high lime plots to bring acid saturation to 25 % (about 0.5 t lime/ha this season to make a total of 2.5 t/ha on these plots) and at 375 kg lime/ha on the low-lime plots (to make a total of 750 kg lime/ha). Also, TSP and KCL were broadcast, each at 50 kg/ha (i.e. 10 kg P and 25 kg K/ha). All these fertilizers and amendments were incorporated with hoes to a depth of about 15 cm.

A local variety of upland rice (disease-tolerant and preferred by local farmers) was planted at a spacing of 40 x 15 cm on September 25, 1985. The trees were pruned again on November 26, 1985 to reduce shading of the rice; the prunings were used as mulch between the rows of rice. Blast, Helminthosporium brown spot and lodging caused some damage, but the rice recovered well and produced a good crop of grain. Mature panicles were harvested on February 3, 1986. The straw and the remainder of the later maturing panicles were harvested on February 13. The straw was returned to the plots and buried.

The trees were pruned again on February 18, and TSP was broadcast at 50 kg/ha (10 kg P/ha) and incorporated by hoe with the leaves. A local variety of semi-determinate cowpea was planted at 40 x 20 cm spacing on March 6, 1986. On April 12, the tree hedges were pruned and the prunings applied as mulch between the rows of cowpea. Mature pods were harvested on May 5, and vines and the remaining pods harvested on May 15, 1986. The trees were allowed to grow uncut into the dry season.

2. *Source and management of green manure*

This experiment is also planted in Sitiung Ve on a Typic Paleudult soil. It is conducted using out in a Randomized Complete Block design with the following treatments:

**Experimental factors**

Species:

1) *Calopogonium mucunoides*
2) *Crotalaria usaramoensis*
3) *Centrosema pubescens*

Methods of green-manure application:

1) In situ incorporation
2) Cut and carry
3) Root residue and stubble from plots used to produce the cut and carry material

Levels of lime:

1) L0 = no lime
2) L1 = 375 kg lime/ha
3) L2 = liming to 40% Acid (Al+H) sat.
4) L3 = liming to 20% Acid saturation

Levels of nitrogen:

1) N0 = no N
2) N1 = 30 kg N/ha (split application)
3) N2 = 60 kg N/ha "
4) N3 = 120 kg N/ha "

**Experimental treatments**

| Trt no. | Green man. species | Applic. method | (N,lime) |
|---|---|---|---|
| Group 1: GM species and application methods) | | | |
| 1) | species 1 | method 1 | (N0,L2) |
| 2) | species 2 | method 1 | (N0,L2) |
| 3) | species 1 | method 2 | (N0,L2) |
| 4) | species 2 | method 2 | (N0,L2) |
| 5) | species 1 | method 3 | (N0,L2) |
| 6) | species 2 | method 3 | (N0,L2) |
| 7) | check (no GM) | -- | (N0,L2) |
| 8) | species 3 | method 1 | (N0,L2) |
| Group 2: (Lime response with GM also applied) | | | |
| 9) | species 2 | method 1 | (N0,L0) |
| 10) | species 2 | method 1 | (N0,L2) |
| 11) | species 2 | method 1 | (N0,L2) |
| 12) | species 2 | method 1 | (N0,L3) |
| Group 3: (Lime response with no GM applied) | | | |
| 13) | check (no GM) | -- | (N0,L0) |
| 14) | check (no GM) | -- | (N0,L1) |
| 15) | check (no GM) | -- | (N0,L2) |
| 16) | check (no GM) | -- | (N0,L3) |
| Group 4: (Inorganic nitrogen response) | | | |
| 17) | check (no GM) | -- | (N0,L2) |
| 18) | check (no GM) | -- | (N1,L2) |
| 19) | check (no GM) | -- | (N2,L2) |
| 20) | check (no GM) | -- | (N3,L2) |

This report covers the crops grown during the 1985/86 cropping season, which include the green manure (GM) crops grown during the 1985 dry season, and then upland rice and peanuts grown during the following rainy season. A uniformity trial was conducted on

this site before the treatments were imposed, in which all plots received 40 kg P/ha as TSP. After the uniformity trial and plot selection, the liming treatments were applied according to the treatment plan on June 13, 1985. The GM crops (see experimental factors above) were planted on June 14, 1985, at a spacing of 40 cm between rows. The plot size was 6 m x 4 m. The months of June, July and August are generally quite dry, averaging 100 mm of rainfall/month, as opposed to 250 to 400 mm during the rainy season. During these dry months crop production is quite tentative and farmers often leave their fields fallow. These GM crops were planted during this normally fallow period to make this technology more attractive to farmers since food crops are not replaced.

The GM crops were harvested on September 19, 1985, with a harvest area of 4 m x 2.4 m, and incorporated with hoes according to the treatment plan as given above. Litter on the soil surface and root residue produced by the green manures were also estimated since this is what is left in the green manure residue treatments. Two strips, each 40 cm wide and 4 m long, were harvested in each of the green manure residue plots (treatment numbers 5 and 6). Surface litter and stubble was collected and roots dug to 30 cm depth and shaken free of soil. These samples were dried and then sieved to remove remaining soil. This simple procedure did not result in complete recovery of fine or deep roots and is only a rough estimate. TSP (10 kg P/ha) and KCL (25 kg K/ha) were also incorporated at the same time as the green manures on all plots.

A local variety of upland rice (disease tolerant and preferred by local farmers) was planted at a spacing of 25 cm x 25 cm on September 24, 1985. Half of the required nitrogen was applied in the N treatments on October 23 (15, 30, and 60 kg N/ha), and the other half on November 27. Blast and Helminthosporium Brown Spot caused severe leaf damage in November, but amazingly by December the rice had produced new leaves and recovered well. This tolerance to diseases is the reason a local variety was grown. Grain set was very heavy and uniform and treatment effects were not evident.

Very heavy winds and rain near harvest time caused serious lodging throughout the experiment. Due to this lodging, the harvest areas were reduced to portions of the plots that were still intact for the first harvest of mature panicles on January 21, as well as the final harvest on February 1, 1986. The rice straw was all returned to the plots and buried by hoe along with TSP at 10 kg P/ha.

A local variety of red peanut (Valencia type) was planted at 25 cm x 25 cm on February 16, 1986. The peanut growth was quite good and minor rat damage was corrected by slightly reducing harvest areas to exclude damaged hills.

The peanuts were harvested on May 13, 1986 with most harvest areas being 8 $m^2$. Excellent nodulation was observed on most plots during harvest. Of the treatments, only the liming rates had a clearly observable influence on peanut yields, with higher rates producing larger, greener tops and better filling of the nuts. After peanut harvest, the green-manure treatments were again planted.

*3. Tree legume species assessment*

The seed for this trial was obtained from the Nitrogen Fixing Tree Association in Hawaii as a part of their effort to assess fast-growing legume trees under various environmental conditions. The trial is planted on two sites that contain different numbers of species and unequal plot sizes. The main planting is at the Center for Soil Research office complex near Gunung Medan, and consists of large (6 m x 20 m) unreplicated plots of trees at 1 m x 1 m spacing. The following 13 species were planted: *Acacia auriculiformis, A. mangium, A. mearnsii, Albizia falcataria, A. procera, Calliandra calothyrsus, Cassia siamea, Gliricidia sepium, Leucaena diversifolia* (K156), *L. leucocephala* (K8), *Pithecellobium dulce, Samanea saman*, and *Sesbania grandiflora*. The trial is designed to add on new species as seed becomes available. A secondary planting was made at a home-garden site in Sitiung Ve village. At this site, plots are 4 m x 7 m, with trees at 1 m x 1 m spacing and the species planted are *A. auriculiformis, A. falcataria, A. procera, C. calothyrsus, G. sepium, L. diversifolia, L. leucocephala*, and *S. saman*.

The tree seeds were planted in plastic bags in a nursery on September 3, 1985. No fertilizer was applied at either site, nor was the soil tilled. Seedlings were transplanted on December 18, 1985 at the Gunung Medan site and on January 2, 1986 at the Sitiung Ve site. Many of the *A. mearnsii* died within two months from transplanting and the *Sesbania* were transplanted too late and were very rootbound,

so that these two species were discarded from data collection. The Gunung Medan site was weeded in February and in April, and thereafter the most vigorous species began to shade out the weeds while the less vigorous species were allowed to compete as best they could with the weeds. Since the Sitiung Ve site was on a home garden, it was weeded about once a month for the first three months and infrequently thereafter because farmers there like their home gardens clean of weeds. Tree height and basal diameter were measured at four, six and nine months after transplanting at the Gunung Medan site (20 trees per plot) and at six months at the Sitiung Ve site (ten trees per plot).

*4. Effects of organic materials on Al toxicity*

Several methods are available to study how decomposition products of organic materials influence Al speciation and phytotoxicity. A method has been developed by Dr. N. V. Hue (University of Hawaii) to purify soil-solution samples to allow measurement of low molecular weight aliphatic and aromatic acids that are known to complex Al by HPLC. Another method involves passing soil solutions through exchange columns where forms of Al can be separated, providing a measure of the proportion of soluble Al which is complexed with organic ligands.

Decomposition and Al complexing studies using these techniques have begun at the University of Hawaii and are being conducted by James Hansen with the assistance of Dr. Hue. The studies follow earlier work by Dr. Hue in which he provided evidence that organic acids reduce Al toxicity as measured by root elongation.

## Results

*1. Alley-cropping experiment*

The yields of leaf and wood, and tree heights at pruning, are shown in Tables 1a, 1b, and 1c, respectively, and are calculated on the basis of total intercropped land area. Clearly *Albizia* was the most productive tree species in the first several prunings, but by February, *Calliandra* had become the most vigorous and productive species. Because of the huge amount of leaf and wood produced by the *Albizia*

**Table 1. Growth and yield of tree hedges, 1985/86.**

**a. Leaf yield***

| Tree sp. | Tree pruning date Sept.'85 | Nov.'85 | Feb.'86 | Apr.'86 | Total annual |
|---|---|---|---|---|---|
| | | | kg/ha | | |
| *Albizia* | 1489 | 538 | 264 | 220 | 2511 |
| *Calliandra* | 397 | 531 | 590 | 332 | 1850 |
| *Gliricidia* | 172 | 196 | 90 | 68 | 526 |
| LSD (0.05) | 335 | 154 | 141 | 87 | 600 |

**b. Wood yield***

| Tree sp. wood** | Tree pruning date Sept.'85 | Nov.'85 | Feb.'86 | Apr.'86 | Total annual | Fuel |
|---|---|---|---|---|---|---|
| | | kg/ha | | | | |
| *Albizia* | 2685 | 416 | 408 | 101 | 3610 | 3093 |
| *Calliandra* | 496 | 391 | 460 | 150 | 1497 | 956 |
| *Gliricidia* | 180 | 111 | 77 | 23 | 391 | 257 |
| LSD (0.05) | 969 | 120 | 139 | 30 | 1092 | 1069 |

**c. Tree heights at pruning**

| Tree sp. | Tree pruning dates Sept.'85 | Nov.'85 | Feb.'86 | Apr.'86 |
|---|---|---|---|---|
| | cm | | | |
| *Albizia* | 253 | 161 | 173 | 92 |
| *Calliandra* | 131 | 143 | 174 | 94 |
| *Gliricidia* | 109 | 94 | 98 | 57 |
| LSD (0.05) | 71 | 20 | 23 | 9 |

*Yield in kg/ha is calculated in the basis of total intercropped land area, not just yield per hedgerow. (To calculate kg yields per meter of hedgerow, multiply yields/ha x 0.0004).

**Fuel wood is the sum of only the September 1985 and February 1986 harvests, since the wood was taken off

during early growth, this species produced highest yields during the first year of pruning. *Albizia* wood yields were especially higher than the other species; however, the wood is soft and, according to local farmers, is not as desirable a fuel wood as is *Calliandra*. *Gliricidia* was far less vigorous and productive. It is probably not as well adapted to the infertile soils in Sitiung, although it may be at a disadvantage in this experiment because it was started from cuttings. The *Albizia* and *Calliandra* were grown from seed and therefore have the benefit of strong taproots. Analysis of variance of leaf and wood yields revealed that neither line nor lime x species interactions caused significant differences in yields. There was, however, a tendency for the *Gliricidia* yields to increase with increasing liming levels.

Rice grain yields increased with both increments of lime, but were not significantly different in response to application of green-leaf manures (Table 2). However, there was a tendency for rice yield to decrease in conjunction with more vigorous growth of the tree hedges, probably due to shading of the rows of rice closest to the trees. Timely pruning of the tree hedges to minimize this shading seems to be very important. Table 3 shows that cowpea grain yield, unlike rice, increased significantly with only the first increment of lime. Also, the application of *Albizia* green leaf manure caused significantly greater cowpea grain yields than the other green leaf manure species or the control. The interaction of green leaf manure species x lime caused significant differences of rice grain yields, but not of cowpea yields. This indicates that only in the case of rice grain, the crop response to green leaf manure application differed at the different lime rates. It is especially interesting to note (Table 2) that for rice

**Table 2. Effects of lime rates and green leaf manure species on grain yields of upland rice during the 1985/86 season.**

| Tree sp. | High lime | Low lime | Zero lime | Species means |
|---|---|---|---|---|
| | kg/ha | | | |
| *Albizia* | 1804 | 1219 | 939 | 1321 |
| *Calliandra* | 1901 | 1511 | 883 | 1432 |
| *Gliricidia* | 2013 | 1938 | 562 | 1504 |
| No Tree | 2349 | 2113 | 464 | 1642 |
| Lime rate means | 2017 | 1695 | 712 | |

LSD (0.05) Between species means = ns
Between lime rates means = 287
Between lime rate means for same species=576
Between species for the same or different lime rates = 774

**Table 3. Effects of lime rates and green leaf manure species on grain yields of cowpea during the 1985/86 season.**

| Tree species | High lime | Low lime | Zero lime | Species means |
|---|---|---|---|---|
| | kg/ha | | | |
| *Albizia* | 921 | 849 | 427 | 732 |
| *Calliandra* | 652 | 510 | 213 | 458 |
| *Gliricidia* | 556 | 459 | 138 | 384 |
| No Tree | 536 | 478 | 121 | 209 |
| Lime Rate Means | 666 | 574 | 225 | |

LSD (0.05) Between species means = 209
Between lime rates means = 143
Between lime rate means for same species=287
Between species for the same or different lime rates = 313

**Table 4. Green manure crop yields.**

| Green manure species | | Aboveground dry matter yield | Soil surface litter | Root residue |
|---|---|---|---|---|
| | | kg/ha | | |
| *Crotalaria* | Lime 0 | 1923 | — | — |
| | Lime 1 | 2806 | — | — |
| | Lime 2 | 3408 | 75 | 690 |
| | Lime 3 | 3710 | — | — |
| *Calopogonium* | (Lime 2) | 2198 | 400 | 640 |
| *Centrosema* | (Lime 2) | 2303 | — | — |
| LSD (0.05) | | 949 | | |

— No data available.

grain at the zero rate of liming, there is a strong tendency (although not significant) for grain yield to increase with increasing amounts of green leaf manure application. This indicates the possibility of reducing liming requirements by green leaf manure application. Cowpea grain yields (Table 3) were higher in response to *Albizia* application at all liming levels (although not significantly so at the zero lime level). The possibility of reducing lime requirements by application of green leaf manure is thus suggested by this data and confirmation will have to be sought in the next season's results, along with information on other possible effects of green leaf manures.

*2. Source and management of green manure*

The yields of the green-manure crops are shown in Table 4. Aboveground dry-matter yields of *Crotolaria* increased with increasing liming rates and was higher than the yields of *Calopogonium* and *Centrosema* at the equivalent lime rate (lime 2). However, all green-manure crops grew fairly well and produced fairly large amounts of dry matter, considering the dryness of the growing season.

The growth of the upland rice was very uniform and yields quite high, averaging 3150 kg/ha (with a range of 1880 to 4330 kg/ha). There were no significant treatment effects. It seems that at the moderately high liming rates (to at least 40% acid saturation for most of the treatments), the upland rice did not respond to either green manure or nitrogen application. A crop more responsive to liming, such as maize, should be used as the test crop next year.

Yields of the subsequent crop of peanuts were influenced by treatment effects and ranged from 100 to 2000 kg nuts/ha (with an overall mean of 980 kg nuts/ha). However, the residual effects of green manures applied in September did not have a significant influence on yields. The overall C.V. was 14.6% for the upland rice and 25.1% for the peanuts. Coupled with the significant replication effects for both crops, this indicates that the preliminary

**Table 5. Regression equations for peanut with and without green manure (GM).**

| X-Variable | Equation | Range of x | R-square |
|---|---|---|---|
| **Liming treatments with gm** | | | |
| % Acid Sat. | Y = 2024 - 20.8x | 24 - 78 | 0.6709 |
| % Acid Sat. | Y = 2115 - 24.9x + 0.04 x2 | 24 - 78 | 0.6713 |
| Exch. Ca* | Y = 201 + 807x | 0.22 - 1.76 | 0.7717 |
| Exch. Ca* | Y = 528 - 156x + 501 x2 | 0.22 - 1.76 | 0.8153 |
| Extr. Al+H* | Y = 2007 - 723x | 0.66 - 2.12 | 0.5955 |
| Exch. Mg* | Y = -33.7 + 4889x | 0.12 - 0.30 | 0.4585 |
| **Liming treatments without gm** | | | |
| % Acid Sat. | Y = 1741 -18.8x | 23 - 74 | 0.7167 |
| % Acid Sat. | Y = 427 +41.6x - 0.61x2 | 23 - 74 | 0.8434 |
| Exch. Ca* | Y = 288 +536x | 0.27 - 2.00 | 0.6522 |
| Exch. Ca* | Y = -375 +2265x - 803 x2 | 0.27 - 2.00 | 0.9137 |
| Extr. Al+H* | Y = 1941 -871x | 0.80 - 1.79 | 0.5937 |
| Exch. Mg* | Y = 296 +2681x | 0.10 - 0.37 | 0.3409 |
| **Liming treatments with and without gm** | | | |
| % Acid Sat. | Y = 1862 -19.6x | 23 - 78 | 0.6551 |
| % Acid Sat. | Y = 1319+5.18x - 0.246x2 | 23 - 78 | 0.6734 |
| Exch. Ca* | Y = 268 +636x | 0.22 - 2.00 | 0.6528 |
| Exch. Ca* | Y = -78.1+1573x - 454 x2 | 0.22 - 2.00 | 0.7133 |
| Extr. Al+H* | Y = 1879 -732x | 0.66 - 2.12 | 0.5184 |
| Exch. Mg* | Y = 195 +3463x | 0.10 - 0.37 | 0.3689 |

*x-values are in cmol/kg units

uniformity trial and special efforts of stratifying plot variability to replications helped to reduce experimental error due to soil variability. This may prove to be a useful technique in field experimentation on soils with high micro-variability, such as on newly cleared land.

Liming significantly increased peanut yields, but linear regressions with or without green manure did not differ significantly, as determined by comparing confidence intervals of slopes and Y-intercepts. To better identify the soil chemical factors associated with peanut yield, regressions were calculated between grain yield and a number of soil test variables (Table 5). The quadratic regressions with exchangeable Ca (cmol/kg soil) have the strongest relationships to peanut yield. Also the weaker relationships with extractable acidity (Al+H) suggest that the Ca nutrition rather than the reduction of Al toxicity is more important in liming for peanut production. The major point of interest, however, is that green manuring using the rates and methods described, did not reduce liming requirements as had been hypothesized. Table 6 shows soil analyses for samples taken during the growth of the peanut crop.

**Table 6. Analyses of soil samples (0-15cm) taken during the growth of the peanut crop on April 14, 1986.**

| Lime Rate | Al+H* | Ca* | Mg* | K** | ECEC | P | % Acid Sat. |
|---|---|---|---|---|---|---|---|
| | cmol/kg | | | | | mg/kg | |
| 0 | 1.84 | 0.31 | 0.12 | 0.23 | 2.51 | 6 | 73 |
| 375 kg/ha | 1.57 | 0.63 | 0.19 | 0.28 | 2.69 | 4 | 58 |
| 40% Acid Sat. | 1.12 | 1.22 | 0.21 | 0.24 | 2.82 | 5 | 40 |
| 20% Acid Sat. | 0.86 | 1.70 | 0.30 | 0.27 | 3.13 | 4 | 27 |

*Extracted with 1N KCl.
**Extracted with Mehlich I (double acid) extractant.

*3. Tree legume species assessment*

Height and basal diameter measurements are shown for the two sites in Table 7. The most vigorous species are *Albizia falcataria, Acacia mangium, Calliandra calothyrsus,* and *Cassia siamea.* These species have produced large amounts of wood and leaves and seem to be the most promising for future agroforestry work in areas with soils and climatic conditions similar to Sitiung. Soil analyses from samples taken in May 1986 are presented in Table 8. These soil test results are fairly representative of those commonly found in the Sitiung region. Monitoring of tree growth will continue for at least two years from transplanting to adequately compare species performance.

*4. Effects of organic materials on Al toxicity*

In preliminary studies in soils of high Al toxicity, addition of cowpea tops permitted increased root elongation in a soil with high extractable Al. Additions of lime or calcium hydroxide also increased root length in the same experiment. The Al complexing of organic breakdown products is also under study.

## Conclusions

The leguminous tree species, *Albizia falcataria* and *Calliandra calothyrsus,* show potential for use in alley-cropping under the soil and climatic conditions in Sitiung (i.e. acidic soils, low in bases, and a warm, humid climate). *Gliricidia sepium,* does not grow as vigorously under these conditions. During the 1985-86 growing season, the upland rice crop did not respond significantly to these green-leaf manure additions, but cowpea crop yields were increased by addition of *Albizia* prunings.

These results indicate that alley-cropping provides only a marginal benefit to farmers during the first year of cropping. However, as the tree pruning and cropping sequence continues on this site, it is quite likely that the frequent additions of green-leaf manure will cause increased soil fertility and crop yields. Also, the hedges of trees can provide other benefits, including an animal forage source, fuel wood, and erosion control when planted along

contours. These considerations indicate that further study of alley-cropping in Sitiung is warranted, along with assessment of farmer interest in the technology.

The legume species *Crotalaria usaramoensis*, *Calopogonium mucunoides*, and *Centrosema pubescens* can be successfully grown as green manures during the dry season in Sitiung. However, during the 1985-86 growing season, neither upland rice nor peanuts responded to green-manure application. The well distributed rainfall may in part explain the lack of response, since rainfall was erratic in previous trials in which strong responses to green manures were observed. Also, in previous trials, green manures were brought in from off-site and at least part of the response can be explained by importing of nutrients. A crop more responsive to N and less tolerant to Al, such as maize, may respond better to green manures. It is possible, however, that herbaceous green manures produced in situ on infertile sites, and not transported in from other more fertile sites, may not increase yields of a rotation of upland rice and peanuts.

The best adapted tree species of the 13 planted in Sitiung are *Albizia falcataria*, *Acacia mangium*, *Cassia siamea*, and *Calliandra calothyrsus*. All of these seem to have promise for fuel wood and agroforestry uses in farming systems in the humid tropics.

**Table 7. Tree heights and basal diameters at Gunung Medan and Sitiung Vc. Tree height in cm (basal diameter in mm).**

| | Gunung Medan | | | Sitiung Vc |
|---|---|---|---|---|
| Species | 4 mo. | 6 mo. | 9 mo. | 6 mo. |
| | cm(mm) | | | |
| *A. auriculiformis* | 86(10) | 129(14) | 210(21) | 120(12) |
| *A. mangium* | 94(16) | 218(29) | 368(38) | - |
| *A. falcataria* | 256(32) | 445(45) | 625(51) | 357(37) |
| *A. procera** | 35(10) | 34(12) | 35(14) | 29(14) |
| *C. calothyrsus* | 179(19) | 258(26) | 324(32) | 193(18) |
| *C. siamea* | 102(19) | 185(26) | 316(36) | - |
| *G. sepium* | 67(15) | 71(19) | 91(20) | 95(19) |
| *L. diversifolia* | 108(12) | 142(13) | 179(14) | 165(13) |
| *L. leucocephala* | 90(13) | 125(15) | 150(17) | 175(17) |
| *P. dulce* | 65(8) | 79(9) | 90(12) | - |
| *S. saman* | 68(16) | 76(21) | 97(24) | 103(24) |

*Shaded heavily by adjoining plots after six months.

## Implications

If, as suggested by these studies, organic materials may be substituted for lime, this will have major implications for resource-poor farmers on acid tropical soils. In many cases, these farmers can not afford to buy lime and government subsidies are expensive and short-lived. Of the technologies tested, alley-cropping with *Albizia* seems to hold the most promise for reducing liming requirements and must now be tested by farmers to determine how well it fits their systems.

**Table 8. Soil analyses of samples taken May 6, 1986.**

| Site | Al+H* | Ca* | Mg* | K** | ECEC | P** | % Acid sat. |
|---|---|---|---|---|---|---|---|
| | cmol/kg | | | | | mg/kg | |
| Gunung Medan | 3.33 | 1.36 | 0.46 | 0.26 | 5.41 | 3 | 62 |
| Sitiung Vc | 1.76 | 1.00 | 0.25 | 0.28 | 3.41 | 0 | 52 |

*Extracted with 1N KCl.
**Extracted with Mehlich 1 extractant.

# Conservation-Effective Rainfed Farming Systems For the Humid Tropics

*Samir A. El-Swaify, University of Hawaii*
*I Putu Gedjer Widjaja-Adhi, Center for Soil Research*
*Soleh Sukmana, Centre for Soils Research*
*Suwardjo, Center for Soil Research*
*Lalit Arya, University of Hawaii*
*Janet Schultz, University of Hawaii*

Soil erosion by water represents the most serious cause of land degradation and loss of productivity in the humid tropics. Transmigration areas, such as Sitiung, West Sumatra are particularly vulnerable to excessive runoff and soil loss due to the exposure of land after forest clearing. Conservation-effective farming systems, (i.e. systems that are both productive and protective against losses of soil and water resources), must be practiced, particularly in rainfed situations, if farming on these soils is to be a sustained enterprise. The deliberate design of such systems requires a quantitative understanding of all those factors which control the erosion process, namely site attributes and viable management alternatives. The effectiveness of potential conservation packages should be ultimately tested at a realistic operational scale.

## New Project Update

*This project has not been under way long enough to yield a substantive report, but should be mentioned because of its importance to the program.*

### Objectives

The objectives of this study are 1) to quantify the rainfall erosion potential for major environments in the area; 2) to evaluate the effectiveness of alternative cropping systems and land-management practices for controlling the erosional losses of soil and water resources, and 3) to integrate the above with other agronomic and socio-economic information for use in developing productive and stable watershed-based farming systems for the humid tropics.

### Results

The intended hiring of a "soil and water conservationist" as new member of the site team was abandoned as funds were not made available for this purpose. For the same reasons the plan of work which was detailed in last year's report cannot be [illegible]uted. Miss Janet Schultz joined us as a graduate research assistant beginning August 1986 following a B.S. degree from Purdue University with considerable experience in soil erodibility determinations at the National Soil Erosion Laboratory. Her thesis research will be the primary erosion/conservation input to the program in the foreseeable future. Her research will be consistent with our stated objectives with the specific focus of quantifying the erosional consequences of forest clearing. Discussions with site team members who visited Hawaii during the past months have revealed several opportunities for conducting this research at Sitiung. Until these opportunities are thoroughly explored, however, a primary experiment has been set up on a managed forest site at Kaiwiki, Hilo, Hawaii.

# Expert Systems to Develop And Transfer Soil-Management Research

*Russell S. Yost, University of Hawaii*
*Stephen Itoga, University of Hawaii*
*Z.C. Li, University of Hawaii*
*James Hansen, University of Hawaii*
*I. Amien, University of Hawaii*
*Phoebe Kilham, University of Hawaii*
*Carol J. Colfer, University of Hawaii*
*I. Putu G. Widjaja-Adhi, Centre for Soils Research*
*M. Sudjadi, Center for Soil Research*
*Michael Wade, North Carolina State University*

Expert systems or knowledge-based systems are designed to record the expert knowledge and problem-solving skill of experienced persons. As a result of experience, experts typically develop a repertoire of most likely causes given certain observations.

This "knowledge base" is what the expert uses to determine the nature and cause of a problem and to make recommendations based on the answers to a list of questions. Depending on the subject, various types of information are needed for a diagnosis. In expert systems for soil management, soil taxonomic category and soil analytical data are needed. We have been assembling soil data from soil survey investigations to supply data as a general background to specific recommendations. A well-organized method of representing and retrieving such information becomes important as the volume of information grows. In addition, we wish to capture and retrieve information in a way that is more natural to the information and to the user.

In further describing how expert system might be of use put yourself in the following scenario:

### Scenario

You have just begun to work in an area and you suspect you may have a problem with soil acidity. What are the first steps you will take to determine whether crop growth is limited by soil acidity? If it is, what will you do about it?

You have been asked to visit a neighboring experiment station. The manager of the station suspects a problem with soil acidity. How do you diagnose the problem and suggest remedial treatment?

The essential question is how would you determine whether soil acidity is really the problem, and if it is the problem how do you make the best recommendation for solving it?

### Possible Approaches and Questions

You might ask whether the soils have been analyzed. If so, how will you use the data? What is the significance of 3 meq/100 g or cmol/kg of extractable Al? How do you adjust for the different acid tolerances in tropical crops? Where do you obtain data on acid tolerance of tropical crops? For example, how would you change your lime recommendation if you are planting cassava, which tolerates approximately 80% Al saturation, instead of mung bean, which tolerates approximately 0% Al saturation (where Al saturation is cmol Al/(cmol of Al, Ca, Mg, K, and Na)?

You might further ask whether there has been a history of response to lime applications in the area. Have there been reports of Al or Mn toxicity or Ca, Mg, or K deficiency symptoms? Are the roots of Al sensitive plants unusually shallow? Has anyone observed the short, stubby discolored roots typical of Al toxicity (Gonzalez et al. 1979)? Do plants wilt sooner than usual after rains (Ibid 1979)? Are there other symptoms of Al toxicity or Ca deficiency (Foy 1974)? Are there symptoms of Mn toxicity, i.e. crinkling of leaves (Parker et al. 1969; Kang and Fox 1980)? If these symptoms appear, then there may be cause to suspect that acidity is indeed limiting crop yields. The next question is: What should be done to remedy the situation? One option would be to measure the levels of Al and Mn in the soil, and interpret the values using standard procedures for making lime recommendations.

Another option would be to conduct field experiments for several years to determine response curves of the crop to lime application or otherwise ameliorating the soil acidity. Seldom do we have the funds, personnel, or time for this approach. Moreover, this would waste valuable resources that could be allocated to other research. In the past, we have been too quick to conduct field studies that did not always provide new information, often because sources of variation such as weather, disease and crops inflated the experimental error and reduced the amount of

useful information that could be extracted from the study. Before resorting to a new study, we should first use existing information from specialists and people with experience. In order to do this effectively, we must develop a series of knowledge bases to record the existing information and keep it up-to-date. The use of expert systems and simulation models holds promise to do just this task.

With these systems we can make the most of the data and information available instead of always assuming that we must generate our own. By exploiting existing information first we can avoid duplication of effort. This approach will increase the efficiency of research effort and speed progress.

Another option is to collect or determine fundamental soil data such as soil pH, levels of extractable Al, Ca, Mg and K, to find out how others with experience in tropical soils and crops have managed similar situations, and to evaluate their approaches and results for our situation. How do we find out about such experience and research elsewhere? Communication channels among researchers within the tropics should be improved so that experience can be shared. Sharing information through the few scientific journals is useful but may miss the critical time when decisions concerning long-term research are made. As a first approximation we should look for similarities in soils, crops, available resources and market structure.

In practice, one of the best ways to find analogous areas is to use soil taxa as classified according to Soil Taxonomy. An example is shown in Table 1 where soils analogous to those of a recent sampling and analysis in Western Samoa are compared with others in the Soil Conservation Database (SCS Staff 1987). In this sample, soils from Brazil, Brunei, Costa Rica, Philippines, Papua New Guinea, New Zealand, Cameroon, Ecuador, Chile, Guatemala, Kenya and Pakistan had similar diagnostic properties as defined by Soil Taxonomy. How much do we know about the similarities in land use and management among these various sites? How much could we learn and benefit from better knowledge of the agricultural systems in these locations?

It is clear that assistance from someone with training and experience in diagnosing soil acidity conditions would be helpful for those who, without such experience, must make the decision to lime, to grow some other crop or to abandon that particular land. It was with these considerations that we decided to explore the expert-system approach and to develop an exploratory system to aid in structuring and transferring experience and problem-solving knowledge.

**How the Lime Recommendations System Develops a Recommendation**

The ACID4 expert system is outlined in Figure 1. As shown in this figure there are several modules in the system. One of the first modules is a soil database containing Soil Conservation Service data (SCS 1987) for several Pacific Basin and Southeast Asian countries. This module allows you to select the country and soil series whose classification and soil chemical data will be used in the recommendation. Effective cation exchange capacity, extractable Al, soil pH and bulk density values will be passed to the expert system for use in developing lime recommendations. These values will be considered the default, but you can enter your own data for each of these during program execution or at the end. All of the data needed for the lime recommendation can be changed and the system rerun. We recommend that you change the data and rerun the system because it is a way of seeing how sensitive the lime recommendation is to changes in the data. From this, you can determine which data are the most critical to the recommendation.

After the program exits the soil database, you must choose the type of crop for which the recommendation is to be generated. The Al tolerance of the crop is inferred from crop selection. Al tolerance is the level of Al saturation to which the soil will be adjusted by liming, if liming is necessary. If you have a graphics display a graph of the estimated relative yield will be shown.

The system then determines various modifying factors to the lime requirement. The modifications include consideration of the depth of liming, with cautions generated if the intended depth of incorporation is either too shallow or too deep. If the crop is Al sensitive, Al saturation of the soil is high, and the incorporation depth is too shallow, the system warns of possible drought due to shallow rooting and consequently reduced amounts of available water (Gonzalez et al. 1979). This module is currently being expanded to more adequately describe the severity of drought resulting from shallow rooting.

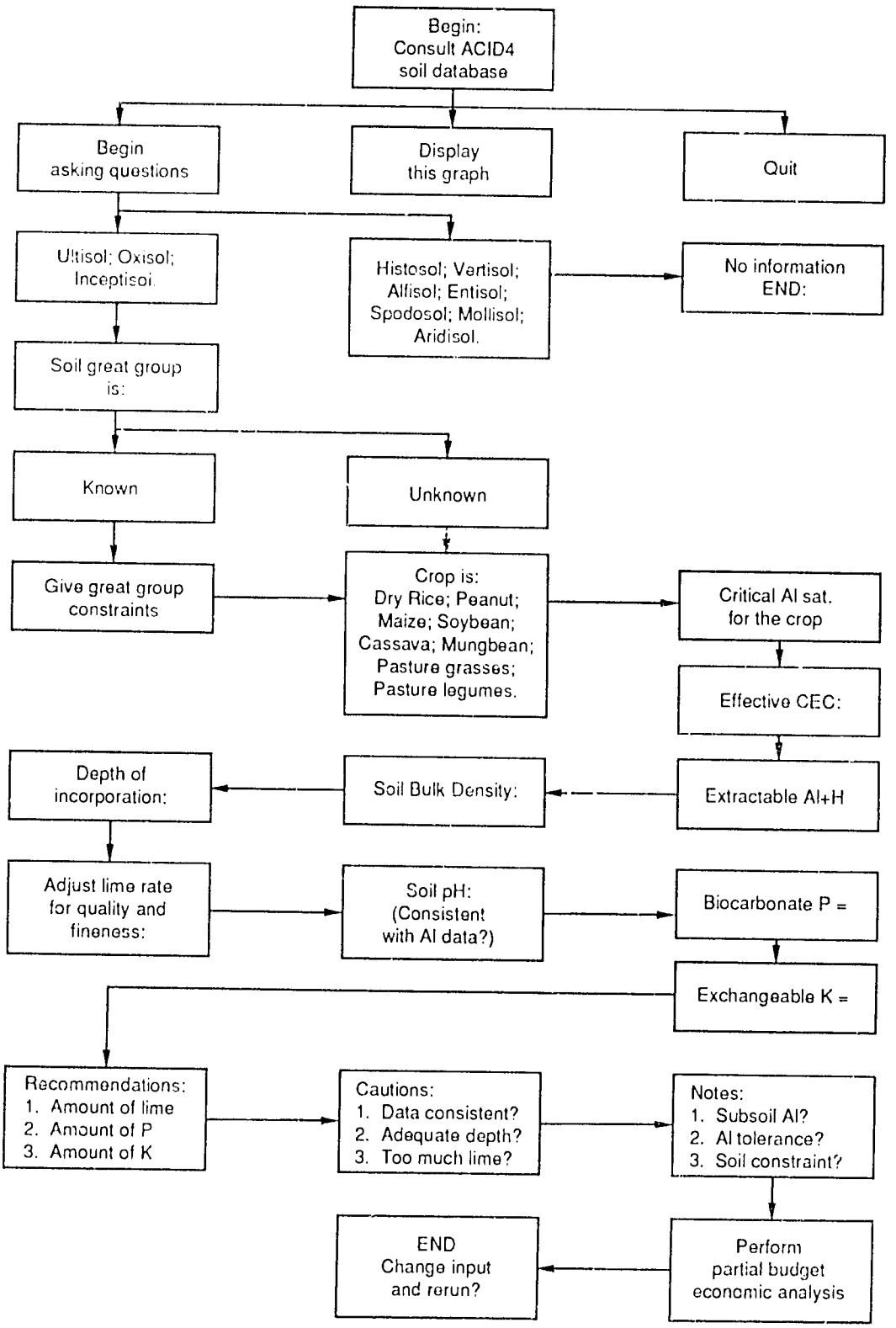


**Figure 1. Directed graph of ACID4 expert system.**

The lime requirement is increased or decreased based on observations that green-manure additions seem to enhance crop yields during drought years (TropSoils/Indonesia 1985). Although the yield increases due to organic material are difficult to quantify, that organic acids modify the toxic effect of Al has been shown by Hue et al. (1986). However, yield increases can be due to the nutrients in green manure materials having been brought in from areas external to the fields. Studies are needed to determine the nature of this benefit so that it might be more thoroughly understood and managed more effectively. The increase in yield due to organic material additions is an example of information that is not as yet sufficiently understood to be described by a mathematical equation, yet seems to be an effect that should be considered in making lime recommendations as it could lead to a reduction in the amount of lime required.

When lime is to be recommended questions are asked about both the chemical and physical quality of the lime. The amount of lime recommended is adjusted according to the neutralization of acid relative to $CaCO_3$. An estimate of effectiveness based on fineness is made from data presented by Barber (1984). We are searching for additional data on soils of tropical mineralogy (kaolinite, amorphous Al and iron oxides) to replace his approximation. In addition, we need estimates of residual effects as influenced by particle size so that allowance can be made for long-term residual effects.

Several checks are made to see if the data presented to the system are consistent with expectations. For example, if the soil pH is less than 4.5 and there is virtually no extractable Al the system will alert you that this is unusual and that you should verify your data. The system will point out that soils of kaolinitic mineralogy usually would have considerable Al at pH 4.5. Similarly, if there is considerable Al at pH's greater than 6.0 the system will warn you that this is unusual and that the data from which the system was developed did not have this characteristic. The Al-based recommendation methodology used by ACID4 does not diagnose all mineralogical groups. In volcanic ash soils, Al toxicity is not usually the most important yield-limiting effect. It may be Ca insufficiency, Mn toxicity or problems with P deficiency (Fox et al. 1986).

Economic analysis is another integral part of a lime-recommendation system because it is important to estimate the profit or loss. We are presently using a partial budget analysis that considers the cost of lime, transportation to the farmer's home and to his field, and the costs of spreading. If farmers routinely hoe their fields the cost of lime incorporation is not included. The value of the potential increased crop yield due to the lime is estimated from farmer or extension agent estimates of high and low yields. The various costs are then subtracted from the value of the crop. We also plan to report profit or loss as a percentage of investment in lime.

The lime-recommendation system described in this paper is still being developed but has already demonstrated a potential for organizing information, both mathematical and experiential, into a decision-making framework and making sound recommendations. It is easy to use, and can assist you in learning elements of the decision-making process.

The information age challenges us to do what humans do best—learn, organize information and deal with uncertainty. Things that we do less well, such as rote memorization and direct information retrieval, should be gradually shifted to microprocessor-based technology. We should be encouraged to do what we do best and have the microprocessor supplement and expand our capabilities in the areas where it is most useful: memory intensive activity and intensive computation.

## Objectives

The objectives of this study are 1) to design and construct expert systems in soil and crop management technology which implement the learning and deductive capability possible with fifth generation logic-based languages; 2) to evaluate the implementation and performance of an interdisciplinary expert system on soil management problems of the humid tropics; and 3) to evaluate the representation of farmer-information within the expert system.

## Procedures

Information has been assembled from a large variety of sources for incorporation into the liming expert system. This includes information from field research efforts in Sitiung and elsewhere, information contributed by those who have reviewed the system, and information from other scientists on the TropSoils project (e.g. work on economic analysis).

For the most part, project members assemble, organize and code the information. Support staff provide considerable assistance in publishing the manuals and aiding in the distribution.

## Results

Several prototype liming expert systems have been developed and distributed (ACID2,ACID3,ACID4). The current version of the lime recommendation system (ACID4) will be distributed to approximately 100 previous users of the other systems. The users represent a wide range of scientists throughout the humid tropics as well as in various institutions in temperate countries, who use the software in teaching and training. In most cases the software is used to provide example applications of expert-system applications. Some scientists have used the software to develop recommendations for large regions and have then plotted the results on maps. Although the main knowledge base for the system now derives from field research in Sitiung, it is apparent that there is utility in using the same approach in many other areas of the humid tropics. Local information can be incorporated into the system and this is encouraged after examination and validation of the original system.

### *1. Soil module*

The Soil Conservation Service and Soil Management Support Services contributed their soil database file from Lincoln, Nebraska. A soil module with the minimum data set required by the expert system has been prepared for use in providing default data for use in the system. The soil data module provides default soil analytical data for selected regions in South East Asia and the Pacific Basin. Selected profiles are provided from Thailand, Indonesia, Philippines, Malaysia and Oceania. Data for Central and South America, and for Africa, or for more specific regions can be substituted for these data to provide default data more in keeping with local situation.

Soil data were preprocessed to include three zones: 0-15, 15-30, and 30-45 cm, soil depths to which the crop may grow or which might result from farmer cultivation or mixing operations. At the present time the module has data recorded by 15 cm depth increments. This permits us to consider what soil characteristics the crop might encounter at various depths of rooting. In addition, this standardization of depths permits pooling soil survey information in a manner necessary to derive estimates of variability. With pooled data the mean values of extractable Al and H can be computed together with corresponding estimates of variances for the soil area. For the Sitiung soil survey area in Indonesia we have computed the means and variances of ex-

**Table 1. List of countries with soils of similar taxonomy to those in Western Samoa.**

| Country | Great group | Name* | Pedon no. |
|---|---|---|---|
| Brazil | AC | | 81 308 220 |
| Brunei | AC | Mutobo | 84 284 232 |
| Brazil | AC | Haplic Acrorthox | 85 729 220 |
| Costa Rica | UM | CR-012 | 84 272 295 |
| Philippines | DY | Not Designated | 82 401 725 |
| Costa Rica | DY | CR-2 | 82 424 295 |
| Papua N. Guinea | DY | PNG No. 6 | 82 798 650 |
| Papua N. Guinea | DY | PNG No. 6 (moist) | 82 700 650 |
| New Zealand | DY | Egmont Black Loa | 83 366 660 |
| Cameroon | DY | Idise | 83 438 257 |
| Ecuador | DY | Ecuador 011 | 83 463 325 |
| Ecuador | DY | Ecuador 005 | 83 465 325 |
| Chile | DY | Pelchuquin | 83 481 275 |
| Chile | DY | Puyehue | 83 487 275 |
| Chile | DY | Puerto Fonck | 83 493 275 |
| Chile | DY | Puerto Octay | 83 503 275 |
| Ecuador | HU | Ecuador 006 | 83 453 325 |
| Ecuador | HU | Ecuador 009 | 83 457 325 |
| Ecuador | HU | Ecuador 004 | 83 461 325 |
| Ecuador | HU | Ecuador 003 | 83 473 325 |
| Ecuador | HU | Ecuador 008 | 83 475 325 |
| Guatemala | HU | Guatemala 2 | 83 512 415 |
| Costa Rica | HU | CR-015 | 84 275 295 |
| Philippines | HU | Not designated | 85 603 725 |
| Kenya | HU | Kenya 162/4-2 | 78 170 505 |
| Kenya | HU | Kenya 162/4-6 | 78 238 505 |
| Terra incognita | HA | Thabana | 82 571 000 |
| Ecuador | HA | Ecuador 001 | 83 459 325 |
| Ecuador | HA | Ecuador 010 | 83 477 325 |
| Guatemala | HA | Guatemala 1 | 83 511 415 |
| Guatemala | HA | Guatemala 12 | 83 522 415 |
| Pakistan | HA | Murree | 84 582 700 |

*AC=Acrorthox; UM=Umbriorthox; DY=Dystrandept; HU=Humitropept; HA=Hapludoll

tractable Al plus H, effective CEC, and soil pH for most mapping units.

Having these calculations stored in the soil database permits the generation of an estimate of precision of the recommendation as it is being generated (Table 1). In this way, the recommendation is based on more complete knowledge not only of a mean value but also of the expected variation in the recommendation. To our knowledge this is not systematically done at present.

By directly accessing a soil database for a region, a person without extensive knowledge of soil chemical measurements or of crop nutrient requirements can develop recommendations nearly as accurately and comprehensively as an experienced person with chemical data in hand. This system further permits far more precise recommendations than possible with Soil Taxonomy alone. All the warnings, inferences and experience suggested by Soil Taxonomy can be included as warnings or cautions when advisable. Key concepts or data are documented in the system for reference and for teaching inexperienced users.

Although we currently are using soil survey data only in developing recommendations for acid soil management, such data will be useful for making other soil- and crop-management decisions. These data together with accurate weather records could provide a sound basis for rapid assessment of potential use and for identification of possible management constraints for land-use planning in new areas, and also could provide a repository for current experience and management of existing systems. Future versions of the system will provide a more extensive soil database and will utilize water balance information to assess the effect of increasing the depth of rooting on drought resistance, nutrient leaching and Ca movement into the subsoil. As described above, the soil database will include estimates of variance associated with each of the data for use in forming estimates of precision for computed values for a variety of interpretations.

Using Soil Taxonomy to retrieve soil information:

Problems encountered in the computer representation of the information contained in Soil Taxonomy are those inherent in representing data from any taxonomic system that identifies taxa on a sequentially differentiated basis, as is the case in Soil Taxonomy, in a system that retrieves stored information in any sequence (e.g., an expert system). With the first system a user follows a prescribed sequence to arrive at a classification; following a different sequence can result in a completely different classification. This method of classification is called procedural. With the second system, classification is independent of any sequence. This method of classification is called declarative. Although the definitions on Soil Taxonomy are in themselves declarative, the sequential keying needed to apply them is procedural. In our expert system, on the other hand, both actions—retrieving taxonomic information associated with a soil name and making interpretations on the soil series, family, or great group—are declarative. Thus when a soil is classified using Soil Taxonomy and then that soil name is used to retrieve information about the soil from the expert system, this combination of approaches is likely to lead to inefficient information retrieval from the system as well as misinterpretation of the information obtained.

One remedy might be to ensure that the specific diagnostic properties are both necessary and sufficient to classify a particular soil in any sequence. Even though the necessary diagnostic properties of a soil category are clearly stated in Soil Taxonomy, the "sufficient" factor presents problems. To be sufficient to classify the soil in Soil Taxonomy, the soil must not only have the diagnostic properties but must also be considered or evaluated in the sequence prescribed by Soil Taxonomy. For example, it is often convenient to key certain taxa on the basis of what they are not. Hence, Orthox soils are keyed as "Other Oxisols" indicating that Orthox is an Oxisol that is not Aquox, Humox, Torrox, or Ustox. This method makes computer-based information retrieval of such sequenced data difficult since the user must know the diagnostic criteria for Aquox, Humox, Torrox, and Ustox in order to deduce properties of Orthox.

Another problem relates to the use of "or" in Soil Taxonomy. At various levels of the taxonomic key one is presented with options to choose one set of criteria or another. Having optional criteria increases the probability of having sufficient data to classify the soil. From a computer-based information-retrieval standpoint, however, this causes more difficulties. Offering divergent criteria for the "or" options leads to significant loss of information for the user. Upon retrieval he does not know which of the

sets of criteria describes the soil and therefore cannot definitively state that the soil has any one of them.

Using taxonomy to infer quantitative soil properties:

More and more scientists, policy-makers, and land-use planners are requiring numerical data before making farming decisions. Taxonomic systems have been used to group and classify objects and properties into units that can be managed and manipulated conceptually. With the advent of microprocessor-based tools for data and information management, the ability to retrieve specific data and use it in decision-making has been substantially expanded. For example, those working with a large number of soils usually cannot remember either the morphological composition of soils as explicitly described in profile descriptions, or the exact numbers of such factors as cation contents or clay contents in each of the soil horizons. The same scientists, however, are able to retain the key features of the information and readily use these features in decision-making and in discussing general concepts. Discussions and decisions can be markedly improved by access to specific data, particularly if there is a need to reconsult data when faced with an unexpected question. This points out the advantage of having access to the specific data whenever and wherever one is in a decision-making position. Intelligent databases, those which store both facts and logical relationships, improve the quality of decisions and problem-solving in soil management situations.

Although certain applications of Soil Taxonomy in the past have taken advantage of the ability of its classification system to retain the essential information without losing all the detail, with the advent of new information-management systems such as ACID4 the use of Soil Taxonomy may change. At the same time, the increased availability of shared databases will allow soil and crop experts rapid access to specific information from other fields. In the long term this trend may fundamentally alter the way in which Soil Taxonomy is used.

A well-designed expert system with supporting weather and soil databases could serve as an information-transfer mechanism among researchers, and as an effective decision-support system for variety of users from laboratory personnel with data needing interpretation to land-use planners with little data. With the inclusion of a soil database and weather data, such systems could be used by government planners to explore potential costs of various land-development schemes. These systems are a powerful new method of using soil survey information for land use planning.

Expert systems that have been carefully crafted contain practical, experience-based knowledge, as well as problem-solving methods and procedures for diagnosing and recommending remedies for soil-acidity related constraints to crop growth. These systems can be improved by increased breadth and depth of soil, crop and weather data. Their database format offers a highly accessible method of storing data needed by the expert system to develop accurate diagnoses and recommendations.

*2. Economic evaluation module*

The current version of the recommendation system provides an economic evaluation module that can generate a partial budget analysis of the profitability of lime applications. One result of the economic analysis is the outstanding importance of considering the residual effects. A preliminary method has been developed to express the benefits of residual effects of lime applications in terms amenable to economic analysis.

Work on an economics module was initiated by James Hansen. This economic module was designed to express some of the constraints to the suggested liming levels and recommendations.

Liming recommendations based solely on near maximum (95%) yields may not be appropriate without considering whether the recommended lime applications are likely to be profitable. An economic-analysis module was added to ACID4 to help the user to estimate the profitability and economic risk associated with liming. The economic-analysis module will attempt to satisfy one of three goals based on estimates of profit associated with liming: 1) liming is recommended, 2) liming is risky or 3) liming is not recommended. Three criteria are used to determine which goal is satisfied: 1) a most likely estimate of profit, 2) a pessimistic estimate of profit and 3) percent profitability. The pessimistic estimate of profit is used as a measure of economic risk associated with yield variability. Percent profitability is used as a measure of the sensitivity of estimated profit to deviations from the estimates of yield, crop

price, and liming cost.

Liming is recommended if the pessimistic estimate of profit is positive and profitability is greater than or equal to 100%. Liming is risky if the likely estimate of profit is positive and either the pessimistic estimate of profit is less than or equal to zero or profitability is less than 100%. Liming is not recommended if the best estimate of profit is less than or equal to zero. Estimates of profit are estimated value of the crop (yield value = yield x crop price) after liming minus the yield value if the field were not limed minus the cost of liming.

User estimates of yield and crop price are required in order to estimate yield values. The user is asked to provide both a pessimistic and an optimistic estimate of yield. A median of the two estimates is offered as a most likely estimate of yield. The user may have reason to change that estimate. The most likely estimate of yield is used to give a most probable estimate of profit. The pessimistic estimate of yield provides a measure of the risk associated with liming. The increase in yield expected from liming is based on a model describing experimental relative yields as a function of soil Al saturation and crop tolerance to Al. The modifying effects of organic materials are also considered.

Liming costs are based on user-supplied estimates of lime price, interest on credit and the labor costs of transporting, spreading and incorporating lime into the soil. Tillage to incorporate lime into the soil, if required, is a fixed cost. It varies with the area of land that is limed, but not with the amount applied per unit of land. The other costs are treated as variable costs, and vary with the amount of lime applied per unit of land.

Lime often remains effective more than one crop season or year. This can reduce the amount of lime needed in subsequent years. We have attempted to account for this in economic calculations by the concept of 'prorated cost.' Prorated cost is the amount of total lime cost which can be considered due or appropriate to be charged to the current cropping year. This means that with liming material of long residual effect (continues effective for several years) we would charge a cost to the current year in proportion to the amount of residual effect. The amount of residual effect is calculated from field data showing by how much lime requirement in future years can be reduced because of the initial lime application. In addition we consider the fact that money has been put aside to buy the lime for which the benefits may only be realized in future years. This is done by deducting interest from the future value of the lime.

There are several assumptions associated with this analysis, including the following:

a. It is assumed that the farmer can deal with the cash flow problem of having money invested in lime but not having that money available to him until the crops are grown and sold.
b. There probably is some aspect of risk that would tend to work against the investment of lime in this manner. For example, we would assume that one is risking in that there is some likelihood of obtaining benefits from the reduced acidity in the future.
c. We intend to include lime fineness in the residual effect because to increase the proportion of lime passing a 100-mesh screen, for example, would cost considerably in terms of energy and equipment wear of the grinding machinery.

The economic-analysis module deals with sequential and relay-cropping patterns in much the same way as it does with sole cropping. Yield values are calculated for both crops based on user yield estimates, soil Al saturation and their respective tolerances to Al.

Several potential sources of error exist within the economic-analysis module. Yield and crop price at harvest time are difficult to estimate accurately. Crop prices and liming costs may not be readily available to users of the system. Plans exist to incorporate a user modifiable data base of prices and costs for Sitiung in a future version of ACID. The model of relative yield as a function of Al saturation is based on a single 95% critical Al saturation and the assumption that yield will decrease linearly to 0 as Al saturation increases to 100%. The accuracy of relative yield estimates may be low at very high Al saturations. Future versions will improve the model by adding a 50% relative yield Al saturation for those crops for which data is available.

Knowledge representation:

Two implementations of the knowledge base are being developed, one in expert system shell format and another using Prolog logic programming lan-

guage. This approach frees us from the confines of one particular knowledge representation approach and encourages comparison and contrast between the methods. Our results confirm experience in medical and industrial expert system development where there seems to be an important role for expert system shells but one can easily outgrow them and wish for more flexibility as the application matures. A programming language, while providing great flexibility, also requires major efforts of a programmer familiar with the language of implementation.

We continue to recommend experienced scientists and agriculturalists to explore implementation of their knowledge in expert-system format. This method of information dissemination and transfer of problem-solving skill should be seriously considered along with the usual methods of journal paper, review paper and research or extension bulletin. We suggest scientists include a diskette of a simple knowledge base along with a bulletin or review paper to illustrate and implement the knowledge described in written form.

## Conclusions and Implications

The efforts to develop an expert system to capture lime-recommendation expertise have been successful to date and have provided tremendous insight into both the recommendation-making process and to methodology to learn and construct expert systems. We have definitely learned a great deal through the effort of implementing a knowledge base in expert-system format and in subjecting this application to the user community for scrutiny. Numerous individuals, including our own students and those in Indonesia and other countries, have begun acquiring expert systems technology for their own applications. This may have a tremendous impact towards using microcomputer technology to solve one of the age-old problems of information development and transfer in agricultural systems.

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# Acid Savannas
# Cornell University

*Prepared by*
*The TropSoils Acid Savannas Program*
*Cornell University*
*Douglas Lathwell, Program Coordinator*

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# Introduction

The vast, tree-dotted acid savannas found in tropical Africa, Asia, and Latin America represent a frontier in the agricultural development of many nations. Past research in the Cerrado of Brazil has shown that the soils typical of that savanna—highly weathered, well-drained Oxisols—can sustain high crop yields year after year if properly managed. But, without adequate lime and phosphorus, crops fail. The soils are acid and infertile, with levels of aluminum toxic to plants. The challenge in the Cerrado, as in other tropical savannas, is to devise cropping systems and soil-management technologies that make the most of the costly amendments necessary to overcome these constraints.

Research at the Cerrados Agricultural Research Center (CPAC) has already led to a basic understanding of lime and fertilizer management in the Cerrado. TropSoils' program here seeks to expand several areas of this understanding in order to increase the efficiency of certain soil amendments, and to learn how research results from the Cerrado can be applied to other regions. TropSoils work has focused on three topics, developed in collaboration with Brazilian scientists at the CPAC: 1) management of nitrogen, including the use of green manures; 2) quantification of soil water and chemical budgets in order to understand the fate of soil amendments; and 3) identification of soil constraints affecting management, such as restricted drainage and chemical or physical barriers to roots.

While agricultural development in the Cerrado has made great strides on the basis of past research, the agricultural potential of other acid savannas remains largely untapped. The studies reported here, which have had the advantage of an association with established research programs and modern facilities in the Cerrado, are intended to help unlock the soil resources of savannas in other tropical regions of the world.

# Personnel

**Faculty - Senior Scientists**

Cornell University

- R. B. Bryant
- D. R. Bouldin
- J. M. Duxbury
- T. L. Grove
- S. D. Klausner
- D. J. Lathwell - Program Coordinator
- R. F. Lucey
- W. S. Reid
- S. J. Riha
- A. R. Van Wambeke
- R. J. Wagenet - Department Chairman

Brazil

- W. T. Bowen
- E. R. Stoner

Cerrados Agricultural Research Center (CPAC)

- A. Suhet
- E. Labato
- E. de Freitas
- J. Pereira
- J. Peres
- L. Miranda
- W. Geodert - Chief, CPAC

**Junior Scientists - Graduate Students**

- I. Buttler
- R. Carsky
- F. Costa
- P. Montavalli
- J. Quintana
- E. Marcano-Martinez
- J. Macedo
- A. Luchiari
- R. Osmond
- T. Carvalho

# Nitrogen Management

The goals of the nitrogen-management work are to find effective ways to manage crop residues, biologically fixed nitrogen and fertilizer nitrogen for sustained crop production and the maintenance of soil fertility in the acid savannas. The research program emphasized biologically fixed nitrogen for several reasons. Organic nitrogen sources have been successfully incorporated into cropping systems in the northeastern U.S. Cornell has conducted a sustained program of organic-nitrogen research. Work in the Cerrado of Brazil has suggested that higher crop yields are sometimes attained using legumes and manure as compared to using fertilizer nitrogen alone. In addition to supplying nitrogen, manures and legumes can also benefit crops by affecting nematodes, plant diseases and the rhizosphere, and by increasing soil organic matter, which can improve soil structure and water availability.

There may also be strong economic reasons for including organic nitrogen sources in the cropping system. Fertilizer nitrogen is expensive and easily leached from the cropping system during tropical rainstorms. The governments of many developing nations subsidize the use of fertilizer nitrogen in order to increase food production. Money thus spent frequently goes outside the country to pay for raw materials or the finished product. It may be as reasonable to subsidize the production of legume green manures, as the money would be more likely to remain in the country.

The projects described here have been conducted in order to learn how much nitrogen can be fixed by legumes in the acid savannas, how much can be used by the succeeding crop, and how to incorporate organic sources of nitrogen into practical cropping systems. Work done thus far has demonstrated that several green-manure legumes fix sufficient nitrogen to satisfy entirely the needs of a maize crop. Techniques using a fallow plot to fallow inorganic nitrogen accumulation have proven to be very useful in screening potential green-manure legumes for their ability to fix nitrogen. The next phase of the work will be directed at designing planting sequences and cropping systems that effectively use organic sources of nitrogen and at determining the effects of green-manure legumes and crop residues on long-term soil productivity.

# Nitrogen Availability from Legume Crop Residues and Green Manures To Succeeding Non-Legume Crops

*W. Shaw Reid, Cornell University*
*Robert J. Carsky, CPAC*
*Walter T. Bowen, CPAC*
*Allert Suhet, CPAC*

Nitrogen remains the most difficult of all plant nutrients to manage for maximum efficiency. Green manures can provide the nitrogen required by succeeding crops such as maize. For maximum efficiency, the N mineralization rate from the green manure must approximate that of crop uptake. There are many legume crops that can be used to supply N, thus a method is needed to provide an estimate of the N mineralization rate and crop response to the nitrogen without the necessity of field evaluation of each legume. The fallow-plot technique examined by Bowen is one successful method. A second method, the buried-bag technique, has promise for evaluation of the differences in the total mineralization rates of green manures.

## Conclusions

Bowen completed the analyses of the mucuna and soybean mineralization experiments conducted in 1984-85. The conclusions were as follows:

1. Inorganic N in the fallow soil was proportional to N uptake by maize, provided leaching did not occur. N release from freshly incorporated mucuna was expressed as Y = 25 + 0.81X (r = 0.91) for the dry season and Y = 43 + 0.85X (r = 0.97) for wet season; where Y = kg/ha of N mineralized, X = days after planting maize. About 60% of the N had mineralized from mucuna after 179 days during the dry-season experiment and after 80 days during the wet-season experiment.

2. The uptake of N by maize was proportional to the inorganic N accumulated in the fallow soil, as shown in Figure 1.

3. The nitrogen accounted for as aboveground N and residual soil N was approximately 80% of the inorganic N accumulated in the fallow soil, as shown in Figure 2.

4. The mucuna and soybean residues had very different mineralization rates (0.32 vs. 0.21 kg/ha/day for mucuna vs. soybean residue during the dry-

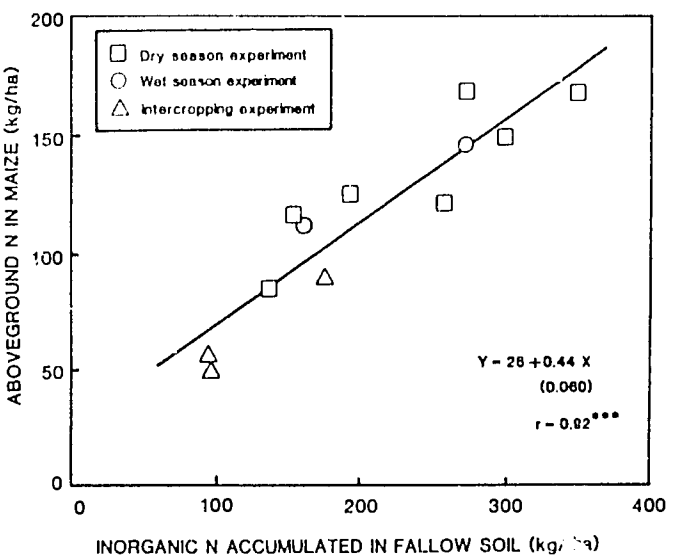



**Figure 1. Relationship between aboveground nitrogen in maize at harvest and inorganic nitrogen accumulated in fallow soil at 83 days (dry-season experiment), 78 days (wet-season experiment), or 72 days (intercropping experiment) after planting maize.**

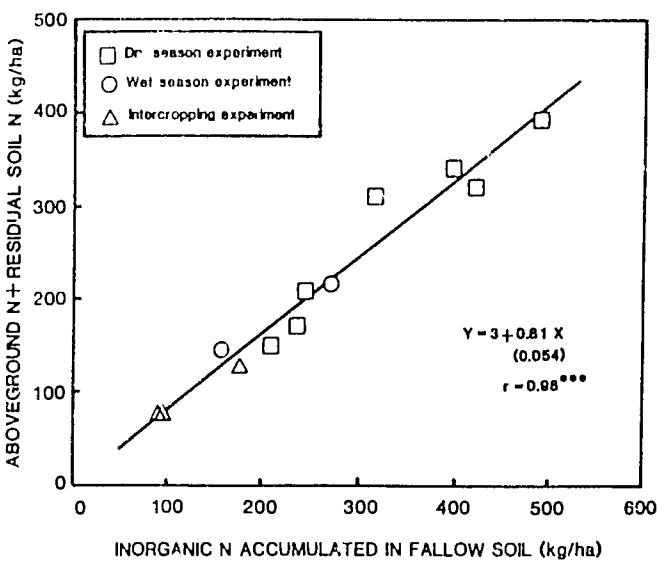



**Figure 2. Relationship between aboveground nitrogen in maize plus residual soil inorganic nitrogen (0-120 cm) and inorganic nitrogen accumulated in fallow soil at harvest (dry-season experiment), or at 78 days (wet-season experiment) or 72 days (intercropping experiment) after planting maize.**

season experiment), yet inorganic N in the fallow soil adequately predicted N uptake.

5. The measurement of N mineralization in the fallow soil can be used to evaluate the ability of various green manures to supply N to the succeeding maize crop, but leaching—other N not accounted for—will make the construction of nitrogen budgets difficult.

Carksy buried thin polyethylene bags containing soil and soil mixed with various legumes from the experimental area at approximately field capacity within the maize experiment reported by Bouldin et al. (pages 304 and 305). The relationship between the N in the bags after three months and the N uptake by maize is shown in Figure 3. This method for measuring the relative N mineralization from green manures looks promising and will receive further evaluation.

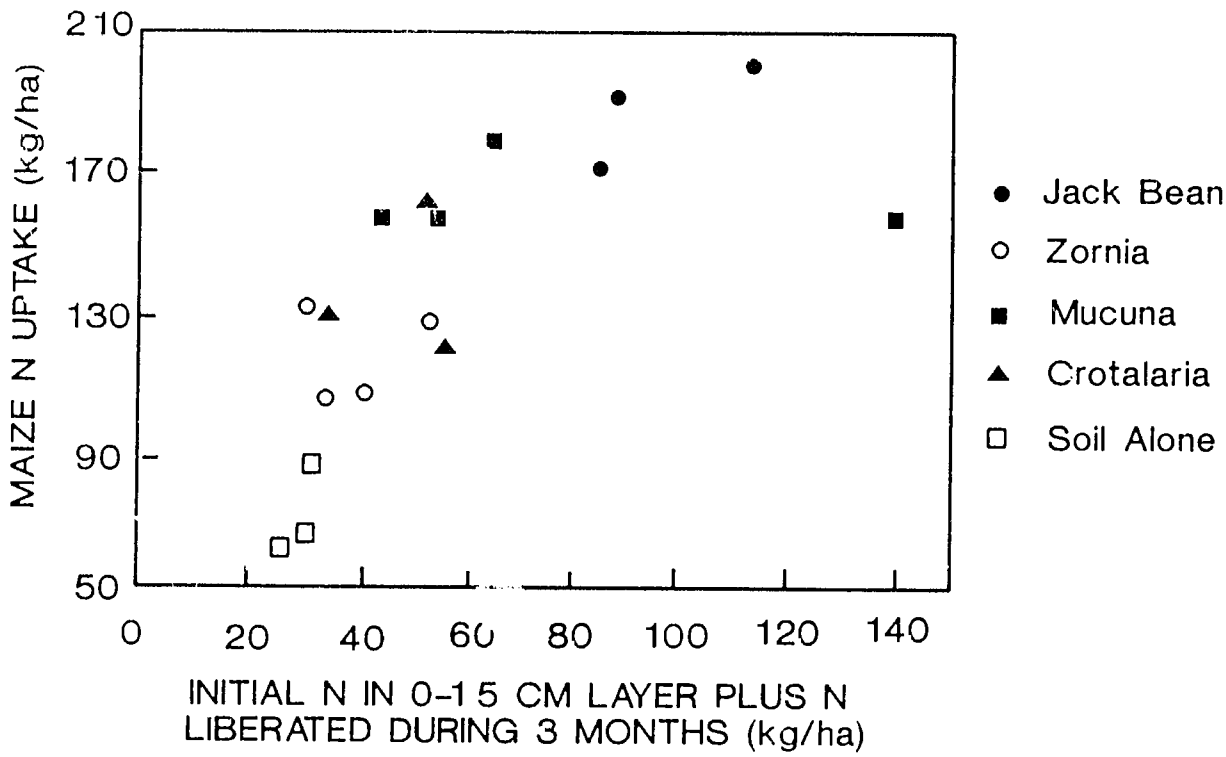



**Figure 3. Relationship between inorganic N in buried bag after three months plus initial soil inorganic N and then uptake by maize.**

# Evaluation of Mineralization Potential of Legume Residues

*David R. Bouldin, Cornell University*
*Jorge Quintana, Cornell University*
*Allert Suhet, CPAC*

## Objective

The objective of this project is to develop screening procedures for legume green manures. The two procedures tested here are incubation of soil samples in the laboratory and measurements of accumulation of mineral N in fallow plots.

## Procedures

Four legume green manures were grown during the wet season, and their value as N sources were evaluated under irrigation during the ensuing dry season by a) measuring accumulation of inorganic N in bare fallow plots, b) accumulation of N in soil samples taken from the plots and incubated in the laboratory, and c) cropping to maize under irrigation. The four legumes used were: mucuna [*Mucuna aterrima* (Piper and Tracy) Merr.], crotolaria (*Crotolaria paulina* Schrank), jack beans [*Canavalia ensitormis* (L.) DC], and zornia (*Zornia latitolia* SM).

At the end of the wet season, the bare fallow plots for measuring accumulation of mineral N were established as follows: One plot that had grown green manure was left fallow. On a second plot of green manure, the tops were removed and placed on a third plot, which had been fallow during the preceding wet season. A fourth plot, which had been fallow, received nothing. The four plots allowed us to compare the roots, tops and the whole plant as nitrogen sources.

In each block, one plot of green manure was planted to maize and one of each of four previously fallow plots was treated with 0, 50, 100 or 200 kg/ha fertilizer N.

## Results

The results are summarized as follows:

1. The yields of corn grain and N in the aboveground dry matter for the first crop of corn following the fallow and legumes are shown in Table 1. Table 2 lists the value of the green manures as a substitute for fertilizer nitrogen. Crotolaria, jack bean, and mucuna all replaced about 150 kg fertilizer N/ha.

2. The mineral N in the fallow plots, 100 days after incorporation of the green manures, was well correlated with the yields and nitrogen content of the aboveground dry matter of the maize grown on the corresponding cropped plots. The results are shown in Figure 1.

**Table 1. Grain yield and aboveground N-uptake of corn, dry season, 1986.**

| Treatment | Corn parameters: Grain yield | Corn parameters: N-content in aboveground |
|---|---|---|
| | (mg/ha) | (kg/ha) |
| Fertilizer-N | | |
| 0 Kg/ha | 3.74 | 69 |
| 50 Kg/ha | 4.60 | 96 |
| 100 Kg/ha | 5.57 | 123 |
| 200 Kg/ha | 6.72 | 172 |
| Legume | | |
| Zornia | 4.72 | 116 |
| Crotolaria | 5.81 | 149 |
| Jack beans | 6.14 | 169 |
| Mucuna | 6.43 | 159 |

**Table 2. Value of green manure as a substitute for fertilizer nitrogen.**

| Legume | N substitution value, kg/ha: 1st crop (1986)* | N substitution value, kg/ha: 2nd crop (1987)** |
|---|---|---|
| Zornia | 50 | 10** |
| Crotolaria | 140 | 50 |
| Jack bean | 160 | 30 |
| Mucuna | 170 | 45 |

*Average of results with aboveground dry matter, grain yield and N content of aboveground dry matter.

**Aboveground dry matter.

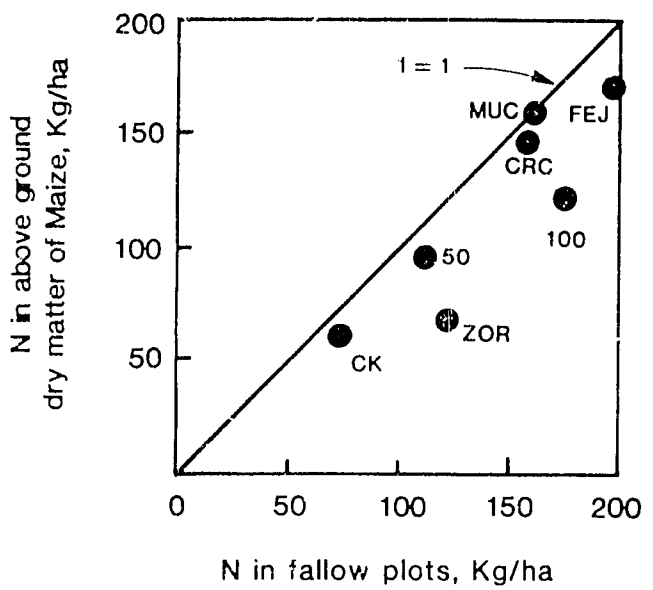



**Figure 1. N content of above ground dry matter of corn plotted against amount of N accumulated in the corresponding plots kept under bare fallow. N accumulation under bare fallow is the average of 62, 77, 98 days after incorporation to a depth of 60 cm.**

Fej =Canavalia; Cro = Crotalaria; Muc = Mucuna; Zor = Zornia; CK = Check (fallow); 50 = Mineral N in fallow plus 50 kg of fertilizer; 100 = Mineral N in fallow plus 100 kg fertilizer N.

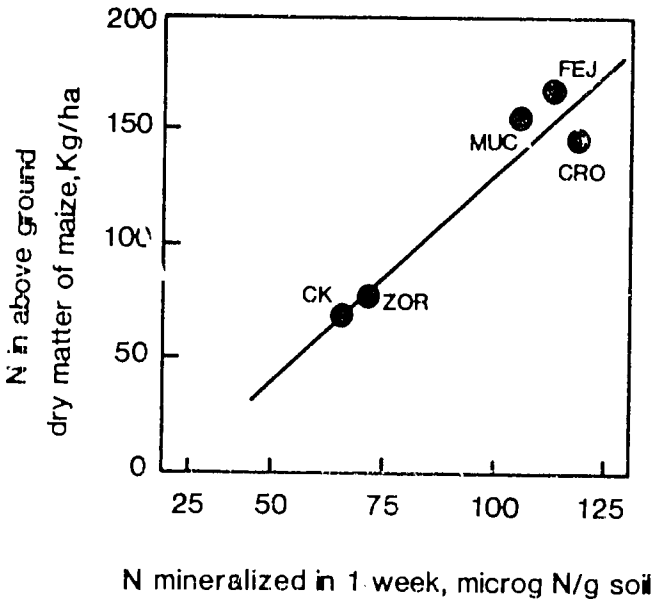



**Figure 2. N content of aboveground dry matter of maize plotted against amount of N mineralized in one week from samples taken at the time of incorporation of the green manure.**

Fej =Canavalia; Cro = Crotalaria; Muc = Mucuna; Zor = Zornia; CK = None.

3. The mineral N accumulated in the soil samples during two weeks of incubation in the laboratory were correlated with yield and uptake of maize. The results are shown in Figure 2.

4. The fraction of the total N in the tops of the different legumes incorporated into the soil, which was recovered as net increase in mineral N in bare fallow plots, varied from about 50% for the Crotolaria to about 80% or more for the other green manures.

5. Both laboratory incubations and fallow plot sampling are suitable procedures for screening legume green manures.

# Estimating N Mineralization By Laboratory Incubation and Effect of Soil-Sample Disturbance

*Stuart D. Klausner, Cornell University*
*Albert Suhet, CPAC*
*Douglas J. Lathwell, Cornell University*
*David R. Bouldin, Cornell University*
*John M. Duxbury, Cornell University*

Laboratory incubation of soil has been used extensively to characterize N mineralization rates. To date, the validity of soil incubation as a predictor of N mineralization in the field is questionable.

Most incubation studies in the past involved traditional sampling procedures where the physical integrity of the soil was destroyed by mixing, grinding or sieving. Since a portion of the organic N pool is thought to be in a physically protected state, soils that have remained relatively undisturbed should have a larger percentage of protected organic N than those that are tilled frequently. Therefore, the effect of the physical disruption of soil on the rate of organic matter decomposition becomes important. In the same regard, a disturbed soil sample used for incubation purposes may mineralize at a different and more variable rate than *in situ*. The value of a laboratory incubation procedure for predicting N mineralization may be improved if the physical structure of the sample is maintained.

## Objectives

The objectives of this study were 1) to evaluate the effect of soil sample disturbance on N mineralization from sampling locations differing in soil management practices, and 2) to determine the suitability of a laboratory incubation procedure for estimating N mineralization from soil organic matter and additions of green manure for corn production.

## Procedures

Four dark red latosols were sampled. Treatment designations and land use are as follows: a) 'native' Cerrado (CE) presumably in its natural state; b) forage grass (FG), sixth year of andropogon; c) corn check (CK), third crop of continuous corn, and d) corn following a legume (CL) cropping sequence of corn-mucuna-corn-corn.

Disturbed (traditional mixing and compositing) and 'undisturbed' (cored) soils were sampled at the end of the dry season to a depth of 15 cm. The samples were processed immediately, to avoid air-drying, by saturating and equilibrating to 0.25 bar water tension on a pressure membrane apparatus. After equilibration, the aggregate size in the disturbed sample was reduced to less than 1 mm. All samples were aerobically incubated at 35° C for a two-, four-, eight- or 12-week period. Moisture contents were adjusted during incubation.

A second soil sample was taken from each location to determine the effect of grinding on N mineralization. Air-dried soils were sieved to obtain aggregates of 1-2 mm, and plant residues removed. A subsample was completely crushed to less than 0.21 mm. Samples were mixed with sand and water and incubated at 35° C for two weeks. Inorganic N was analyzed by steam distillation.

## Results

The rate of N mineralization for each location was best described by linear regression. A test of homogeneity of regression coefficients (Table 1)

**Table 1. Regression equations and decay rates of organic N.**

| Site | Sample preparation | Equation** | $R^2$ | Decay rate*, kg N/ha/wk within | between |
|---|---|---|---|---|---|
| CE | disturbed | Y= 1.4 + 2.39X | 91% | 3.2 a | 3.5 b |
| | undisturbed | Y= -4.3 + 2.85X | 97% | 3.8 a | |
| FG | disturbed | Y= 4.2 + 0.78X | 86% | 1.2 a | 1.5 b |
| | undisturbed | Y= 1.4 + 1.24X | 80% | 1.9 b | |
| CK | disturbed | Y= 6.1 + 2.69X | 93% | 4.5 a | 5.3 b |
| | undisturbed | Y=-1.9 + 3.54X | 80% | 6.0 a | |
| CL | disturbed | Y= 0.4 + 4.06X | 89% | 7.0 a | 7.9 c |
| | undisturbed | Y=-0.9 + 5.10X | 88% | 8.8 a | |

* Decay rates followed by the same letter are not significantly different at the .05 level.

**Y= net N mineralized in ppm, X= time in weeks.

showed no significant difference in mineralization rate between the disturbed and undisturbed sample within the native Cerrado, continuous corn and second crop of corn following mucuna. The andropogon site showed a small but significant increase for the undisturbed sample. An analysis of combined regression coefficients showed mineralization rates on the order of: corn following mucuna > continuous corn ~ native Cerrado > andropogon (Table 1). It was postulated that the low mineralization rate in the andropogon site was due to a wide C:N ratio of the large dense root mass in the soil sample. Mineralization potential in newly cleared Cerrado soils could be improved with the addition of lime and fertilizer.

Fallow plots, containing the same residual legume treatments (+ and - mucuna) as the CK and CL sampling sites, were maintained to allow for soil profile N analysis without N loss due to crop uptake. The data in Table 2 suggest that N mineralization in the first-year residual mucuna treatment was not very different from the non-legume check. The absolute difference between the two is due to residual N carryover from the previous season in the mucuna treatment. The correlation between N mineralization in laboratory-incubated soil with that in the fallow plots showed no meaningful relationship. Differences in corn yield and N uptake between check plot treatments was the best indicator of the N status in the soil.

The effect of vigorous soil disturbance (grinding) on net N mineralization is shown in Table 3. Nitrogen production during a two-week incubation increased appreciably when the soil was finely ground.

## Conclusions

The data suggest that as long as some degree of soil aggregation exists, soil disturbance has no effect on N mineralization. However, more vigorous disturbance, such as grinding, caused a significant increase in mineralization. A mechanism for physically protecting a portion of soil organic matter against short-term N mineralization probably does exist. The mechanism appears equally effective within the context of normal soil sampling and preparation but physical protection becomes ineffective when soil aggregation is completely destroyed.

Laboratory incubation of a soil planted to corn over-predicted N mineralization in fallow plots. Incubation may be effective for qualifying differences in N mineralization based on soil-management practices, but it does not appear to be a quantitative measure of the residual N effects from a legume during the second succeeding crop. The predictability of mineralization in the field was not improved by using an undisturbed soil sample.

## Implications

Preliminarily, it appears that normal soil tillage will not increase the rate of N mineralization by destroying the physical protection of soil organic matter unless a significant amount of soil aggregates are destroyed. Further investigation, through well-designed field experiments, will be required to test the validity of this observation.

**Table 2. Inorganic N in the top 120 cm. of fallow plots receiving two legume treatments.**

| Treatment | Days after corn emergence -32 | 26 | 57 | 81 | 114 |
|---|---|---|---|---|---|
| | kg N/ha | | | | |
| no mucuna | 139 | 137 | 129 | 158 | 195 |
| mucuna | 231 | 259 | 249 | 241 | 308 |

**Table 3. The effect of soil disturbance on net N mineralization during a two-week incubation at 35° C**

| Sampling site | Grinding treatment* 1-2 mm | < 0.21 mm |
|---|---|---|
| | ppm N | |
| CE | 24 a | 59 b |
| FG | 20 a | 27 b |
| CK | 29 a | 40 b |
| CL | 24 a | 51 b |

* Means followed by the same letter, between grinding treatments, are not significant at 5% level.

# Soil- and Crop-Management Systems for Acid Savanna Soils Using Green Manures and Crop Residues as N Sources

*Douglas J. Lathwell, Cornell University*
*David R. Bouldin, Cornell University*
*Walter T. Bowen, CPAC*
*F. Costa, Cornell University*

## Objectives

Work on this project may be divided into two parts. The objective of the first part, conducted at CPAC, was to clarify methods of using green manure legumes so that they might be fitted into soil- and crop-management systems. The objective of the second part was to develop an extrapolation site where results obtained at CPAC might be tested under different soil and climatic conditions.

## Progress, Objective 1

*Green manures as sources of N*

Experiments were carried out at CPAC to test the differences among green manure legumes as N sources, and to evaluate the effect of green manure legumes on N mineralization and accumulation of inorganic N in fallow soils.

The first study was conducted to measure the N accumulation of four legume green manures and to measure the rate of inorganic N accumulation in bare fallow plots following incorporation of the legumes. The four legumes evaluated were *Canavalia insidformes*, *Crotolaria paulina*, *Doliches lablab*, and *Mucuna aterrina*.

The legumes were grown during the wet season of 1985-86 and were incorporated or surface-placed on the soil at the beginning of the dry season of 1986. The plots were maintained in bare fallow during the dry season. Irrigation water was applied to keep the plots moist, but the amount applied was kept small enough in any one irrigation to prevent leaching beyond about 45 cm depth. Soil samples were taken periodically and mineral N accumulation was determined.

The bulk density of the soil samples has not yet been determined so that a quantitative summary of the results is not complete. Preliminary examination of the results indicate the most mineral N was accumulated under the *Canavalia* green manure.

*N volatilization from green manures*

In a second experiment, N volatilization from surface-placed green manures during the course of microbial degradation was investigated. A greenhouse experiment was conducted in which mineral N accumulation was measured in fallow pots in the greenhouse when mucuna leaves were surface-placed or mixed. The decomposition of the surface-placed material was determined by periodically collecting the residue from the surface and analyzing for total N.

The results were as follows: After 49 days there was twice as much mineral N in the pots where mucuna was mixed as compared to surface-placed mucuna. In the mixed treatment, this was about 45% of the organic N added. The total N in the surface residues decreased rapidly and, after 49 days, was 60% of the amount added.

Similar studies were made in a field experiment. The results from the field experiment are currently being analyzed in detail, but preliminary examination of the data appears to agree with the results obtained in the greenhouse.

These results indicate that green manures should be incorporated in order to prevent possible volatilization losses from surface applications.

*Screening legumes for dry-season use*

An experiment to screen legumes for dry season survival in acid savanna soils was begun in February 1987. This project has been started under the auspices of the TropSoils CRSP but most of the support for this project will come from the Special Research Grants of USDA-AID program on factors limiting symbiotic nitrogen fixation. Two sites at CPAC of at least 1 ha each were set aside for conducting the planned experiments. The two sites differ in soil type; one is a red yellow latosol (Acrustox), and the other is a dark red latosol (Haplustox). They also differ in water table depth. Both sites were cleared of native Cerrado vegetation several years ago, and have been cropped and fertilized, with only tillage varying as a management factor. In late February and early March, both sites were moldboard-plowed, disked, limed (1 t/ha red yellow site, 2 t/ha dark red site), and fertilized (200 kg/ha of $P_2O_5$ and 120 kg/ha of $K_2O$).

Fifty-two different legumes were sown at each site during the period March 19-21, 1987. Each legume was sown in plots of 6 x 2.4 m size (four rows with 0.6 m between rows), replicated three times at each site. The CPAC soil microbiology laboratory provided *Rhizobium* for inoculating all legume seed at planting. In addition to the 52 legumes, a limited amount of seed for 35 lines of *Canavalia* species, obtained from CIAT, and seven lines of *Avena sativa*, selected for good dry season production in southern Brazil, were planted for observation at one site.

*Implications*

Information gathered from these projects will be useful when cropping systems are developed for arid savanna soils. Efficient use of nitrogen in cropping systems developed will be a key to their successful adaption by farmers. Likewise, only green manure legume systems which use them effectively and economically have a chance to succeed on the farm.

**Progress, Objective 2**

We have devoted considerable effort to develop an extrapolation site in Africa. While possibilities seem to exist none have materialized as yet. Meanwhile, Dr. Boven has been stationed in Brazil on a temporary basis to assist the program at CPAC and to investigate the possibility of doing some work on extrapolation of CPAC results to Manaus in the Amazon Basin of Brazil.

# Water and Chemical Budgets

Previous research into methods of increasing the rooting depth of plants in order to overcome water stress during dry periods has broadened to include work toward a comprehensive description of the fate of amendments in acid savanna soils. These studies are investigating such factors as the transport and distribution of water and solutes, and the chemical reactions influencing crop yields.

Results from this program of research will be integrated with data from previous studies at Cornell and the Centro de Pesquisa Agropecuaria dos Cerrados (CPAC). The ion-movement projects will develop and test a simulation model similar in approach to models which have been used to describe salt movement. Laboratory and field studies will be used to guide the model's development. This model, and the quantitative understanding of ion movement derived from such studies, would be valuable in the extrapolation of experimental results to new locales.

One study in this group, "Crop Water Requirements in Cerrado Soils," led by Susan J. Riha of Cornell, has not been under way long enough to produce results and is not presented. The study's objectives are to determine the components of the water budget; to quantify the effects of tillage practices upon the ability of Cerrado soils to hold and conduct water; and to develop and test a simplified model relating water use to crop yield. The model is expected to predict how crop yields on different soils would be affected by periods of rain or drought, and would be useful in estimating the benefit of increased irrigation.

# Fertilizer Nitrogen Movement In Cerrado Soils

*Susan J. Riha, Cornell University*
*R. J. Wagenet, Cornell University*
*Elias Freitas, CPAC*
*Alberi Suhet, CPAC*

## Objectives

The objectives of this study were 1) to develop a comprehensive description in simulation model form of nitrogen movement and transformation in cropped soils of the Cerrado; 2) to use the model of (1) as a guide in interpreting previous studies and in designing further field experiments to increase understanding of nitrogen fertilizer fate in Cerrado soils, and 3) to develop a simplified model of nitrogen fertilizer fate in Cerrado soils that will be useful in guiding nitrogen management programs.

## Progress

*Objective 1*

A general-purpose simulation model (GAPS) of water movement in the soil-plant-atmosphere has been developed. The program contains user-friendly input/output routines and allows the user to select from procedures that simulate various components of the soil-plant-atmosphere system. In addition, the user can choose from a variety of procedures representing the same component of the system (such as ETP or soil-water flow routines). Procedures can be selected on the basis of the data available to the user, the particular modeling objective, or the level of complexity desired. Extensive documentation of the simulation procedures accompanies the software package. The program structure allows the user to incorporate additional procedures into the program. We are currently developing procedures for nitrogen transformation and nitrogen-soil particle surface reactions.

*Objective 2*

We have been compiling both the necessary input data and results of previous CPAC field experiments to run and evaluate our current nitrogen simulation model. We have initiated a field experiment at the CPAC to determine the effects of varying rainfall on nitrogen transformation and movement in highly weathered Oxisols planted to corn. This experiment is being conducted during the dry season, so that water input can be controlled and manipulated through the use of a line-source sprinkler.

*Objective 3*

A comprehensive literature review of nitrogen fertilization of maize in tropical regions has been initiated and is near completion. Additionally, we have decided to use a nitrogen partitioning model similar to one developed by C. T. DeWit, and linked to a simple expert system as a guide for nitrogen management programs.

# Ion Movement in Cerrado Soils: Effects of Gypsum Amendment On Charge Properties of the Soils

*Murray B. McBride, Cornell University*
*Eugenio Marcano-Martinez, Cornell University*

The application of gypsum as an amendment to overcome deleterious effects of soil acidity has been suggested by some authors (Ritchey et al., 1980; Reeve and Sumner, 1972). The greater mobility of gypsum with respect to lime makes the former a better source of Ca to promote root growth in the soil's lower layers.

The rate of Ca moment is dependent on the relative retention and reactivity of the accompanying anion and on the charge of the soil minerals. By studying the adsorption of Ca and $SO_4$, and the chemical processes affecting their retention, we can understand some of the factors that determine gypsum fate and efficiency in these soils.

## Objectives

The objectives of this study are 1) to estimate the sulfate and calcium retention capacity of the A and B horizons of a dark red Acrustox (DRA and DRB) and a red yellow Acrustox (RYA and RYB), and 2) to study the effect of sulfate and calcium adsorption on the development of charge in the soils.

## Procedure

Ca and $SO_4$ retention were studied by adsorption isotherms of $CaCl_2$ and $K_2SO_4$ in a 0.01N KCl medium using a soil solution ratio of 1:10, in all four soils. $CaSO_4$ adsorption was also studied in a similar way but only in both A horizons.

## Results

Ca adsorption isotherms followed an almost linear behavior and conformed to the Freundlich equation. These results are shown in Figure 1 for the DRA. When Ca was applied together with $SO_4$ (gypsum) there was a significantly higher adsorption of Ca above an equilibrium concentration of 0.04 mM. Precipitation as $CaSO_4.2H_2O$ cannot explain these results because the solubility product of this compound was not exceeded.

$SO_4$ adsorption isotherms had a Langmuir shape in both cases ($K_2SO_4$ and $CaSO_4$), but the best fit was given by a Freundlich equation. $SO_4$ adsorption was also higher when gypsum was applied than when $K_2SO_4$ was used as the adsorbate, as shown in Figure 2 for the DRA.

Ca adsorption was not significantly different between the A and B horizons within each soil; this is probably due to the higher concentration of $Al^{3+}$ in the A horizon (see previous report). This strongly adsorbed $Al^{3+}$ would block the negative sites.

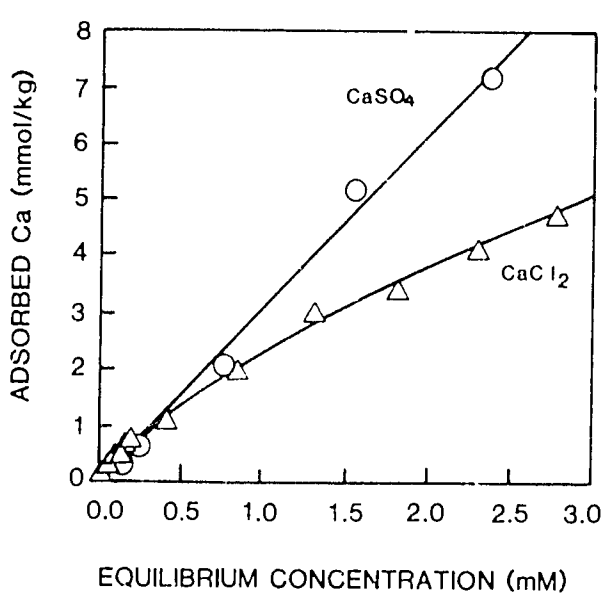



Figure 1. Calcium adsorption isotherms in the dark red Acrustox.

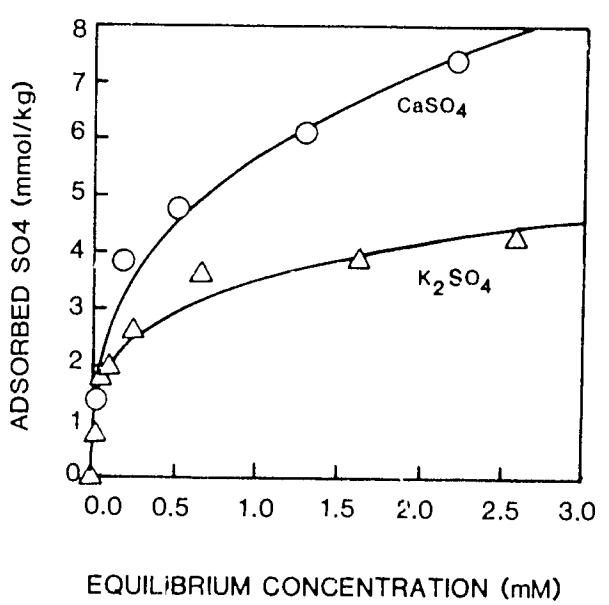
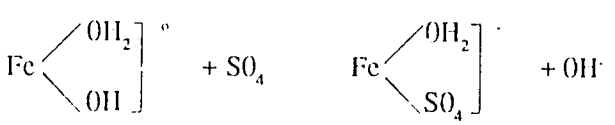



Figure 2. Sulfate adsorption isotherms in the dark red Acrustox.

$SO_4$ was retained more strongly in the B horizons than in the A horizons and the dark red Acrustox showed a significantly higher retention than the red yellow. This can be attributed to the higher iron content in the first soil. The CBD-extractable Fe levels were 7.82 and 6.37% for the DRA and DRB, respectively, and 4.00 and 3.73% for RYA and RYB, respectively.

Ca adsorption did not affect the pH of the soil nor increase the retention of $Cl^-$. On the other hand, $SO_4$ adsorption increased the pH of the solution almost linearly, this effect being more noticeable in the B horizons and when $SO_4$ was applied as $K_2SO_4$. The retention of $K^+$ was also affected by the adsorption of $SO_4$ as shown in Figure 3 for adsorption of $K_2SO_4$. Application of $CaSO_4$ also caused an increase in the cation retention which was less linear than in the previous case. The increase in cation retention may be due in part to an increase in pH that makes the soil surface more negative due to the pH-dependent charge of these soils (see previous progress report); this could have been the case for both B horizons, where the increase in pH might have caused a significant change in negative charge. In the A horizon, the rise in pH was smaller (probably because of a buffer effect of organic matter) and was not enough to cause a significant increase in negative charge. Therefore, the higher $K^+$ retention is attributed to creation of negative charge upon $SO_4$ adsorption by a ligand exchange mechanism as shown in the following reaction:



This reaction can also explain the higher pH resulting from $SO_4$ adsorption.

The maximum Ca adsorption measured in this experiment represented between 55 and 88% of the total CEC of the soil at its natural pH; thus, Ca adsorption could be explained by a cation exchange mechanism. $SO_4$ adsorption for both $K_2SO_4$ and $CaSO_4$ treatments was higher than the anion exchange capacity of the soil measured by $Cl^-$ retention, on a equivalent basis. This implies that $SO_4$ adsorbs more preferentially than $Cl^-$ in these soils, probably by the ligand exchange mechanism shown above.

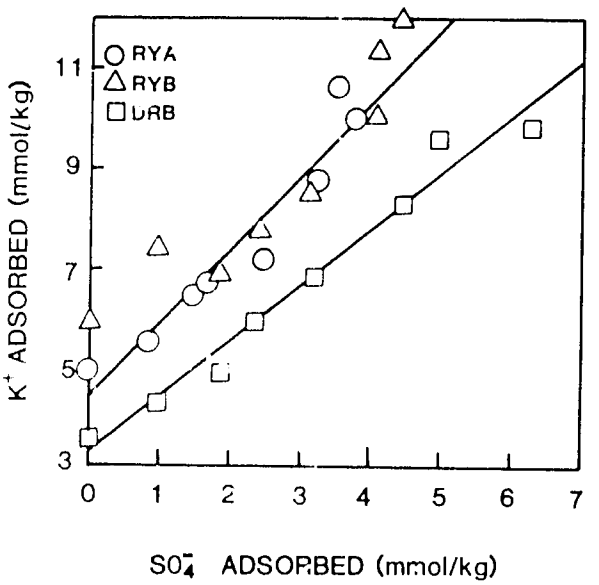



**Figure 3. Effect of sulfate adsorption on the $K^+$ retention capacity of the soils.**

## Conclusions

Sulfate and calcium retention are dependent on the equilibrium concentration of these ions in solution. While calcium retention was almost linearly dependent on Ca concentration, sulfate tended to approach a maximum adsorption which was not reached within the experimental range of $SO_4$ additions. Retention of both ions conformed to the Freundlich equation. Gypsum application caused a greater Ca and $SO_4$ adsorption, probably due to ion pair adsorption.

Ca was adsorbed as an exchangeable cation without affecting the pH of the soil nor the total surface positive charge. Sulfate was adsorbed by a ligand exchange mechanism that caused displacement of hydroxyls from the surface, raising the pH of the soil solution. At the same time, $SO_4$ caused an increase in the total negative charge.

## Implications

Data from this study support the specific adsorption mechanism by which sulfate is adsorbed in oxides. This mechanism affects the balance of charge in the soil and can be used to reduce cation leaching.

Application of gypsum increases the retention of both Ca and $SO_4$ by the soil, as well as the total CEC. This can have some practical use because of the importance of these nutrients.

# Ion Movement in Cerrado Soils: The Effects of Inorganic And Organic Amendments On Sulfur (S) Availability

*John M. Duxbury, Cornell University*
*Peter P. Motavalli, Cornell University*
*Wenceslau Goedert, CPAC*

Oxisols of the Cerrado are potentially deficient in sulfur, although the use of ordinary superphosphate and gypsum has largely prevented deficiencies from occurring to date. Recommended management practices for these acid savanna soils include large additions of phosphorus and lime, both of which can affect sulfate adsorption and mobility in the soil profile. Recent work by Cornell TropSoils researchers has shown that legumes, such as mucuna and crotalaria, grown as green manures, supply substantial amounts of nitrogen to succeeding crops. The green manures would also be expected to supply sulfur through mineralization processes, and could further influence sulfur availability by alteration of soil chemical properties.

## Objectives

The purpose of our study is to evaluate the effects of inorganic (Ca, P and S) and organic (green manures) amendments on three components of sulfur availability—adsorption reactions, movement in the soil profile, and mineralization of organic sulfur.

## Progress

*Laboratory studies of sulfur mineralization and sulfate adsorption*

An incubation experiment was performed using the A and B horizons of a dark red latosol and a red-yellow latosol in order to evaluate sulfate adsorption over time as affected by additions of a green manure (alfalfa) and an organic anion (oxalate). The experimental design allowed us to separate the effects of pH and of organic additions on sulfate adsorption, and to measure sulfur mineralization. Soils were incubated for 0, 8, 15, 29 and 63 days. At each time, mineralization was measured using distilled water and 200 mg P ($KH_2PO_4$)/L extracting solutions, and sulfate adsorption was evaluated at levels of 0, 120 and 240 mg $SO_4$/L in 0.01 M KCl. One group of alfalfa and oxalate-treated soils had pH adjusted to the pH level of the control in order to examine pH effects on sulfate adsorption.

Addition of alfalfa caused soil pH to rise immediately by about 1 pH unit, whereas oxalate addition depressed pH from 0.5 to 1.0 pH units. Soil pH continued to rise upon incubation with alfalfa to about pH 7.5 to 8.0, while the pH of oxalate-treated soils gradually rose to that of the unamended soils (4.4 to 5.3). As shown in Figure 1, addition of alfalfa immediately reduced adsorption of $SO_4$ relative to the unamended soil and this effect was maintained even

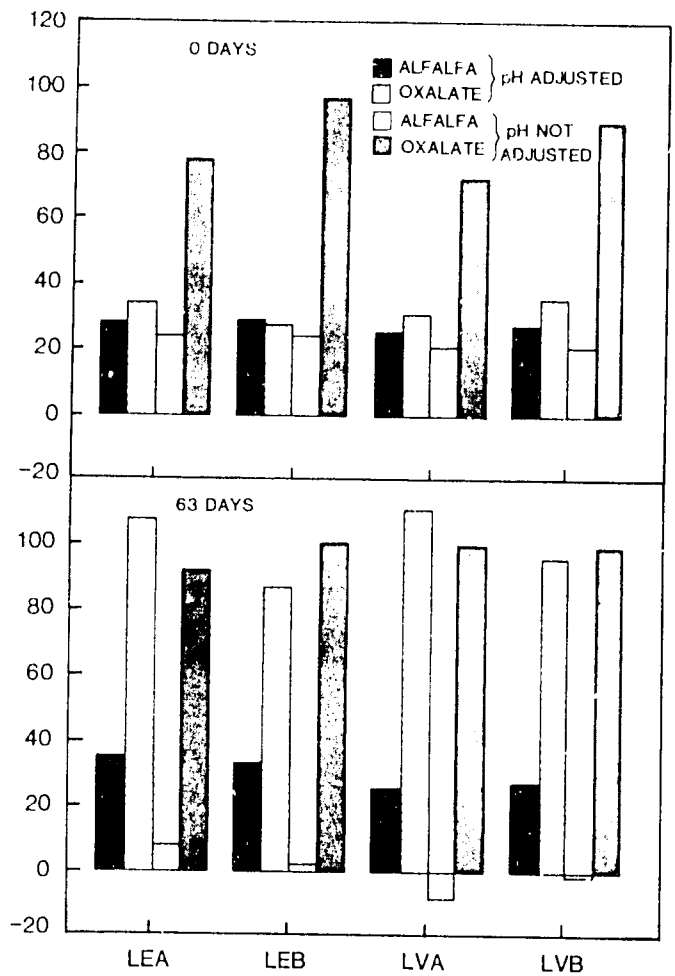



**Figure 1. Relative adsorption (untreated control soil = 100%) of sulfate after incubation of the A and B horizons of a dark red latosol (LE) and a red-yellow latosol (LV) with alfalfa (5 g/100 g soil) or oxalate (10 mg/100 g soil). Adsorption measurements were made without pH adjustments and after adjustment to that of the unamended soil. Data represent the mean of values obtained for equilibration with solutions containing 120 and 240 mg $SO_4$/L.**

after adjustment of pH to that of the control soil. The effect of alfalfa on $SO_4$ adsorption persisted throughout the 63-day incubation period. Oxalate addition also tended to reduce adsorption of $SO_4$, but the magnitude of the reduction was initially sensitive to pH and the effect was transient. The B horizons of both soils adsorbed more sulfate than the A horizons, perhaps due to higher native organic matter levels in the A horizons.

The range of sulfur mineralization after alfalfa was added was between 9.2 and 36.7 mg $SO_4$/g soil/week. The patterns of S mineralization varied both between the soils and soil horizons (Figure 2).

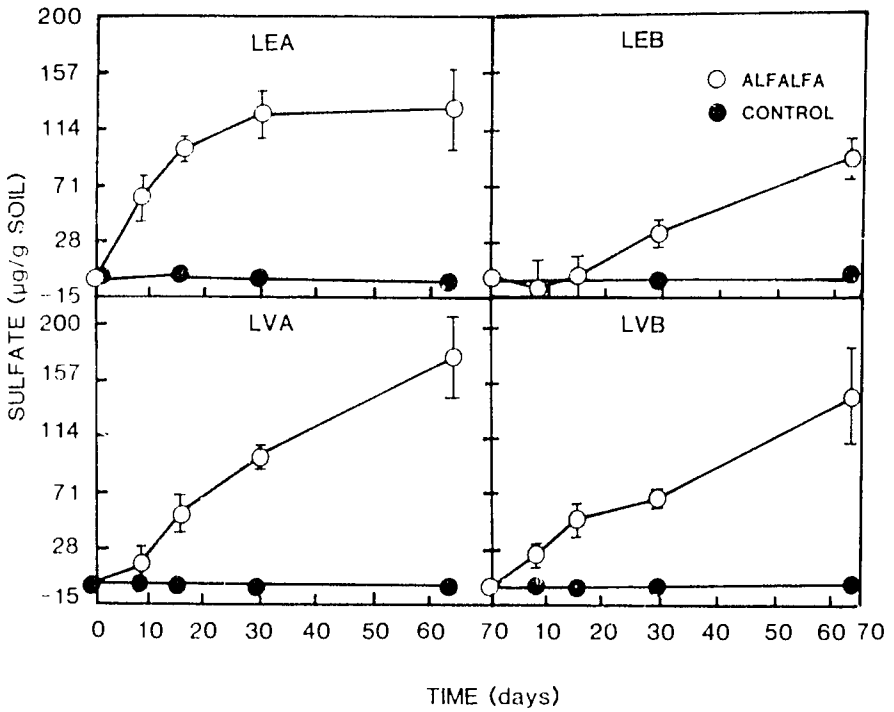



**Figure 2. Mineralization of sulfur in A and B horizons of dark red (LE) and red yellow (LV) latosols amended with alfalfa (5 g/100 g soil).**

*Sulfate movement in long-term experiments on dark-red latosols at CPAC*

Three-year P source experiment:

Soil samples were collected to 120 cm from one repetition of plots which had received various levels of P and S fertilizers. The soils were extracted with a 200 ppm $KH_2PO_4$ solution and sulfate determined by ion chromatography. The results are shown in Figure 3. Without added P, plant growth was poor, uptake of S was low, and substantial amounts of sulfate were found in the upper 60 cm. With P addition and much better plant growth, soil sulfate levels were reduced.

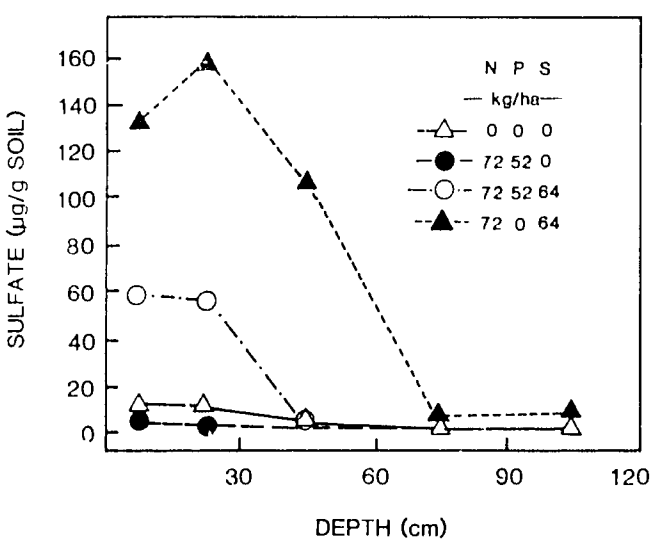



**Figure 3. Effect of three years of N, P and S fertilizer treatments on phosphate extractable sulfate in a red latosol.**

Five-year gypsum experiment:

Three repetitions of plots which had received gypsum additions (0, 107, 306, and 427 kg S/ha) in 1979 were sampled to a depth of 120 cm. All plots except those receiving 306 kg S/ha had also received 4.7 Mt lime/ha. Extractable sulfate levels were determined as previously described and are shown in Figure 4. The higher rates of gypsum addition resulted in more downward movement of sulfate, which also appeared to be accentuated by lime addition. A significant correlation between extractable sulfate and Al was found.

Ten-year green manure experiment:

Different green manure crops (mucuna/crotalaria, rice and natural vegetation) were grown three out of the ten years. Crop residue was either removed or incorporated and two levels of lime (1 or 4 Mt/ha) had been applied the first year of the experiment. Approximately 500 kg S/ha, contained in simple superphosphate, had been applied over the ten year period. Levels of phosphate extractable sulfate in the soil

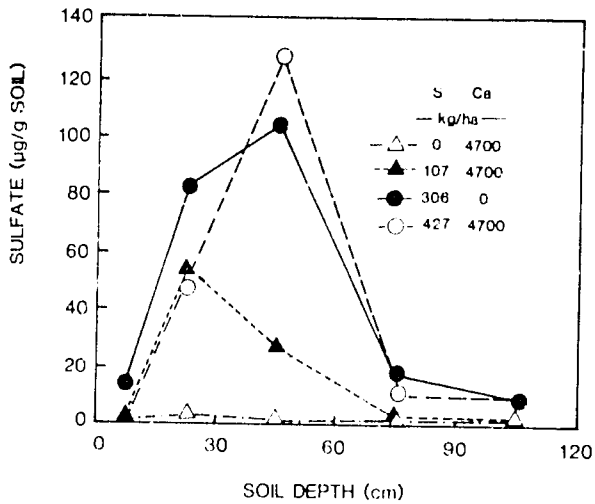



**Figure 4. Phosphate extractable sulfate from a red latosol seven years after amendment with gypsum and lime.**

profile are shown in Figure 5. Downward movement of sulfate was generally greater at the higher lime rate, but there was no effect of incorporation of crop residue on sulfate movement.

*Field evaluation of green manures as a sulfur source:* A field experiment was begun on a dark red latosol at CPAC in November 1986. Treatments consisted of an incomplete factorial design with three rates of gypsum (0, 60 and 600 kg S/ha), three green manure treatments (0, 10 Mt/ha *Canavalia ensiformis*, 10 Mt/ha *Panicum maximum* on a dry weight basis), with-and-without lime treatment (0 and 3.4 Mt/ha), and with-and-without crop treatment. Only unplanted plots had the 0 lime treatment. Plant material for green manure treatments was harvested from adjacent areas and passed through a forage chopper before being spread uniformly over the treated plots. There were three replications of each treatment. A blanket application of 65 kg N/ha, 200 kg $P_2O_5$/ha, and 150 kg $K_2O$/ha was made to the experimental area and all plots were rototilled. Corn (*Zea mays* L.) was planted on December 2, 1986 and an additional 165 kg N/ha was split into two applications later in the season.

Soil and plant samples were collected at regular intervals throughout the growing season. Preliminary results of extractable sulfate in soils from the bare plots showed that liming appeared to improve sulfur mineralization, especially in the *Panicum* treatment,

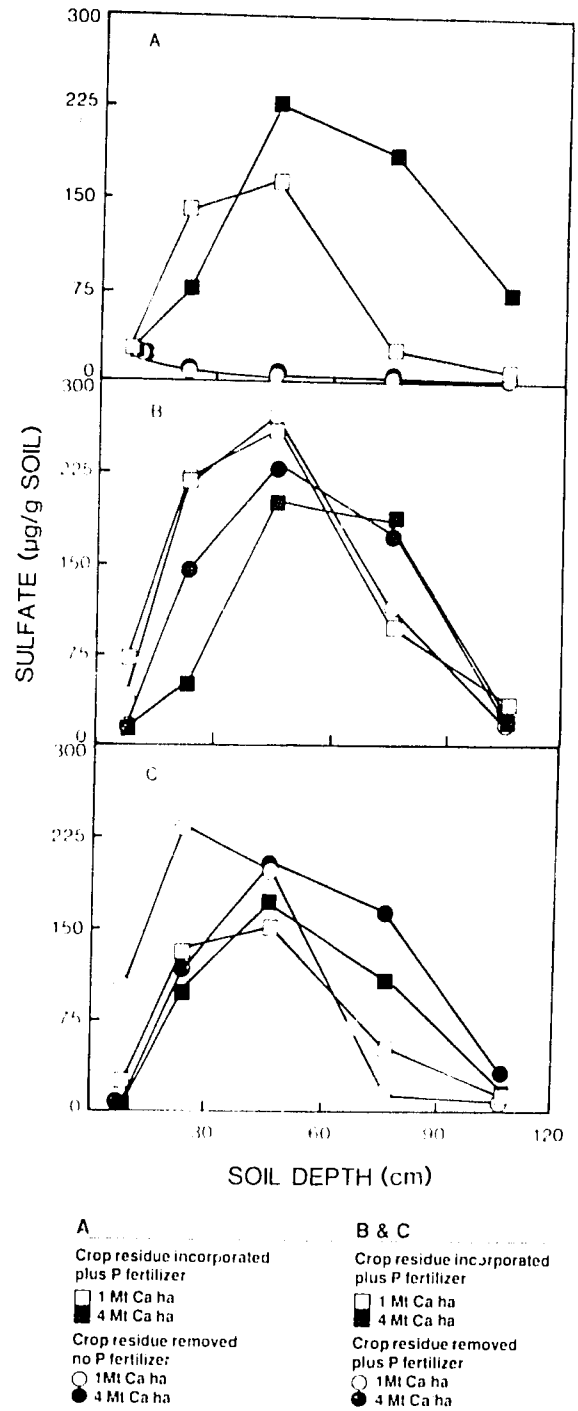



**Figure 5. Effect of seven years of cropping interspersed with three years of green manuring on phosphate extractable sulfate in a red latosol. Green manure crops were natural vegetation (A), mucuna/crotalaria (B), and rice (C). A total of 500 kg S/ha was added in simple superphosphate over the ten-year period, except for the unfertilized treatment (A).**

and perhaps also promoted downward movement of sulfate. The experiment was harvested in early April 1987, and results will be forthcoming shortly.

### Conclusions

Soil sampling of several long-term experiments at CPAC confirmed that both lime and phosphate additions to Cerrado Oxisols appear to promote downward movement of $SO_4$ in the soil profile. This could eventually lead to leaching of $SO_4$ from the profile and to S deficiencies when plant rooting depth is not great.

The laboratory incubation studies showed that additions of plant material to Oxisols can be expected to reduce $SO_4$ adsorption. Several mechanisms, including effects on soil pH, surface charge and extractable Al, may be involved in this process. Sulfur also mineralized readily when alfalfa was added to these soils.

## Crop Water Requirements In Cerrado Soils

*Susan J. Riha, Cornell University*
*R. J. Wagenet, Cornell University*
*Elias Freitas, CPAC*

The progress of this project has been greatly helped by the enrollment of Ariovaldo Luchiari as a graduate student of Dr. Susan Riha. Mr. Luchiari conducted several experiments over a number of years with irrigated wheat that will allow us to test several models for potential use in predicting wheat water requirements in the Cerrado. This year Mr. Luchiari visited with Dr. John Norman at the University of Nebraska to learn how to use a comprehensive crop canopy model (CUPID) he has developed.

### *New Project Update*

*This project has not been under way long enough to yield a substantive report, but should be mentioned because of its importance to the program.*

# Soil Constraints to Management

The goals of this group of projects are to identify the chemical and physical factors of importance in the management of acid-savanna soils, and to understand these properties in a way that leads to improved management techniques. While the Oxisols of the acid savannas are generally considered to have physical properties favorable to cultivation, there is evidence that soil erosion, compaction, and root-restricting pans can develop with long-term, mechanized cropping unless a better understanding of soil processes leads to more appropriate farming practices. There are also differences in water tables and drainage among these soils, and a method of identifying areas with restricted drainage would assist the selection and management of agricultural fields. In addition, there is evidence that dispersion of clays may result from addition of chemical amendments to these soils to improve their fertility. Mechanisms resulting in clay dispersion and structural stability need to be understood to minimize chemical effects on soil structure.

# Characterization of Root-Restricting Zones In Cerrado Soils

*Eric R. Stoner, CPAC*
*Elias Freitas, CPAC*

Concern over the effects of excessive disc tillage, as traditionally practiced in monoculture cropping systems devoid of rotational or fallow periods, has been growing among farmers and researchers in the Cerrado region. Researchers at Brazil's National Soybean Research Center have noticed unexplained decreases in soybean yields in corrected Cerrado soils after ten years of monocrop production, even with the use of improved varieties. The occurrence of reduced yields is often accompanied by farmer observations of superficial root development in soils that have had adequate fertilizer applications and enough time to ameliorate subsoil acidity.

The pressure packing action of disc tillage implements is well known to be capable of greatly increasing the bulk density of frequently-tilled soils, especially when these soils are tilled at high moisture content, as is often the practice in tillage management of Cerrado Oxisols. This greenhouse experiment was conducted as a complement to the study of root restricting zones in Cerrado soils in an attempt to observe the severity of root restriction of several important crop plants under controlled soil density and moisture conditions.

## Objectives

For Cerrado latosols of varying clay content, the objectives are 1) to identify which of the major crop varieties commonly grown in the Cerrado region are most susceptible to mechanical impedance of root development, and 2) to determine the critical soil bulk density levels beyond which little root penetration can be expected for these crops.

## Procedures

Bulk soil samples of dark red latosols were collected within the Federal District from surface soils of sandy loam (16% clay content) and clayey (53% and 70% clay content) texture classes. Fertilizer and lime were added according to recommendations based on soil test levels. Rigid 10 cm diameter by 10 cm height PVC cylinders were prepared as pots with gauze bottoms to hold the soil in place and interior walls covered with paraffin to avoid root exploration of side walls. An appropriate amount of soil placed in the pots was compacted with a hydraulic press to a depth of 5 cm to attain the desired density levels of 1.0, 1.1, 1.2, 1.3 and 1.4 Mg/m$^3$. Three to 4 cm of loose soil were placed on top of the compacted layer for seed placement and to assure uniform seedling development among the compacted treatments.

Frequently planted crop varieties in the Cerrado region were seeded three to a pot (thinned to two): maize (*Zea mays*, var. Cargill 111), soybean (*Glycine max*, var. Doko), wheat (*Triticum aestivum*, var. BR12), and beans (*Phaseolus vulgaris*, var. Carioquinha). Four replications were made in a randomized block design.

A system of subirrigation consisting of a 2 m by 3 m gravel and sand bed tension table was devised to maintain a constant moisture tension near field capacity throughout the one month growing period.

Plant roots were harvested by first washing and dyeing the superficial roots, followed by washing of the roots in the compacted layers. The visual contrast of dyed and undyed roots served as the basis for comparison of root development among treatments.

## Results

Roots of all four crop species developed normally in the sandy loam dark red latosol, even at the greatest bulk density of 1.4 Mg/m$^3$. In the clayey dark red latosol with 53% clay content there was root penetration at all bulk density levels, although slight root restriction was noted in all four crop species at the bulk density of 1.4 Mg/m$^3$.

In the clayey dark red latosol with 70% clay content there were serious restrictions to root penetration for all four crop species. Critical levels of soil bulk density, beyond which little or no root penetration occurred, were as follows:

1.4 Mg/m$^3$ = no root development in soybean, wheat, maize or beans.

1.3 Mg/m$^3$ = no root development in wheat, maize or beans.

1.2 Mg/m$^3$ = no root development in maize or beans.

1.1 Mg/m$^3$ = no root development in beans.

**Conclusions**

Of the four crop species tested under the above-mentioned conditions, it can be concluded that susceptibility to mechanical impedance of root growth is greatest for beans and decreases in the order: maize, wheat, and soybean. By far the most problematic soil studied was the 70% clay content dark red latosol which impeded penetration of bean roots at a bulk density of 1.1 $Mg/m^3$.

**Implications**

Severe restriction of root penetration in the 1.1-1.4 $Mg/m^3$ soil bulk density range for the major crop species grown in the Cerrado region should be cause for special concern, given the disc tillage practices traditionally used here. It should also be pointed out that these root growth restrictions occurred under conditions in which soil water was not a limiting factor, indicating that similar bulk density levels in the field situation may be even more critical for root development under low rainfall situations.

Results from this experiment indicate that the high clay content Oxisols may be more subject to root-restricting soil compaction than low clay content Oxisols. The prominence of high clay latosols in the Cerrado region is demonstrated by data from the Soil Survey of the Federal District that show that 48% of the soils in this area are mapped as latosols of a clayey surface texture class. Of these latosols, profile descriptions show clay contents ranging from 40% (from a profile at CPAC) to 88% (from a profile at the core of the Guided Settlement Plan farming area) with an average clay content for the 41 profiles studied of 70%.

Dark red latosol profiles from colluvial sites comprising the main experimental area at CPAC contain surface clay contents of 40 to 45%, well below the average clay content in excess of 70% for the more common plateau level dark red latosols where most of the farming is conducted in the Federal District.

A consequence of this study will be that sampling studies of root-restricting zones will be focused on farms in the Federal District where these high clay soils occur. It would be advisable to plan to have future on-farm tillage trials located near the cooperative headquarters in the Guided Settlement Plan of the Federal District where these soils occur.

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# Semiarid Tropics
# Texas A&M University

*Prepared by*
*The TropSoils Semiarid Tropics Program*
*Department of Soil and Crop Science,*
*Texas A&M University*
*Lloyd Hossner, Interim Program Coordinator*
*E. C. A Runge, Principal Investigator*
*Ruben Puentes, Program Manager*

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# Introduction

Rainfed agriculture has failed to provide an adequate food supply for most countries in the semiarid tropics (SAT). There are multiple reasons for this shortfall, but a primary constraint to agricultural development in the semiarid tropics has been a lack of suitable soil- and water-management technology. Soils of the semiarid tropics frequently have low water-holding capacities in an environment with recurrent rainfall shortage periods and high evaporative demand. Chemical constraints, particularly soil acidity and macronutrient deficits, also contribute to the inability of the soil resource to support adequate food production.

There have been several international conferences in recent years that have addressed problems of agricultural production on the soils of the semiarid tropics. Each has concluded with an extensive list of areas of research that urgently need to be initiated or expanded. Unfortunately, financial resources and political support to fully implement such efforts have not been forthcoming from the LDC's or donor institutions. The funding and implementation of the TropSoils Semiarid Tropics Program is a significant step forward in fulfilling this need.

## Objectives

The objectives of the TropSoils Semiarid Tropics Program are 1) to develop and adapt, in cooperation with national and international centers, improved soil-management technology for productive, sustained farming systems in marginal lands of the semiarid tropics on an agronomically, economically and ecologically sound basis, and 2) to foster the transfer of such technology through a network of institutions with similar interests.

## Program Implementation

The TropSoils Semiarid Tropics Program is a multilocational, collaborative research program involving several Texas A&M University on-campus and overseas senior scientists, and counterpart researchers from other US, host-country and international institutions.

## Program Coordination and Personnel

Dr. E. C. A. Runge is responsible for the overall coordination of the Semiarid Tropics Program since the departure of Dr. Frank Calhoun. Dr. L. R. Hossner was appointed as interim program coordinator. The program administration is handled from College Station. Mr. Ruben Puentes is the program manager. Ms. Gloria Northcut was the program secretary up to May 1987. Margaret Parker is the new program secretary. The Texas A&M Research Foundation

(TAMRF) is in charge of the administration of the grant. Ms. Sandra Wheaton was assistant administrator and Ms. Juanita Shihadeh is the project specialist for the Semiarid Tropics Program at TAMRF. Ms. Suzanne Cardwell took Ms. Wheaton's position in May 1987. Equipment and supplies procurement and shipping are handled from Lubbock by Dr. C. W. Wendt and Mr. N. Piwonka. A list of TropSoils semiarid tropics personnel and collaborators is included on page 337.

Supporting domestic research is carried out both at Lubbock and College Station. Drs. C. W. Wendt, A. B. Onken and R. Lascano collaborate from Lubbock. Drs. L. R. Hossner and L. P. Wilding collaborate from College Station. On-campus personnel, mainly Drs. Hossner, Wendt, and Wilding, are responsible for coordination of graduate pursuits by junior scientists, and training of American and African junior scientists in the areas of soil fertility, soil physics and soil resources, respectively. Christophe Zaongo (from Burkina Faso), Steve Long, William Payne, Mohamadou Gandah (from Niger) and Jim Gardiner are junior scientists who have been posted in Niger during this reporting period and have returned to College Station to complete analysis and reporting of research results. Bernard Yerima (from Cameroon), Elizabeth Bui and John Wendt have completed their research programs and left the TropSoils program. Anne Pfordresher and Mamadou Ouattara (from Niger) are finishing their on-campus program prior to their departure for Niger to conduct field research. Abdoul Sow (from Mali) and Julius Takow (from Cameroon) have just arrived at TAMU to begin advanced studies; both are supported by external funding and will be conducting research under the TropSoils semiarid tropics umbrella.

## Research Sites

### *Niger*

Niger is the primary research site. The Institut National de Recherches Agronomique du Niger (INRAN ) is the main host-country partner institution. Collaborative research has also been conducted with the ICRISAT Sahelian Center. Other institutions involved are the University of Niamey, Direction de la Meteorologie Nationale, AGRHYMET, CARE, and the NCRP. Dr. N. Persaud is the TropSoils semiarid tropics senior scientist posted in Niger. Dr. A. Manu has been recently assigned project leader status with a partial appointment as senior scientist to the Niger project. Ms. Jessica Davis is the only TropSoils junior scientist currently conducting research in the country. Ms. Katy Ferrari is the project secretary in Niger.

### *Mali*

Mali is the secondary research site. The Institut d'Economie Rurale (IER) is the host-country partner institution. Implementation of the program in Mali differs from the program in Niger: there is no in-country-posted TAMU senior scientist. Most research efforts are conducted by national scientists from the IER and one TAMU junior scientist (Mr. M. Doumbia) under the the supervision of on-campus based project leaders. Mr. Zoumana Kouyate (IER) is the TropSoils Semiarid Tropics Program's research coordinator in the country.

### *Cameroon*

TropSoils involvement in Cameroon was initially targeted to address soil-management prob-

lems of Vertisols. This soil order occupies large areas of the semiarid tropics; however, it is not extensive in Niger. Vertisols dominate vast tracts of lands in northern Cameroon. The research was conducted by Dr. B. Yerima. The National Office for Forest Regeneration (ONAREF) was the collaborating institution. Initial objectives were achieved and the project was suspended due to financial constraints. However, the TropSoils Semiarid Tropics Program has prepared a new research proposal to reinitiate activities in this country. The proposal has been submitted to the TropSoils Management Entity for consideration.

**Research Areas**

The scope of the program was gradually redefined after four years of operations. Research results from initial survey-type studies, recommendations from the External Evaluation Panel, close contact with scientists from collaborating institutions, and recognition of farmers' needs through direct observation, were all elements that contributed to narrow the focus of the Semiarid Tropics Program. Efforts during 1986 can be grouped into two main general research categories: 1) soil water and fertility management: technology development and evaluation, and 2) baseline data studies. Further refinement is presented in the 1987 work plan.

The TropSoils semiarid tropics research activities dealing with soil water, fertility, and crop management under rainfed conditions include experiments on a wide range of agronomic practices. They include cropping sequences and intercropping, tillage, fertilization, residue management, biomass control, microclimate modification and rainfall and runoff management. These experiments are grouped into several interdependent projects being carried out both in West Africa and Texas.

Most of this applied research, which represents the main effort of the Semiarid Tropics Program, requires some support from fundamental studies. Without these studies, technology-development efforts would include an element of uncertainty that the program cannot afford. Extrapolation of results would also be risky. These basic studies can be grouped into three main areas: 1) agroclimatic data base, 2) soil data base, and 3) plant behavior under semiarid environments.

Research objectives, brief descriptions of experimental procedures, main achievements for this reporting period, and future activities are described for each individual project.

**Progress and Achievements**

This section will briefly summarize main achievements for this reporting period. The reader may look for specific details by referring to the individual project description. Project numbers are indicated in parenthesis.

Climate has been traditionally considered the key environmental factor for explaining food shortages in the semiarid tropics. Extreme variability of precipitation, both in time and space, and high evaporative demand interact with soils with low water holding capacity. These factors determine the length of the growing season and have important effects on crop yields. Sahelian farmers have developed empirical perceptions of the reliability of the rainfall regime. These perceptions underlie many soil- and crop-management decisions. The TropSoils Semiarid Tropics Program has provided a more objective insight into rainfall reliability. The compilation,

analysis and interpretation of available rainfall records by TropSoils in Niger has resulted in tables with probabilities of receiving specified decadal rainfall totals for different regions. Temporal variation has been quantified and some trends and periodicities have been established (p. 340).

Probabilities of specified rainfall totals can be used in conjunction with data on evaporative demand to define length of growing periods with specified levels of reliability (p. 340). The TropSoils Semiarid Tropics Program has conducted several studies to estimate soil evaporation and plant transpiration. They include both field measurements under different vegetative cover conditions (pp. 360, 363) and the development of mechanistic models (p. 344). Information on length of the growing season is important not only for decisions on soil and crop management but also for plant-breeding programs.

The consideration of soil hydrological properties is an additional element to refine the soil-water balance. Characterization of the soil moisture regime for soils in the Sahel has been an important topic of research for the TropSoils Semiarid Tropics Program (pp. 340, 347, 358, 360, 372). A valuable data base has been collected on infiltration rates, hydraulic conductivity, and evaluation of soil-water storage throughout the growing season. Soil moisture regimes are being correlated with soil physical properties and toposequence position and the soil-water balance has been characterized for different land uses. This information supports applied research on crop and soil management technology development.

Excessive emphasis on soil-water management aspects has frequently masked soil fertility problems in semiarid regions. An important finding of the TropSoils Semiarid Tropics Program is that in many locations soil fertility, not lack of water, is the main constraint for increasing crop production. Significant interactions between soil-water management and fertilization have been found in most field experiments (pp. 358, 360, 363, 368, 372). In many instances, a breakthrough in yields can only be obtained through adequate fertilization or the removal of chemical constraints.

The research program has shown that nutrient deficiencies under rainfed conditions result in poor utilization of available water (p. 368). Water use efficiency (biomass produced per unit of evapotranspirated water) has been significantly increased with proper fertilizer practices. It has also been observed that in order to increase water use efficiency through soil fertility, efficient and responsive cultivars must be identified and used (p. 368). Under suboptimal conditions, on the other hand, local varieties, better adapted to a harsh environment, may show more consistent yields (p. 360). These findings have important implications in soil management and plant breeding. For many regions in West Africa, widespread use of fertilizers and amendments is limited by economical constraints and/or difficulties in availability. In addition, chemicals will need to be applied judiciously, due to the fragile nature of the Sahelian soils (p. 368). Research efforts are focused on how to optimize interactions among soil-water management, limited fertilization and varietal differences in order to secure consistent yields for farmers whose decisions are risk-aversion motivated.

Both water and nutrients are taken up by plant roots. If a soil factor exists which limits root growth, it may contribute to water and/or nutrient stress and low crop yields. The identification of such limiting factors is being addressed by TropSoils scientists (p. 366). Dramatic effects of

some soil properties have already been detected (pp. 358, 366). Soil acidity, which appears to be widespread in the Sahel (pp. 347, 353), may be one of the most common limiting factors. Once these constraints are identified for each type of soil, the strategy may be either to develop management practices to eliminate them, or to select improved, tolerant varieties.

All these research endeavors are aimed at providing basic pieces of information for technology development and transfer. Extreme spatial variability, consisting of drastic differences in crop establishment and growth over short distances, has evolved as an important obstacle for the interpretation of field research. The problem is present both in Niger and Mali. It seems to be significant at the farmer level although an assessment of its aereal extent and geographical distribution is still lacking. TropSoils is preparing an aereal survey utilizing sophisticated infrared video imagery to determine the extent and cause of unproductive soil areas (p. 347). Parallel efforts are being devoted to determine causal relationships between unproductive areas and soil properties. Some sources of variability already have been identified, such as termite mounds, proximity of trees and past human activities; however, the cause of the problem for extensive areas remains elusive. Multiple working hypotheses are being tested (pp. 347, 353). Interaction between soil acidity and extreme phosphorous deficiency has been also identified as an important causal factor.

The goal of the TropSoils Semiarid Tropics Program is to develop and adapt soil management technology that will reduce constraints to plant growth. Innovations must be agronomically, economically and ecologically sound for developing countries in the semiarid tropics. There are three main sources of information that are supporting research efforts by the TropSoils Semiarid Tropics Program. The first is basic principles of soil management that have been developed in semiarid areas in the U.S. or elsewhere, which could be transferred or adapted to West African conditions. The second is the first hand information and data base gathered by TropSoils' scientists through four years of on-site activities. Some of these achievements and conclusions have been already reviewed in this section. The third source of information is a careful consideration of the indigenous knowledge data base. Sahelian farmers have been dealing with these soil management constraints for centuries. Their attitudes and approaches cannot be neglected.

Several technology components dealing with soil-water, fertility and crop management for the Sahel region are being developed and tested by TropSoils. The approach is to gradually integrate these improved practices into several alternative low- and medium-input farming systems. Various soil-management systems (preparation, liming and fertilization combinations) are being compared in Mali (pp. 372, 353). Tillage treatments include deep plowing, ridging, and tied-ridging. Studies are focused to determine what combinations of practices are technically, socially, and economically feasible. Results indicate that fertilization is more effective than tillage. Similar studies including effects of planting dates, plant densities, residue management, water harvesting, fallowing, biomass control, and microclimate modification are being carried out in Niger (pp. 358, 360, 363, 372).

The effects of fallowing and residue management on soil-water storage were tested at three sites in Niger with a wide range in average rainfall (p. 372). Storage of water from rainfall in bare plots was low, thus, fallowing does not appear as an efficient method for water storage.

Different mulch rates were also tested. Results showed that mulching did not significantly affect the amount of water stored for the next cropping season. However, residue management may have other beneficial effects, such as decreasing wind erosion and capturing blowing sands (p. 347).

Water harvesting principles can be applied at the small-farm level as well as at a small-watershed scale. The potential of water-harvesting techniques for increasing grain yields has been demonstrated by TropSoils' research findings (p. 358). In reducing evaporation losses and increasing weed control and rainfall water-use efficiency, the technique shows advantages in water conservation and increasing grain yields. The next step is to determine specific water harvesting practices which can be adopted by local farmers through the utilization of local, readily available materials. A further step will be application of water harvesting principles at the small watershed level: extensive, impervious laterite plateaus will be evaluated as water harvesting areas for intensive agriculture in small sand basins located at a lower elevation (pp. 347, 358). This traditional farming system, which is common in several Sahelian regions, could be improved.

Reducing evaporation losses from crop stands may result in a lengthening of the growing season (p. 340). Local millet varieties exhibit high tillering capacity. Tillers play an important role in plant growth and grain yield. But from a water conservation viewpoint, tillers transpire, and, if not productive, they increase the ratio of water used per unit of grain production. TropSoils' research has demonstrated that tiller removal may have a positive effect on grain yields (p. 360). Varietal differences and interactions between fertility levels and soil-moisture status were found significant. This simple, labor intensive practice looks promising as a tactical tool during drought periods, particularly at the end of the growing season.

Microclimate modification is another alternative strategy to decrease evaporation losses. TropSoils' studies on growth and yield of cereals between rows of neem tree windbreaks have shown higher relative humidity and lower pan evaporation within the windbreaks (p. 363). Extensive, ten-year-old neem plantations are being used by TropSoils for these studies. The plantations were established by CARE. Farmers perceive advantages in increased comfort and protection for themselves, their dwellings and animals as a result of being shielded from high winds and dust. They are also interested in harvesting wood from these trees. TropSoils' research has shown that windbreaks significantly increase millet dry-matter production. There was also an important (23%) although statistically nonsignificant increase in grain yield. Finally, some wood-harvesting methods, such as partial pollarding, would allow utilization of the plantation for wood but would not seriously affect protection from prevailing winds.

Although training is not an explicit component of the Soil Management-CRSP activities, the CRSP philosophy requires close linkages with local scientists and strengthening of the host country research capability. Joint activities at both planning and implementation stages result in more innovative approches and effective results. The TropSoils semiarid tropics has implemented a Junior Scientist program through which both African and American graduate students are trained on-the-job while advancing in their academic degree programs.

Finally, the initiation and implementation of a research program in several remote locations with minimum infrastructure facilities, involving on-campus and overseas University personnel,

host countries counterparts, IARC's, and graduate students require careful administration and management. The TropSoils Semiarid Tropics Program has emerged from a period of budget constraints and personnel adjustments. The program has adopted important adjustments to the modus-operandi which have been successful in rationalizing budgeting and accounting. Some staffing problems are still being addressed with minimum disruption for the research program. A new "Five-Year Plan" is being prepared by project leaders which will address recommendations from the EEP reviews, from USAID's missions, and suggestions from host country counterparts. Priority research topics have been identified and targetting will increase the efficiency of the research investment.

# Personnel

**Principal Investigators**
Ed C. A. Runge
Frank Calhoun*

**Interim Program Coordinator**
Lloyd R. Hossner

**Program Manager**
Ruben H. Puentes

**Senior Scientists**
Robert Chase*
Robert Lascano*
Andrew Manu
Arthur Onken
Naraine Persaud
Charles Wendt
Larry Wilding

**Clerical and Support Staff**
Margaret Parker
Kati Ferrari
C. Campos
Norman Piwonka

**Junior Scientists**
Elizabeth Bui*
Jessica Davis-Rainey
M. Doumbia
M. Fritz**
Mahamadu Gandah
James Gardiner
J. Landeck**
Steve Long
P. Louis**
Mamadou Ouattara
William Payne
Ann Pfordresher
Abdoul Sow
J. Takow
John Wendt*
Bernard Yerima*
Christopher Zaongo

*Until 1986
**Until 1984

# Soil and Agroclimatic Data Base

The overriding factor in characterizing the Sahel is climate. The variability of precipitation and the high evapotranspiration in relation to rainfall has significant effects on crop yields. As a consequence, improved soil management systems for this environment would necessarily require a quantitative understanding of rainfall patterns, length of the growing season, and soil water balance.

Baseline information about soils is also vital to the development of soil-management technology. Soils in the Sahel are fragile and droughty, and commonly exhibit nutrient deficiencies and toxicities. Spatial variability of soil properties is common, and constrains the transfer of research results unless research sites are carefully characterized.

This section reports a range of studies related to climate and soil characterization. Rainfall patterns have been analyzed from the standpoint of agricultural production on the basis of rainfall probabilities. Data presented offer guidelines for selection of planting dates and crop varieties as a function of location and length of the growing season. Other studies report findings on soil characteristics, particularly soil physical, chemical, and hydrological properties and relationships with topography. The problem of spatial variability over short distances has been particularly addressed.

Results from the agroclimatic and soil data base studies are supporting the technology-development projects discussed in the following section.

# Quantification of Rainfall Patterns And Hydrology of Representative Cropped Soils in Niger

*Naraine Persaud, Texas A&M University*
*I. Alfari, Direction de la Meteorologie Nationale*
*Mamadou Ouattara, INRAN*
*Mohamadou Gandah, INRAN*

The amount and distribution of rainfall profoundly influence crop and livestock production in the semiarid tropics of West Africa. The variability in space and time, and the irregularity of the rainfall in the zone of settled rainfed crop production result in a high risk of crop failure. Traditional food-production strategies arise in response to this high-risk agroecological environment. They have evolved from collective experience and observation over many generations. Sahelian farmers have developed empirical perceptions of the reliability of the rains and semi-quantitative notions of the probability of a certain rainfall amount occurring at a given time during the growing season. These perceptions underlie many soil- and crop-management decisions.

More quantitative insight into the rainfall reliability, probability of rainfall amounts, and risks of crop failure can be obtained by analysis of available point rainfall records. The density of the existing raingauging network in Niger is very low. However, the rainfed agricultural region is fairly homogeneous, unbroken by marked changes in topography and landscape. The main source of the rainfall variation is the behavior of the monsoonal air mass circulation over West Africa. These facts increase the confidence in extrapolating results inferred from low density point rainfall records over larger areas.

## Objectives

The objectives of this project are 1) to quantify temporal variation and distribution, overall trends and periodicities, patterns of wet and dry spells of rainfall, and length of the growing season; 2) to measure and/or catalog the physical and hydrological properties of major cropped soils in Niger, quantifying moisture loss patterns and rain-use efficiency; and 3) to estimate evapotranspiration of economically important crops from climatic data.

This report addresses activities related to objective 1. Experiments related to objectives 2 and 3 are described on pages 372 through 375.

## Procedures

A compilation of available daily rainfall data for 80 raingauging stations in Niger from their origin to 1965 was done and published in 1966 by ORSTOM (Office de la Recherche Scientifique et Technique Outremer, France). A record of these data was kept on magnetic tape as part of the meteorological data bank at the Centre AGRYMET (Centre for Training and Applications in Agrometeorology and Operational Hydrology) in Niamey. This file was updated by staff of the ICRISAT Sahelian Center and includes available years of data from 1966 through 1983 inclusive. These data were obtained from the Direction de la Meteorologie Nationale, Niger.

The database was carefully checked for data entry errors and these were corrected. All stations with 25 years or more of complete record were chosen for analysis. There were 43 such stations.

The calculation of the probabilities was patterned after similar studies in the literature for other geographical areas. Rainfall totals were accumulated by decades, for each year. These totals were summed and averaged over the years of data to yield the mean rainfall for the decade. The totals for each period were then ranked in descending order of magnitude and the probability of a specified rainfall total was taken as the number of years in which the specified total was exceeded divided by the number of years of data. For a given rainfall amount this ratio represents the counting probability of receiving at least the specified amount of rainfall or higher during the period under consideration. Probabilities were calculated for the following specified totals: 5, 10, 15, 20, 30, 40, 50, 60, 80, 100, 120 and 140 mm.

## Results and Discussion

### *Overall Probability Patterns*

Tables containing results of the calculations were prepared for the 43 raingauging stations. All tables were included in the TropSoils-SAT report "Probability of Receiving Specified Decadal Rainfall Totals for Selected Stations in Niger, West Africa." One example, the station Niamey-aero, is included in this Progress Report (Table 1). Geographical coordinates, altitude, mean annual rainfall and number of years of complete record are provided for each station. The

**Table 1. Probability of receiving specified decadal rainfall totals for the Niamey-aero station.**
**Station: Niamey Aero Code: 320001 Lat.: 13 29N Long.: 02 10E Alt.: 221m**
**Mean Annual PCPN. = 585.25mm Years of Record = 41**

| Decade begins | Mean PCPN (mm) | Probability (percent) of receiving at least the following amounts (mm) of precipitation: 5 | 10 | 15 | 20 | 30 | 40 | 50 | 60 | 80 | 100 | 120 | 140 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| APR 1 | 1.72 | 7 | 7 | 4 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| APR 11 | 1.08 | 7 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| APR 21 | 2.55 | 12 | 7 | 7 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| MAY 1 | 3.79 | 19 | 12 | 4 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| MAY 11 | 10.34 | 48 | 39 | 26 | 19 | 4 | 2 | 2 | 2 | 0 | 0 | 0 | 0 |
| MAY 21 | 20.51 | 65 | 58 | 36 | 34 | 24 | 19 | 12 | 7 | 2 | 2 | 2 | 0 |
| JUNE 1 | 21.97 | 68 | 60 | 51 | 39 | 31 | 26 | 17 | 4 | 0 | 0 | 0 | 0 |
| JUNE 11 | 29.67 | 82 | 75 | 58 | 48 | 39 | 26 | 19 | 14 | 9 | 2 | 0 | 0 |
| JUNE 21 | 27.18 | 90 | 82 | 78 | 63 | 39 | 14 | 12 | 4 | 0 | 0 | 0 | 0 |
| JULY 1 | 36.82 | 97 | 92 | 87 | 82 | 51 | 36 | 24 | 14 | 2 | 2 | 0 | 0 |
| JULY 11 | 55.04 | 100 | 95 | 92 | 87 | 80 | 70 | 46 | 39 | 17 | 9 | 4 | 0 |
| JULY 21 | 69.04 | 100 | 100 | 90 | 87 | 78 | 70 | 60 | 53 | 36 | 17 | 12 | 7 |
| AUG 1 | 57.82 | 97 | 92 | 92 | 92 | 80 | 63 | 53 | 39 | 17 | 12 | 4 | 4 |
| AUG 11 | 66.04 | 97 | 97 | 97 | 95 | 82 | 70 | 58 | 51 | 36 | 19 | 9 | 2 |
| AUG 21 | 68.38 | 100 | 95 | 92 | 92 | 73 | 65 | 56 | 48 | 36 | 17 | 9 | 7 |
| SEPT 1 | 49.09 | 100 | 92 | 90 | 85 | 68 | 46 | 36 | 26 | 14 | 12 | 2 | 2 |
| SEPT 11 | 34.34 | 85 | 78 | 70 | 65 | 48 | 36 | 26 | 19 | 4 | 0 | 0 | 0 |
| SEPT 21 | 13.78 | 65 | 53 | 43 | 29 | 12 | 4 | 2 | 0 | 0 | 0 | 0 | 0 |
| OCT 1 | 7.43 | 36 | 24 | 21 | 19 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| OCT 11 | 3.99 | 17 | 17 | 7 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| OCT 21 | 1.82 | 17 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

code numbers given for each station are those used originally by ORSTOM. Since rainfall pattern is unimodal everywhere in Niger, only the probabilities for the period March 13 through November 6 are presented for each station. Outside of this period rainfall can be considered to occur with zero probability.

The mean annual rainfall and decadal mean precipitation reflect the influence of increasing north latitude and the influence of the advance and retreat of the inter-tropical convergence zone (ITCZ) on the rainfall pattern over Niger. Figure 1 shows the mean decadal rainfall plotted versus time for five stations at different latitude: there is a decrease of close to 2 mm per minute of increase in latitude.

These results confirm previous observations that the northward advance of the ITCZ is slower and more irregular and variable than its retreat southward. The

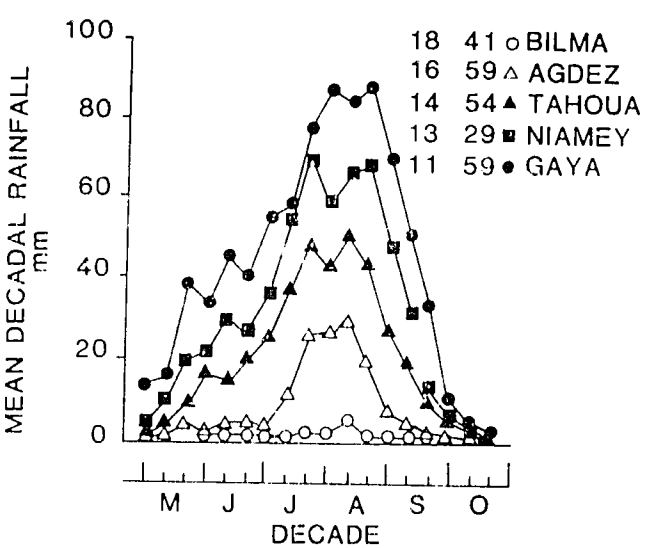


**Figure 1. Mean decadal rainfall for five stations in Niger with increasing north latitude.**

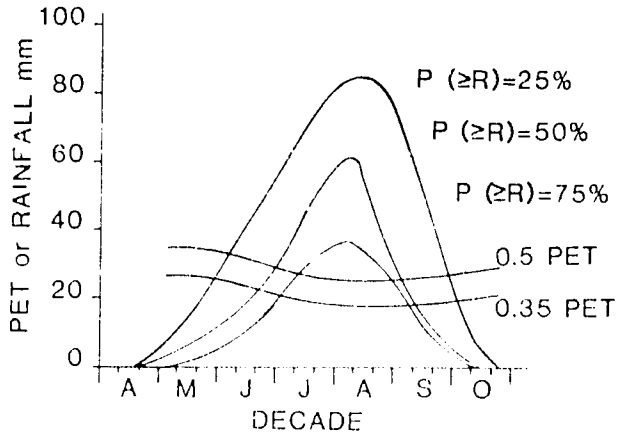


Figure 2. Example using data from station Niamey-aero to illustrate estimation of the length of the growing period based on PET/rainfall relations for different levels of exceedance probability.

onset of the rainy season tends to be more gradual and variable than the end. This pattern is reflected in the probabilities of the specified rainfall totals for all 43 stations. For a specified amount, the probabilities increase gradually to a maximum but fall off rapidly as the season ends. The highest probabilities occur during the ending decade of July and throughout August, which is the period of most reliable rains in Niger for all stations. High decadal rainfall totals have a low probability of occurrence. Totals of 60 mm or more occur less than 50% of the time even for Gaya, the most southerly station.

Linear interpolation between tabulated values is possible: three methods are described in the above-mentioned report. Calculations are easily performed with a programmable, hand-held calculator.

Table 2. Length of the growing period based on PET/rainfall ratio, at three levels of reliability; Niamey-aero sation.

| Reliability % | Growing period in days: Rain > 0.5 PET | Rain > 0.35 PET |
|---|---|---|
| 75 | 49 | 68 |
| 50 | 69 | 83 |
| 25 | 114 | 127 |

Table 3. Parameters for fitting the gamma distribution to the frequency hystograms of decadal rainfall totals; Niamey-aero station.

Station: Niamey-aero Code: 320001
Yrs. of Record = 41

| Month And Decade | Parameters: X | m | A | a | b |
|---|---|---|---|---|---|
| May 2 | 13.3 | 9 | 0.584 | 0.075 | 0.999 |
| 3 | 20.2 | 4 | 0.783 | 0.038 | 0.776 |
| June 1 | 23.7 | 3 | 0.607 | 0.041 | 0.966 |
| 2 | 30.4 | 1 | 0.460 | 0.041 | 1.233 |
| 3 | 28.6 | 2 | 0.165 | 0.112 | 3.197 |
| July 1 | 36.8 | 0 | 0.168 | 0.085 | 3.128 |
| 2 | 55.0 | 0 | 0.101 | 0.099 | 5.120 |
| 3 | 63.6 | 0 | 0.149 | 0.055 | 3.506 |
| Aug 1 | 57.8 | 0 | 0.145 | 0.062 | 3.603 |
| 2 | 66.0 | 0 | 0.101 | 0.077 | 5.116 |
| 3 | 59.6 | 0 | 0.251 | 0.036 | 2.147 |
| Sept 1 | 49.0 | 0 | 0.153 | 0.070 | 3.421 |
| 2 | 35.2 | 1 | 0.398 | 0.040 | 1.407 |
| 3 | 14.1 | 1 | 0.523 | 0.078 | 1.100 |

*Definition of growing periods*

The probability tables can be used to define growing periods with specified levels of reliability either directly from the tables or in conjunction with data on evaporative demand.

To illustrate definition directly from the tables, let the reliable growing period be defined as that in which the decadal rainfall total (R) be at least 30 mm with 75% probability (symbolically: P(R>=30)=75%). Using interpolation, the beginning and ending dates for station Niamey-aero are July 1 through September 10. Variations in the definition can be selected to suit different crops by specifying the appropriate criteria for the beginning and ending of the growing season.

When data for evapotranspiration are available these can be used in conjunction with the tabulated

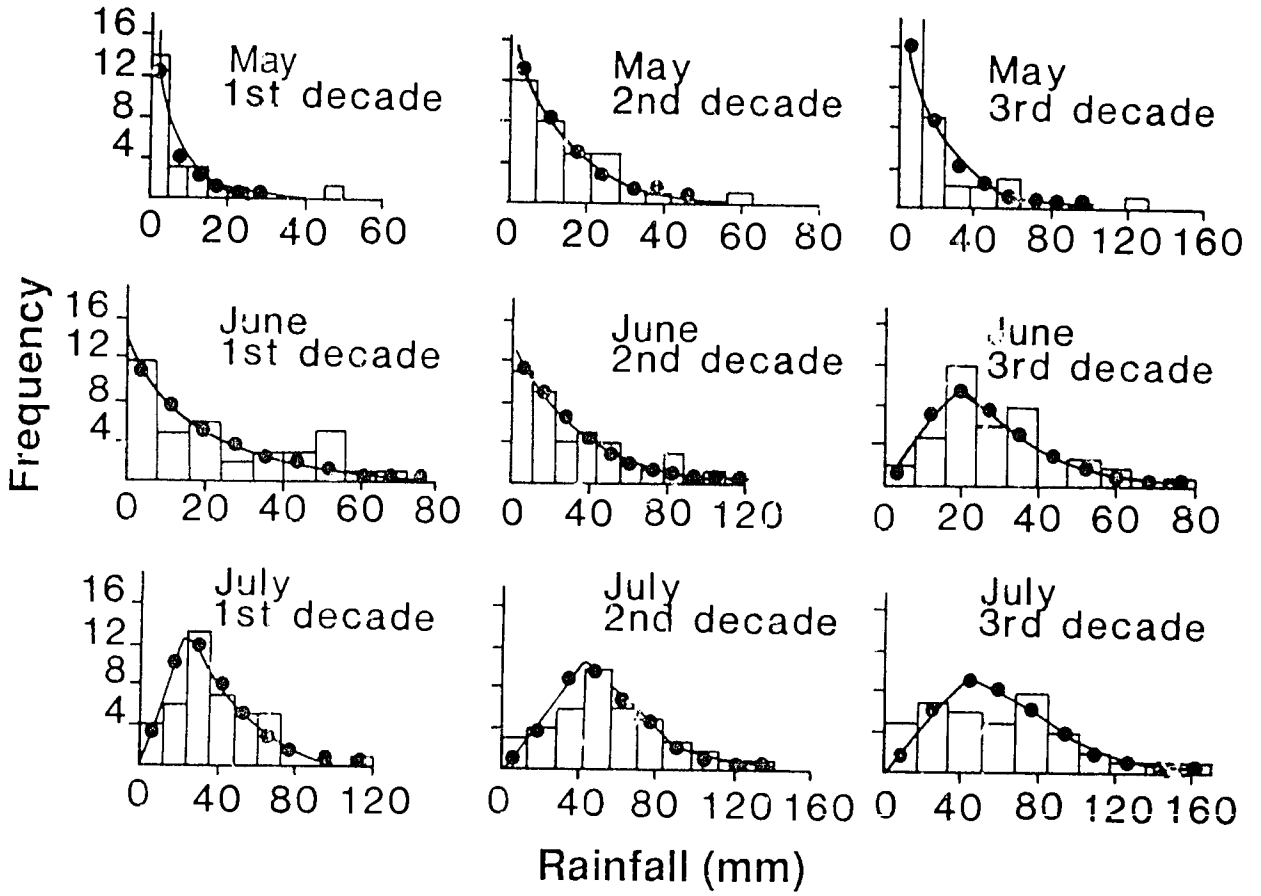


**Figure 3. Fitting of the gamma distribution to the frequency histograms of decadal rainfall totals for several decades for station Niamey-aero.**

results to obtain better definition of the growing period at specified levels of reliability based on rainfall supply/demand relationships. One example is shown in Figure 2 for station Niamey-aero. Decadal rainfall totals (R) satisfying the criterion P(>=R)=75%, P(>=R)=50%, and P(>=R)=25%. These curves were smoothed using a Fourier series, truncated to two harmonic terms. Also drawn on Figure 2 are the curves corresponding to 0.5 and 0.35 for mean decadal potential evapotranspiration (PET) calculated by the Penman method. The growing periods, based on the two definitions of the PET/rainfall ratio and for the three levels of reliability, are shown in Table 2. Similar calculations an be done for other locations in Niger.

*Probabilities by fitting theoretical distributions*

The probabilities presented in Table 1 were obtained by an empirical counting procedure. Another approach is to fit a theoretical probability density distribution to the frequency histogram of the decadal rainfall total. Once the parameters of the distribution are obtained, the formula for the distribution can be manipulated to calculate probabilities as required without the need for the extensive tabulation and interpolation processes. The gamma density distribution was fitted to the frequency histograms for 23 stations with more than 40 years of data. This distribution was chosen since it is flexible enough to describe shapes of early and late season and also of midseason rainfall distribution totals. Table 3 shows the parameters and other results for fitting of the gamma distribution for the Niamey-aero station. Figure 3 illustrates graphically the fits of the gamma distribution for several decades for the same station The suitability of the gamma distribution is clearly

**Table 4. Growing periods (in days) at different levels of reliability for the Niamey-aero station data using both the empirical and theoretical probabilities.**

| Reliability | Growing period in days | | | |
|---|---|---|---|---|
| % | Rain > 0.5 PET | | Rain > 0.35 PET | |
| | Emp. | Theo. | Emp. | Theo. |
| 75 | 49 | 48 | 68 | 64 |
| 50 | 69 | 74 | 83 | 90 |
| 25 | 114 | 94 | 127 | 116 |

demonstrated: as the season advances, the histograms become more normal and less skewed. Table 4 compares results obtained for the growing periods at different levels of reliability from the Niamey-aero station data using both the empirical and theoretical probabilities.

### Implications

Results obtained from this study provide a quantitative insight into the reliability of the rains during the growing season for many locations in Niger. They can also be used by plant breeders to infer quantitative definitions of the length of the growing season to various degrees of reliability, either directly or in conjunction with data on crop evapotranspiration requirements.

## Water and Energy Balance of Crops With an Incomplete Canopy Cover

*Robert J. Lascano, Texas Agricultural Experiment Station*
*Cornelius van Bavel, Texas A&M University*
*Jerry L. Hatfield, USDA-ARS, Cropping Systems Research Laboratory*
*Dan R. Upchurch, USDA-ARS, Cropping Systems Research Laboratory*

In semiarid climates, such as that of the High Plains of Texas and Niger, West Africa, crops such as cotton and millet are commonly cultivated under dryland conditions, seldom developing a leaf area index over 2.0. Therefore, throughout the growing season a large portion of the soil surface, mostly between rows, is not covered by the plant canopy. Thus, in order to describe soil evaporation and crop transpiration, the water and energy balance for both the soil surface and the crop canopy must be considered separately.

### Objective

The objective of this project is to mechanistically simulate soil evaporation and plant transpiration for a row crop with an incomplete canopy cover from standard weather data and soil and crop properties. The experimental objective was to test the proposed model by comparing measured and predicted values of soil evaporation and crop evapotranspiration.

### Procedures

A 100 x 100 m plot at the Texas Agricultural Experiment Station near Lubbock was used in this study. Cotton was planted on north-south bedded rows, 1 m apart, with a plant population at emergence of 139,000 plants/ha. The experimental site was divided in two plots: dryland and irrigated. Each plot was instrumented for the measurement of water content and temperature at five locations within each plot. Crop evapotranspiration (ET), over the growing season, was determined from the weekly measurements of the volumetric water content profiles; daily soil evaporation (E), at two time periods, was measured with microlysimeters.

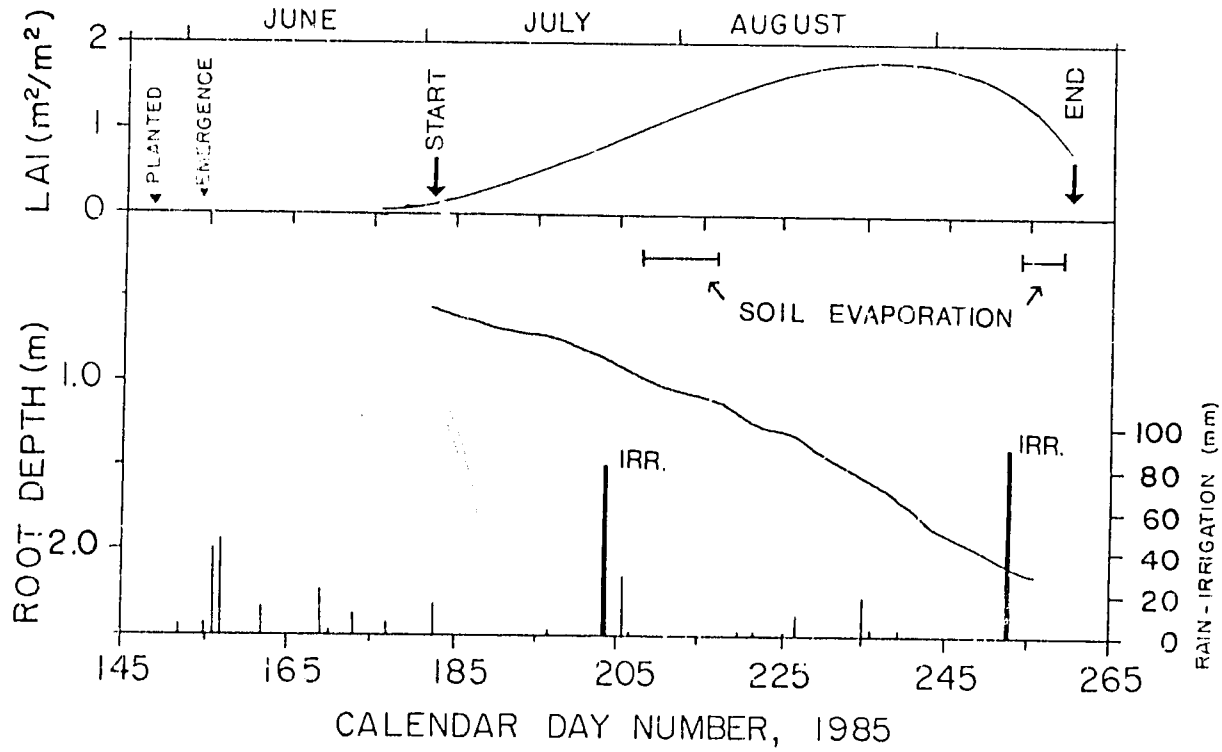


Figure1. Leaf area index (LAI), root depth and rain or irrigation against calendar day number for the irrigated cotton crop in 1985. Dates of planting, emergence, start and end of simulation dates, and the periods over which measured and simulated soil evaporation rates were compared are included.

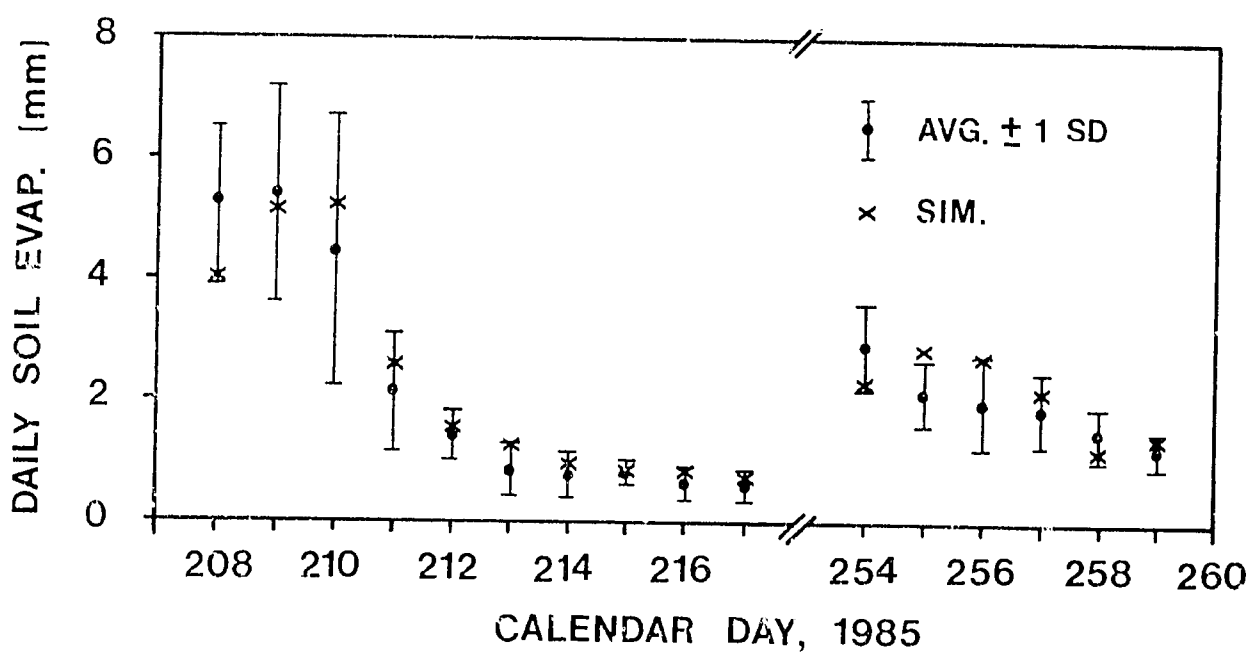


Figure 2. Comparison between measured ( ) and simulated (X) daily soil evaporations (mm) for the irrigated cotton crop against calendar day number. The bar equals one standard deviation (SD).

Inputs to the model are the following: leaf area index, root distribution, initial water and temperature profiles and weather variables (global radiation, air temperature and humidity, and windspeed). The above inputs were measured over the growing season.

The test of the model consisted in comparing measured to simulated values of crop ET, soil E, and water and temperature profiles. The experimental period was 78 days. The development of leaf area index, root depth, and rain and irrigation against calendar day number, for the irrigated crop, are shown in Figure 1. Also shown are the dates the crop was planted and emerged, the start and the end of the simulation period, and the two time periods during which soil E was measured.

## Results

A comparison of measured and simulated daily soil E rates for the two time periods in which it was measured is given in Figure 2. The pattern of the average daily soil E under the crop canopy shows that the daily rate remained relatively constant during the first period at 5 mm/d for three days and thereafter declined to a constant value (1 mm/d).In the second time period, the daily rate decreased gradually from 3 to 1 mm/d over a six-day period. These results clearly show that the calculated daily soil E rates were within the variance of the measured values.

Comparisons of measured and simulated cumulative ET for the irrigated and dryland cotton crop are shown in Figures 3 and 4, respectively. Measured and simulated values show close agreement. Given the adequacy of the model in calculating values of daily soil E, the simulated values of crop transpiration should be of commensurate accuracy. At the end of the experimental period the ratio of calculated total crop transpiration to total ET was 0.68 for the irrigated crop, and 0.79 for the dryland crop.

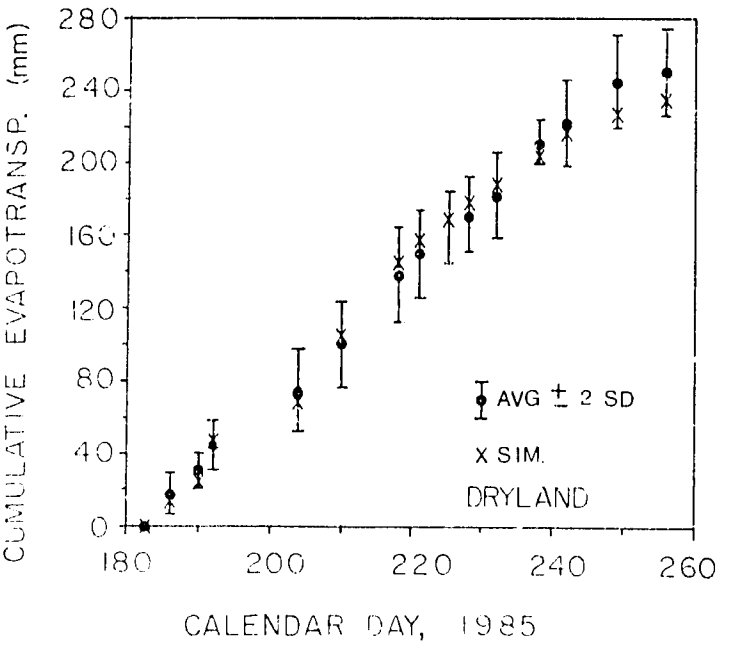


**Figure 3. Comparison between measured ( ) and simulated (X) cumulative evapotranspiration (mm) for the irrigated cotton crop against calendar day number, 1985. The bar equals 2 standard deviations (SD) and n is the number of replicates.**

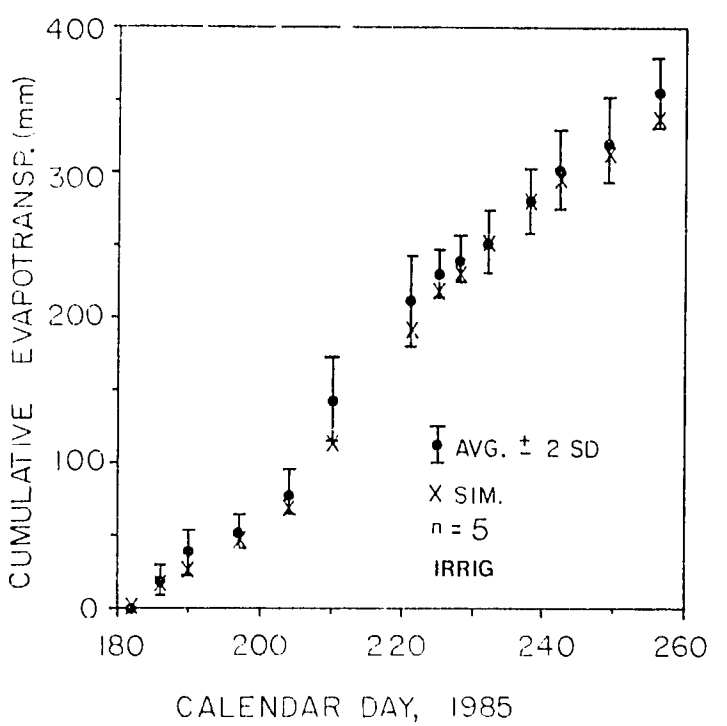


**Figure 4. Comparison between measured ( ) and simulated (X) cumulative evapotranspiration (mm) for the dryland cotton crop against calendar day number, 1985. The bar equals 2 standard deviations (SD) and n is the number of replicates.**

### Conclusions

Experimental verification of the daily soil E and ET rates, as computed with a model for a cotton crop from standard weather and soil data, showed good agreement between simulated and measured values. The verification was done over a period of 74 days in a semiarid climate, the crop having a small leaf area index and over a wide range of soil wetness and temperatures. The results show that the total soil E, for the conditions of the test, was about 30% of the total ET. Predictions of water and temperature profiles (data not shown) also showed good agreement with measurements.

### Implications

We conclude that the proposed model is adequate for calculating soil evaporation and crop transpiration separately, for a row crop with an incomplete canopy cover. It is suggested that this model will be a useful tool in analyzing alternative irrigation and crop management systems in water-limited areas, and in the design and analysis of field experiments regarding water use efficiency over the entire growing cycle.

## Soil Resource Evaluation In the Semiarid Tropics

*Larry P. Wilding, Texas A&M University*
*Elisabeth Bui, Texas A&M University*
*Bernard Yerima, Texas A&M University*
*Anne Pfordresher, Texas A&M University*
*Ruben Puentes, Texas A&M University*
*Mamadou Ouattara, INRAN*
*Andrew Manu, Texas A&M University-INRAN*

Research conducted under this project includes the characterization of dust inputs into Niger, classification and characterization of INRAN target research sites used by TropSoils in Niger (Chikal, Kale Pate, and N'Dounga), classification and mapping of the spatial variability sites in Mali, soil moisture/chemistry dynamics in Plateau/Dry Valley toposequences in Western Niger, soil structure/porosity dynamics on physical and hydrological properties of Vertisols in the semiarid tropics, quantifying areal distribution and extent of poorly responsive millet areas in sandy fields of Niger, and development of a semiarid-tropics research initiative in Cameroon. Major conclusions of research completed by Drs. E. Bui (1986) and B. Yerima (1986) were reported in the *TropSoils Technical Report, 1985-1986*, and will not be duplicated herein.

### Objectives in General

The general objectives of this research are 1) to establish baseline soil resource conditions for major soil and targeted research sites in the semi-arid tropics to facilitate understanding of soil water/fertility interactions and technology transfer; 2) to establish the quantity and composition of dust inputs into semiarid tropics as a nutrient renewal vector to soil water/fertility interactions, and 3) to integrate soil, climate and plant interactions into a land evaluation model closely tied to toposequence/land use relationships for millet and sorghum.

## Chemical and Physical Characteristics Of Dust Inputs in the Sahel

Dust samples have been collected in open-bucket trap designs at Chikal and Sadore, from the period

June 1985 to date. Sixteen samples have been analyzed. Collection heights were at 3.5 and 7 m above the ground surface before they were changed to 2.5 and 4.5 m height in July 1986. Collection dates for both locations have been similar — sampling intervals range from two to six months, corresponding to seasonal harmattan dust and rainfall events. Samples are being characterized for particle-size, soluble cations, exchangeable cations CEC, mineralogy and total elemental Ca and K.

The potential for nutrient renewal in the Sahel soils via dust inputs is apparently quite significant (Table 1). Dust inputs, particle-size and chemical properties are highly site specific, seasonally variable and independent of sampling heights (3.5 vs. 7 m). On the average, dust inputs approximate 0.8 g/month/trap = 150 g/m²/year or about 1500 kg/ha/year (Table 1). This constitutes a long-term chemical influx to these soils that helps explain observed depth distributions of nutrients, base saturations and mineralogy.

Insufficient sampling has occurred to verify positive relationships between total dust inputs, particle-size, and seasonal fluxes. Most dust samples are distinctly finer-grained than surface soil horizons in the immediate area. Dusts are higher in total clay (<2 m) and fine silts (2-20 m) than reference soils (Table 1). About 60% of the dust samples have clay contents that range from 15 to 30%, while clay percentages for the surface soils commonly range from 1 to 5%.

Chemically, dust samples contain 10 to 30 times higher levels of exchangeable Ca, Mg, Na and K than reference soils (Table 1). Annual influxes are 2.7 kg/ha Ca, 0.9 kg/ha Mg, 0.04 kg/ha Na, and 1.2 kg/ha K. The CEC values of dust are about five times higher than reference soils. The dust samples are essentially base saturated while surface horizons of soils in this area commonly are only 20 to 30% base saturated with exchangeable Al comprising the remainder of the cations. Long-term impact of dusts on surface horizons of soils is evident in the accumulation of

**Table 1. Physical and chemical properties of dusts and reference soils.***

| Property | Chikal site | | Sadore site | | Mean (both sites) | |
|---|---|---|---|---|---|---|
| | Dust | Soil | Dust | Soil | Dust | Soil |
| **Total dust inputs (g/month)** | | | | | | |
| | 0.3- 1.3 | — | 0.1-2.5 | — | 0.8 | — |
| **Soluble cations (meq/l)** | | | | | | |
| Ca | 0.1-14.0 | — | 0.1-4.5 | — | 3.0 | — |
| Mg | 0.4- 3.6 | — | 0.1-2.6 | — | 1.1 | — |
| Na | 1.3- 3.8 | — | 0.8-8.9 | — | 2.5 | — |
| K | 1.0- 3.8 | — | 1.2-9.1 | — | 2.7 | — |
| **Exchangeable cations (meq/100g)** | | | | | | |
| Ca | 2.3-13.0 | 0.1-0.7 | 8.5-11.7 | 0.1-0.4 | 9.1 | 0.3 |
| Mg | 0.4- 3.0 | 0.1-0.8 | 1.3- 6.2 | 0.1-0.2 | 2.5 | 0.2 |
| Na | 0.2- 1.2 | 0.1- — | 0.4- 2.4 | 0.0-0.1 | 1.1 | 0.1 |
| K | 0.6- 1.7 | 0.1- — | 1.5- 3.8 | 0.0-0.1 | 2.0 | 0.1 |
| **CEC (meq/100g)** | | | | | | |
| | 3.4-15.9 | 0.5-1.8 | 15.2-18.5 | 1.2-2.6 | 12.4 | 1.5 |
| **Clay (%)** | | | | | | |
| | 4.4-24.6 | 1.7-3.1 | 0.1-27.5 | 3.2-8.0 | 14.0 | 3.7 |

*Diameter of dust trap is 28.5 cm = 0.064 square meters

small quantities of smectite and mica, common to dust samples but less evident in subsoils. Kaolinite is the dominant mineral of the clay fraction while quartz is dominant for silt and sand fractions in both dusts and soils. Secondary quantities of feldspars also occur in the coarser separates of dusts and soils.

## Classification and Characterization Of Research Sites in Niger

Representative soils at N'Dounga, Kale Pate, and Chikal INRAN Centers were described in July 1985, and subsequently characterized in 1986. These are the sites where Mr. William Payne and Christophe Zaongo conducted their water-harvesting and water-balance research in 1985-86. All soils are coarse-textured and have similar hydrological properties, but differ significantly in chemical properties. Selected physical and chemical data are presented in Table 2.

The N'Dounga site has the strongest textural differentiation, finest-textured subsoil, a continuous Bt and exhibits moderate levels of exchangeable Al except in surface horizons. The Kale Pate site has loamy sand lamellae Bt bands from 40 to 185 cm that aggregate a total thickness of 13 cm. This soil has the highest exchangeable Al percentage and lowest base saturation of the three sites. The Chikal site is the driest of the three climatically, and has the highest base saturation, pH and CEC per unit clay of the three soils studied. Small quantities of smectite and mica in the clay fraction of the Chikal site occur throughout the profile, which may explain the higher charge characteristics.

Soils at the N'Dounga site are classified as Psammentic Paleustalfs, reflecting their sandy nature, thick argillic horizon and higher base saturation at depth. Soils at Kale Pate are classified as Alfic Ustipsamments, reflecting their sandy nature, slight textural differentiation, discontinuous [illegible]ded Bt lamellae that are too thin to constitute an argillic horizon, and lower base saturation. Soils at the

**Table 2: Selected physical and chemical data of soils at N'Dounga, Kale Pate and Chikai INRAN Centers.**

| Horizon | Depth | Organic C | pH | Sand | Clay | CEC | ECEC | Al sat. | Base sat. |
|---|---|---|---|---|---|---|---|---|---|
| | (cm) | (%) | ($H_2O$) 1:1 | — % — | | (meq/100g) | | — % — | |
| **N'Dounga (Psammentic Paleustalf)** | | | | | | | | | |
| Ap | 0-7 | 0.14 | 5.1 | 94.2 | 2.0 | 1.0 | 1.0 | 10 | 90 |
| A | 7-26 | 0.08 | 5.2 | 95.1 | 1.7 | 1.1 | 0.5 | 40 | 27 |
| Bt2 | 39-60 | 0.10 | 4.8 | 90.5 | 4.8 | 1.5 | 0.7 | 43 | 27 |
| 2Bt4 | 95-140 | 0.14 | 5.0 | 86.1 | 9.5 | 1.9 | 1.2 | 17 | 53 |
| 2Bt6 | 198-220 | 0.06 | 5.8 | 88.7 | 6.6 | 2.0 | - | - | 65 |
| **Kale Pate (Alfic Ustipsamment)** | | | | | | | | | |
| Ap | 0-12 | 0.12 | 5.7 | 94.8 | 1.0 | 1.0 | - | - | 30 |
| BA | 12-30 | 0.07 | 5.2 | 94.9 | 2.2 | 0.8 | 0.4 | 75 | 13 |
| 2Ab | 70-78 | 0.12 | 4.7 | 88.0 | 5.7 | 1.2 | 0.6 | 83 | 8 |
| 2Btb2 | 102-120 | 0.10 | 5.0 | 85.9 | 5.1 | 1.2 | 0.5 | 40 | 25 |
| 2Btb4 | 193-235 | - | 5.0 | 86.9 | 3.7 | 1.0 | 0.5 | 40 | 30 |
| **Chikal (Ustic Torripsamment)** | | | | | | | | | |
| C | 0-16 | 0.13 | 5.5 | 90.2 | 2.1 | 1.8 | - | - | 72 |
| A | 16-32 | 0.11 | 5.8 | 88.3 | 4.7 | 2.5 | - | - | 44 |
| Bw2 | 52-79 | 0.10 | 5.6 | 86.0 | 6.5 | 2.8 | - | - | 79 |
| BC | 79-120 | 0.11 | 6.0 | 85.0 | 7.2 | 2.9 | - | - | 76 |
| 2C2 | 150-210 | 0.04 | 6.3 | 94.6 | 0.6 | 0.9 | - | - | 67 |

Chikal site are classed as Ustic Torripsamments, reflecting their sandy nature, an aridic soil moisture regime borderline to Ustic, weak textural differentiation, and relatively thin solum thickness.

## Classification and Mapping Of Spatial Variability At Research Sites in Mali

At the IER Cinzana Research Center, Mali, a detailed soil map was made of research plots which were highly variable in their response to grain sorghum. Forty-four observations (one per plot) were made over an area of about 1.5 ha to record the morphological soil characteristics that might impact sorghum response. These properties included soil reaction, thickness and texture of surface sandy horizons, and depth to the root- and water-restrictive plinthite layer. The area was mapped on the basis of these grid observations into three soil types that corresponded to different slope elements of the general plot area. This soil survey serves as a resource base for Mr. Mamadou Doumbia's research project. The map will be incorporated into his report.

About 20% of the plot area was represented by well-drained soils that were strongly acid to 180 cm. These soils are classified as fine loamy, siliceous, hyperthermic, Plinthic Paleustults. They occupy the gently sloping (2–3%), slightly convex upper slopes of the plot area and have about 25 cm of sandy loam surface over 25 cm of sandy clay loam Bt subsoil, which in turn overlies a sandy clay loam to clay loam plinthite layer (iron pan). The plinthite layer is strongly root- and water-restrictive, and limits the effective root zone of these soils to 50 cm. A detailed description of this soil and samples for characterization analyses were collected from a pit just outside the plot border. Mamadou Doumbia will analyze these samples and incorporate the baseline data into his research project report.

Over 75% of the plot area occupies a nearly level (<1%) back-slope that topographically sets between the better drained soils above and less well-drained soils below. These soils have moderately to strongly acid surface and upper subsoil horizons that become moderately acid at a depth of about 1 m. The surface horizons are thicker and commonly have 10 to 20 cm of recent fluvial overwash sediments that bury the original surface. The plinthite zone is again strongly water and root restrictive but occurs at a depth of 85 cm to 1 m. Thus, these soils have up to twice the effective root volume of the adjacent better-drained sloping analogues and are less acid in lower subsoils. They are classified as fine loamy, siliceous, hyperthermic Plinthic Paleustalfs (provisional placement). A detailed description of this soil and samples for laboratory characterization were also collected from a pit between plots.

About 5% of the research plots occupied slightly concave, somewhat poorly drained alluvial toeslope positions. These soils were markedly influenced by termites in the subsoil, resulting in clayier textures and near neutral soil reactions. The soils were classed as Plinthaquic Paleustalf (provisional placement). They will be avoided in future plot layouts because they are not representative of the general plot area.

### Conclusions

1. This survey will provide a database to define the variability in macro-morphological properties of these research plots.

2. The spatial variability in macromorphic soil properties as delineated in the soil map does not appear to be responsible for the variability in grain sorghum observed over these plots. The scale and configuration of macromorphic soil variability does not appear to coincide with differential grain sorghum response.

3. Sandy soils in this region are strongly subject to surface crusting and water runoff. The effective soil thickness is determined by the depth to plinthite. The iron pan does not apparently resaturate during the rainy season but does perch water at the pan interface.

## Soil Moisture/Chemistry Dynamics In Plateau/Dry-Valley Toposequences In Western Niger

Water table versus water-quality monitoring in the Dallol Bosso, Niger, was terminated at the beginning of this year. Access tubes implanted into channel and adjacent dunal plains along a N-S axis of the Dallol Bosso were destroyed by vandalism shortly after emplacement in the fall of 1985. This work will not be reinitiated because the 1986 TropSoils Review

Team in Niger placed a lower priority on this effort in view of the limited budget and expected benefits.

A new research program is being initiated by Mr. Mamadou Ouattara of INRAN, DRE, to investigate the dynamics of soil moisture/soil chemistry changes along two plateau/dry-valley toposequences of increasing rainfall in Western Niger. The objectives of this research are 1) to classify and characterize soils along the toposequences with emphasis on soil acidity and phosphorous fixation chemistry; 2) to determine the soil moisture regime as a function of toposequence position during the growing season; 3) to determine millet crop growth response as a function of toposequence position, and 4) to survey problems encountered by farmers in management of the soils of the Plateau/Dry-Valley Systems.

## Structure/Porosity Dynamics Of Vertisols in the Semiarid Tropics

Vertisols occur extensively in semiarid regions of Africa. For example, 50 million ha occur in the Sudan, 13 million in Ethiopia, and nearly 3 million in West Africa, including Cameroon, Mali, Burkina Faso, Benin, Togo, Ivory Coast and Niger. Potential productivity of Vertisols is high, but management is extremely difficult due to unique soil/water interactions that result in shrink-swell volume changes upon wetting and drying cycles. These physical reactions directly or indirectly govern soil tilth, workability, infiltration, water recharge, internal drainage, aeration, surface runoff, flooding and erosion.

### Objectives

Specific objectives of this work are 1) to develop methodologies to quantitatively analyze changes of structural conditions of Vertisols at both macro-and microfabric levels, and 2) to apply methodologies developed to investigate impacts of change in structural condition on physical and hydrological properties of Vertisols in semiarid regions of Texas and West Africa.

### Progress

To date target research sites have been selected, a literature review completed and samples collected to test methodologies for sample drying and preparation. Equipment has been procured for image analyses of thin-sections but it has not yet been put into service. A total of 64 samples of surface and near surface horizons have been collected from Pellusterts under different long-term land use (uncultivated meadows of various ages versus continuously cultivated croplands) and different cropping systems (continuous conventional versus conservation tillage). This work has been initiated at the USDA-ARS and Texas Agriculture Research Centers at Riesel and Temple, Texas.

Minimizing fabric changes during sample drying is being tested by using a method of acetone replacement (combined vapor/liquid transfer). The procedure requires nearly 60 days for saturated samples.

## Quantifying Areal Distribution And Extent Of Poorly Responsive Millet Areas In Sandy Soils of Niger

Areas of poor growth in millet fields associated with short-range variability of soil properties are believed to be a significant problem in sandy soils of Niger. The magnitude of this problem, however, has not been verified. It was the recommendation of the 1986 EEP TropSoils Review Team in Niger that this should be done before further efforts be devoted to understanding the causal soil factors. Hence, the objective of this research is to quantify the areal extent and distribution of poorly responsive areas within millet fields with the use of infrared video imagery. A ground truth survey will be conducted to help calibrate the infrared spectra with probable soil causes identified in the field. Areas to be imaged include the Dallol Bosso, Plateau/Dry-Valley Systems and Sandy Plains east of the Niger River.

## Development of a Cameroon Initiative

Dr. Bernard Yerima, a native of Cameroon, developed a draft research proposal for expansion of the TropSoils-SAT program into that country. The focus of this program was 1) natural resource conservation and forest regeneration and 2) establishment of soil fertility/management practices to enhance sorghum/cowpea intercropping on Vertisols and Alfisols in northern Cameroon. The draft was submitted to the TropSoils Management Entity for further considera-

tion and possible action. The TropSoils program would collaborate with appropriate divisions of the Ministry of Agriculture in Cameroon to enhance adoption of research results for lateral and horizontal integration into the agricultural system.

**Implications in General**

Long-term inputs of dust as a nutrient renewal vector to sandy soils of the Sahel appear significant, especially in this environment where leaching losses are minimal and renewal to surface horizons is primarily by biocycling. Mica and feldspars in dusts are sources of K reserves that may explain why these soils rarely respond to K fertilization. Establishing the areal extent and distribution of poorly responsive millet soils in sandy resources of Niger is a prerequisite to further research to develop management technologies to rectify this production constraint. The applicability of infrared video imagery to appraise soil resources and crop production in developing countries will be tested. Prediction of management constraints of soils will be enhanced by elucidating soil moisture/chemistry dynamics as a function of toposequence/climatic interactions. Planning soil management strategies for Vertisols that reduce unfavorable physical properties depend on a knowledge of porosity/structure changes under different land use and tillage practices.

Technology transfer in the Sahel is based on a knowledge of soil resources. Characterization, classification and mapping of target research sites will provide this necessary input.

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# Causes and Control of Pronounced Plant Growth Variability Over Short Distances

*Lloyd R. Hossner, Texas A&M University*
*James B. Gardiner, Texas A&M University*
*Mamadou Doumbia, Texas A&M University*
*John Wendt, Purdue University*
*Robert Chase, ESR L Project*

Red, sandy, strongly weathered, acid soils dominate extensive areas of the Sahelian region in west Africa. The soils vary markedly in thickness, associated geologic deposits and geomorphic landforms, and reflect both semiarid tropical environments and more pluvial paleoclimates. In many regions of the Sahel, these soils display a marked spatial variability in crop establishment, growth and yield within a single field. While soil variability may frequently be attributed to the existence of termite mounds, proximity to trees, previous human activity, soil-borne pests or to various pedogenic influences, a pronounced variability exists over short distances which does not appear to fall into these categories. Millet and sorghum growth can diminish from highly productive stands to completely barren areas over distances as short as two meters. These relatively small (6-30 m diameter), irregular and often ubiquitous patches of poor growth not only result in overall yield losses for the Sahelian farmer but also confound treatment effects in field experiments.

## Objectives

The objectives of this project are 1) to document soil characteristics that typify regions of poor millet or sorghum growth compared to regions capable of supporting vigorous growth; 2) to determine specific soil properties that occur within the unproductive areas and account for the poor millet and sorghum growth, and 3) to recommend agronomic practices that will improve the productivity in areas of poor plant growth.

## Procedures

Research projects in Niger and Mali consist of combined laboratory, greenhouse and field trials designed to determine whether adverse soil chemical properties are limiting plant growth in the field. Field sites where variable plant growth has been documented have been located, representative soil samples taken from productive and unproductive areas for laboratory analysis and greenhouse studies, and field plots established at each site. Although a number of possible amendments are being evaluated, the two soil properties that appear to be most limiting to plant growth are soil acidity and phosphorus deficiency. Therefore, much of the work being conducted consists of characterizing the acidity parameters of the soil and evaluating the fate and reaction of phosphate applied to the soil. Results of laboratory and greenhouse studies are extrapolated to the field in the form of fertilizer and lime recommendations.

Laboratory determinations have generally included soil texture, pH, exchangeable Al and H, exchangeable basic cations (Ca, Mg, K, Na) and Bray extractable P. Effective cation exchange capacity (ECEC) is calculated and the percent Al saturation determined with depth in the soil profile.

Greenhouse trials have been conducted during the dry season to evaluate the influence of soil amendments on crop growth, plant composition and soil properties.

Field experiments were conducted on research centers and in farmer fields. Plots are generally small and replication difficult because of the nature of the spatial variability in the field. Treatments generally involved blanket application of nitrogen and other nutrients with variable rates of lime and P or other soil management inputs. In addition, a number of excursions to farmlands in the vicinity of Niamey, Niger have been made to gather production history and examine characteristics of affected soils.

## Results

Acidity in soils of the Sahel may be attributed to 1) the indigenous acidity of parent sands, 2) the development of acidity in soils weathered under wetter paleoclimates, 3) leaching of bases from shallow soil systems under contemporaneous climates with concomitant development of acidity, and 4) vector dynamics between base renewal to surface horizons and base loss to lower subsoils by leaching under contemporaneous climates. It is most probable, however, that acidity in these soils reflects multiple causes and counterbalancing base renewal vectors.

Aluminum saturation and pH with depth for three

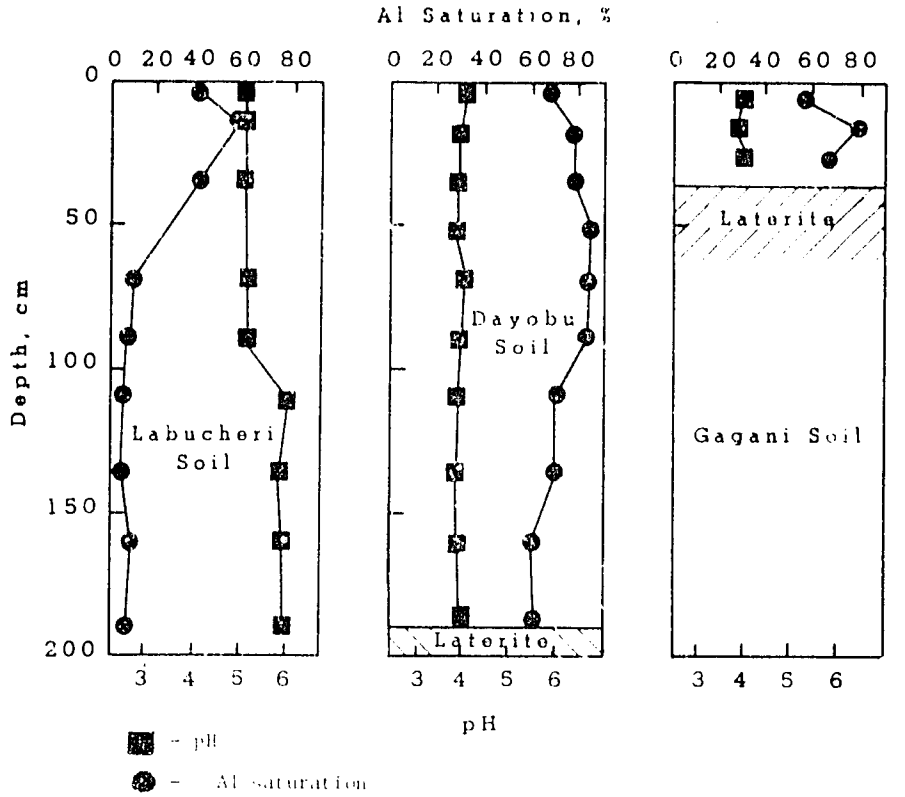


**Figure 1. Aluminum saturation and pH of Labucheri, Dayobu and Gagani soils with depth.**

soils from the ICRISAT center near Niamey, Niger are presented in Figure 1. The soils vary in profile thickness to the laterite with the Labucheri being greater than 200 cm, Dayobu 190 cm and the Gagani 35 cm. The pH of the Dayobu and Gagani soils is near 4.0 through the entire profile, while that of the Labucheri ranges from pH 5.0 to 6.0. Aluminum saturation of the Labucheri is highest in the surface and approaches 60% at 15 cm. Below 70 cm the percent Al saturation is 10% or less. The Dayobu and Gangani soils have Al saturations of 50 to 80% throughout the profile. The Labucheri and Dayobu soils are used for millet production.

**Table 1. Characteristics of unproductive "ganggani" soils.**

1. Markedly red color
2. Loamy sand texture
3. Weak structure with a feel much like that of brown sugar
4. A pH in water below 5.0 and pH in 1M KCl below 4.5
5. Low topographic position
6. History of low productivity
7. Surface crust

In an effort to determine whether soils could be visually diagnosed as being unproductive, fields around Niamey, Niger were examined by James Gardiner in 1986 for color, structure, texture, pH and other characteristics that could be evaluated using field observation. Without exception, soils with the characteristics shown in Table 1 prove to be unproductive. These characteristics are representative of soils which have been eroded with subsequent exposure of the $B_t$ horizon. Historically, these soils have been unproductive and have been termed *ganggani* by the local farmers, which in the Zharma language refers specifically to the presence of a surface crust.

A second factor which historically has resulted in increased millet production on West African soils is application of P fertilizers. A great many authors

have examined the P content of Sahelian soils. There appears to be near unanimous agreement that African soils in general, and Sahelian soils in particular, are deficient in P. Phosphorus applied to the acid sandy soils will tend to react with Al and Fe oxides and hydroxides. Reaction with Al in acid soils could decrease the amount of exchangeable Al, but at the same time, reduce the availability of the applied P.

Trials conducted on two farmers' fields in 1986 were designed to study the effect of various soil management practices and P application on growth and production of millet. Both fields had areas of unproductive soils which met the criteria outlined in Table 1.

Data presented in Table 2 indicate limited response of millet to several soil-management practices, but tremendous yield responses to application of P fertilizer. Applications were made on the basis of exchangeable Al. The data indicate that P application in large quantities, with a small pocket application of N, resulted in the highest yield (Table 3). Rates of P application were extremely high. Additional research is needed to determine optimal rates of P on the *ganggani* soils.

Preliminary studies conducted in Mali are inconclusive at this time. Field trials in 1986, designed to test the effect of lime and P on sorghum growth, show little effect of either input. Seedlings in the field exhibited poor growth regardless of treatment combination. The symptoms in the field include purpling of leaves, yellowing and necrosis of the leaf tip. The more developed plants exhibit interveinal chlorosis in the younger leaves and death of the growing point. The seminal root develops a hard region about 2 cm from the base of the plant below which active growth may resume. Adventitious roots may die or grow almost parallel to the soil surface. Better growth occurs on the micro-high compared to the micro-low locations in the field.

A partial soil analysis of plot 44 productive and unproductive areas by Dr. Art Onkens' laboratory at Lubbock is presented in Table 4. Laboratory and greenhouse trials during the dry season were used to substantiate the 1986 field trials and test for other possible deficiencies or toxicities.

**Table 2. Millet production at Guilheal and Damari near Niamey, Niger, in 1986 on unproductive and productive soil as influenced by soil treatment.**

| Treatment* | Production Dry matter | Production Grain |
|---|---|---|
| | —— kg/ha —— | |
| **Guilheal** | | |
| Control-unproductive soil | 6 | 0 |
| Control-productive soil | 2,834 | 1,178 |
| Tillage to 30 cm | 106 | 1 |
| Mulch | 1,037 | 24 |
| Heavy phosphate application | 6,009 | 1,369 |
| **Damari** | | |
| Control-unproductive soil | 4 | 0 |
| Control-productive soil | 1,071 | 31 |
| Tillage to 30 cm | 28 | 0 |
| Mulch | 321 | 1 |
| Heavy phosphate application | 2,699 | 181 |

* Phosphate was applied as a function of the level of exhangeable Al in the soil. This rate averged 1100 kg P/ha at Damari, and 2400 kg P/ha at Guilheal. Nitrogen was applied to all treatments at a rate of 47 kg/ha N.

**Table 3. Millet dry matter production in a pot study after three weeks of growth on unproductive soil as influenced by fertilizer and lime treatment.**

| Treatment* | Dry matter production g/pot |
|---|---|
| Unproductive soil-control | 0.06 |
| Unprouctive soil-fertilized | 0.62 |
| Productive soil-fertilized | 1.83 |
| Unproductive soil-limed and fertilized | 0.49 |
| Unproductive soil-no lime, fertilized, heavy application of phosphate | 4.21 |

* Fertilizer was pocket applied at a rate of 0.37g N as urea and 0.14 g P as triple superphosphate, per pot.

## Conclusions

1. Unproductive soils of Niger can be identified in the field as having the following properties: red color, loamy sand texture, weak structure, pH < 5.0, lower topographic position, a hard crust, and a history of low production.

2. Soil acidity and extreme P deficiency appear to be two factors which govern crop growth of the acid, sandy, unproductive soils of Niger.

3. Large applications of phosphate fertilizers in combination with normal rates of nitrogen resulted in excellent millet yields in pot and field studies on unproductive soil.

4. Studies in Mali on soils of variable productivity are inconclusive at this time.

**Table 4. Exchangeable Al and pH of productive and unproductive areas of plot 44 at the Cinzana station, Mali.**

| Sample | pH | | Exchangeable | |
|---|---|---|---|---|
| | $H_2O$ | 1M KCl | Al | Acidity |
| | | | —meq/100g— | |
| plot 44 - productive | 5.6 | 4.3 | 0.034 | 0.055 |
| plot 44 - unproductive | 5.0 | 3.9 | 0.275 | 0.317 |

# Technology for Rainfed Agriculture

Small, subsistence farms of rainfed millet and sorghum are the most common use of land in the Sahel. The farmers here use tools and techniques that have changed very little for centuries. The objective function of each farming unit is to minimize the risk of production failure in a naturally difficult and unpredictable environment.

Because of the high risk of crop failure in this environment, farmers typically will not attempt radical changes in their methods, or invest their limited resources in the intensive management of one crop, but will spread their inputs over different types of crops proven to be reliable, and over different soils and larger areas farmed less intensively. Thus, land productivity would not necessarily be improved simply by providing farmers with inputs such as fertilizers. For this reason, much of the research presented here has focused on low- or medium-input techniques for improving or stabilizing the yields of traditional crops.

In Niger, millet is the most common crop on sandy soils. Traditional African varieties of millet, which are well adapted to this environment, have given the best results. So far, no new varieties have been successfully introduced, largely because the African soils where millet is grown are not well understood. Significant improvements in cereal production will depend on a knowledge of the complex interactions of water, nutrients, and plants in these soils. The research reported here has examined these interactions, and includes experiments on a range of agronomic practices, including cropping sequences and intercropping, tillage, fertilization, residue management, biomass control, microclimate modification, and the management of rainfall and runoff. These studies have been designed to be applicable not only in Niger and Mali, but in other semiarid environments as well.

# Rainfall Management To Increase Crop Yields

*Naraine Persaud, Texas A&M University*
*Christophe Zaongo, Texas A&M University*

Cereals are often sown in dry soils, before start of the rains. If rainfall less than required for germination is received, the crop stands are spotty and replanting is necessary. The problem might be alleviated and the stands and yields stabilized by rainfall-harvesting techniques.

In many parts of Niger, the landscape is characterized by elevated hardened laterite surfaces adjacent to lower areas of colluvium and alluvium, which are cultivated in sorghum and millet. During rains, the water rushes from the impervious laterite areas into the valleys below, causing severe gullying and sedimentation problems in small dams for irrigation. If the water could be spread or impounded and allowed to infiltrate in the valleys, the potential exists to increase sorghum and millet production by overcoming the erratic rainfall regime. At the same time sedimentation and erosion problems would be alleviated. In many cases the hardened laterite surface is thin and there is a deep, underlying soil. This surface could be broken in strips, which would receive the runoff from adjacent strips with the surface intact. This technique could bring into use for crop production otherwise unused land and at the same time permit reforestation and agroforestry practices.

## Objectives

The general objective of this project is to improve management of rainfall to enhance infiltration/rainfall and evapotranspiration/infiltration ratios. The specific experimental objectives were 1) to determine whether contour strip rainfall harvesting (CSRH) has a potential for cereal production in three main agroclimatic regions of sandy soils in Niger; 2) to monitor the harvested water; and 3) to evaluate the influence of fertilization and plant density on the harvesting systems.

## Procedures

Contour strip rainfall harvesting (CSRH) was used as the water management technique to test the potential for improving the natural rainfall distribution through the growing season. Polyethylene sheeting was used to direct rain water onto parallel adjacent cultivated strips. Grain sorghum and pearl millet were grown separately at three different locations, with different rainfall regimes: Kala Pate

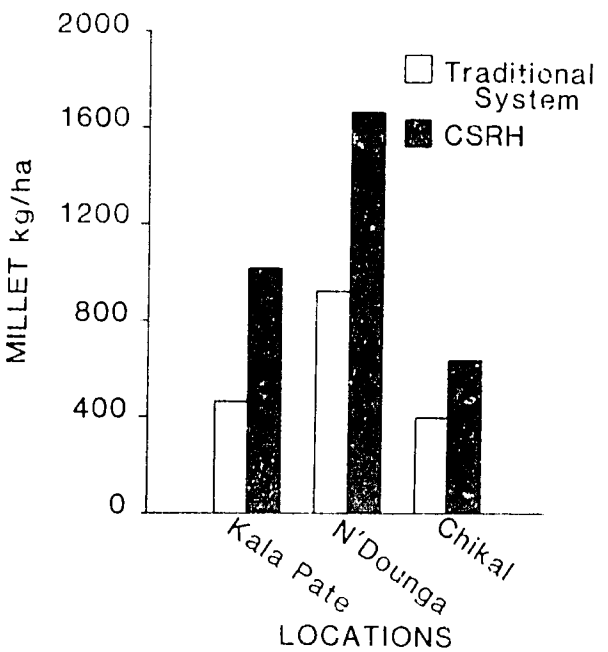


Figure 1. Effect of water management on millet yield at three locations in Niger.
CSRH = Contour Strip Rainfall Harvesting.

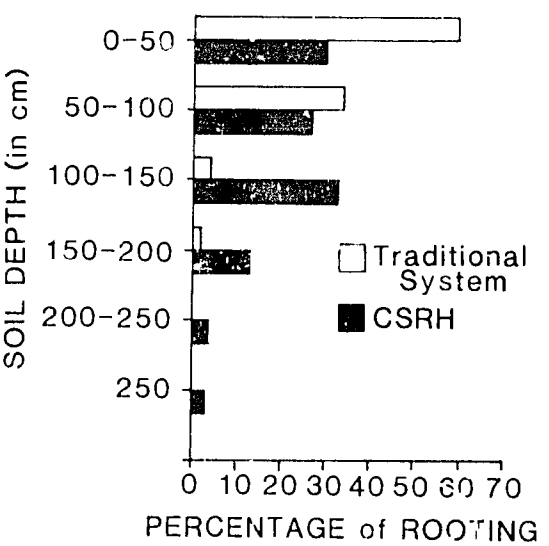


Figure 2. Distribution of roots with depth for millet for the traditional system compared to CSRH, at high plant density (15,000 hills/ha) and fertilizer rates of 22.5 kg $P_2O_5$/ha and 45 kg N/ha.

(650 mm average), N'Dounga (500 mm average), and Chikal (300 mm average).

Treatments included fertilization and plant densities. Fertilization levels were a) no fertilizer and b) 22.5 kg/ha of $P_2O_5$ and 45 kg/ha of nitrogen. Plant densities were a) 10,000 and 15,000 hills /ha for millet, and b) 11,000 and 16,000 hills /ha for sorghum. There were three plants per hill for both plant densities.

**Table 1. Effects of water management, fertilization and plant density on millet yields for three locations in Niger.**

| Site | Water management* | | Fertilization** | | Plant density*** | |
|---|---|---|---|---|---|---|
| | Trad | CSRH | None | Fert | Low | High |
| Kala Pate | 464 a | 1019 | 641 a | 841 | 786 | 697 |
| N'Dounga | 923 a | 1667 | 1135 a | 1455 | 1216 | 1374 |
| Chikal | 401 a | 644 | 476 a | 569 | 518 | 527 |

* Trad=Traditional water management CSRH= Contour Strip Rainfall Harvesting.
** Fertilization rates were none or 22.5 kg $P_2O_5$/ha and 45kg N/ha.
*** Low plant density was 10,000 hills/ha,and high plant density was 15,000 hills/ha. There were three plants per hill for both plant densities.
a. Significant at the 95% probability level.

**Table 2. Effects of water management, fertilization and plant density on sorghum yields for three locations in Niger.**

| Site | Water management* | | Fertilization** | | Plant density*** | |
|---|---|---|---|---|---|---|
| | Trad | CSRH | None | Fert | Low | High |
| Kala Pate | 321 | 501 | 274 a | 547 | 334 | 486 |
| N'Dounga | 1140 a | 1814 | 1204 a | 1751 | 1035 a | 1920 |
| Chikal | 288 a | 312 | 255 a | 345 | 257 a | 346 |

* Trad= Traditional water management; CSRH= Contour Strip Rainfall Harvesting.
** Fertilization rates were none or 22.5 kg $P_2O_5$/ha and 45 kg N/ha.
*** Low plant density was 11,000 hills/ha, and high plant densiy was 16,000 hills/ha. there were three plants per hill for both plant densities.
a. Significant at the 95% probability level.

## Results

Results obtained from this experiment showed significant effects due to water-management techniques. Dry matter production was dramatically increased with CSRH. Increases in grain yield ranged from 56% to 120%. A significant effect of CSRH was obtained on all sites except for one sorghum experiment grown at Kala Pate. Millet yields for the three locations are presented in Figure 1. Grain yields as influenced by water management, fertilization and plant-density treatments are shown in Tables 1 and 2.

The CSRH technique induced a deeper rooting system, as shown in Figure 2. Maximum root depth increased from 110 cm on the control to 220 cm with CSRH. This resulted in an increased capacity for plants to absorb water and nutrients. The monitoring of harvested water behavior and crop response revealed that this technique can lengthen the growing season by making early planting and late growth possible.

Fertilization had significant effects at all sites and with both crops. The effects of fertilization on sorghum yield are shown in Figure 3. Results suggest that nitrogen and phosphorous fertilizers should be used if high yields are to be expected. The site with medium rainfall (N'Dounga) produced the highest yields. This site has the most fertile soil. The amplitude of the crop response from one site to the other strongly suggests that soil fertility problems must be addressed if efficient utilization of water is to be achieved.

Grain sorghum yield increased with the higher plant density. With pearl millet, plant density did not have any significant effect. This differential behavior may be due to the tillering capacity of millet (auto adjustment capacity).

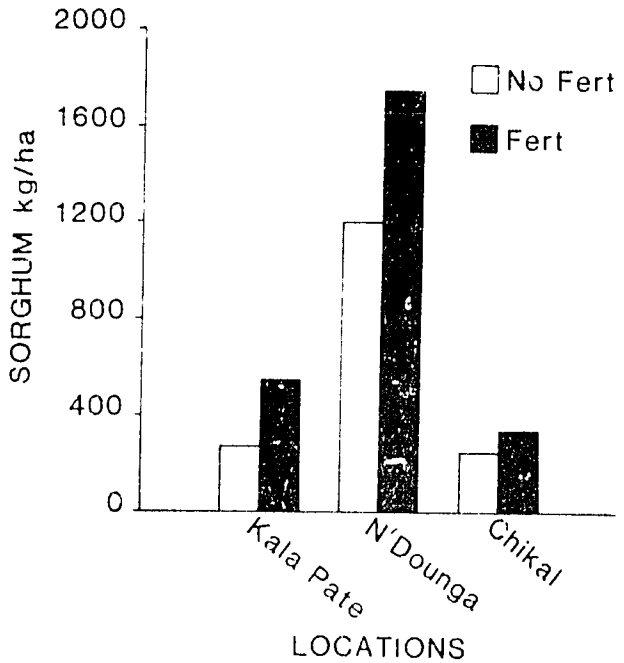


**Figure 3. Effect of fertilization on sorghum yields for three different locations in Niger. Fertilizer rates were none and 22.5 kg $P_2O_5$ ha and 45 kg N/ha.**

Implications

Contour strip rainfall harvesting (CSRH) has a potential for cereal production for regions with limited rainfall and sandy soils in Niger, grain yield being the criteria for evaluation. This technique exhibits advantages from the standpoints of reducing evaporation loss and weed growth, and increasing water conservation. Thus, CSRH is a promising technique for securing higher cereal yields. However, more studies must be undertaken to determine the most economically, socially and technically appropriate way to adapt this technique to the local needs.

# Evaluation and Development Of Management Practices For Rainfed Crops

*Naraine Persaud, Texas A&M University*
*Mamadou Ouattara, INRAN*
*Mohamadou Gandah, INRAN*
*Wiliam Payne, Texas A&M University*
*J. Gonda, INRAN*

Soil water and fertility are the principal soil constraints to crop production in the Sahel. It is estimated that millet and sorghum require approximately 300 mm of available soil moisture to reach maturity. Short term drought stress during the growing season is frequent in the Sahel, and can lower yields or result in total crop failure. Practices such as bare fallow, residue management, biomass control, minimum tillage, response farming, etc. can be used to enhance rain-use efficiency and crop yields. Information about the response of millet and other crops to different soil moisture deficits and crop management practices (cropping sequence, fertilization, tillage, tiller removal) is essential for the development of appropriate soil and water management technologies. The need exists to understand the effects of these practices on soil moisture storage, patterns of soil moisture use by the crop, patterns of soil moisture loss, and fertilizer-use efficiency, so that they can be adapted to increase or stabilize rainfed crop yields.

**Table 1. The effect of planting date on plant length (in cm) for three millet varieties at N'Dounga in the 1986 growing season.**

| Variety | Planting date 1 | Planting date 2 |
|---|---|---|
| | cm | |
| HKP | 130 cd | 120 d |
| CIVT | 132 c | 123 cd |
| Local | 156 a | 144 b |

Planting date 1 = June 17
Planting date 2 = July 7
Treatments with the same letter are not significantly different at the 95% probability level.

### Objectives

The general objective of this project is to evaluate and/or develop low- to intermediate-input soil-, water-, or crop-management practices to increase and/or stabilize yields of rainfed crops.

### Progress

This report addresses two experiments related to the project objective: (a) Soil-moisture use patterns and grain yield under contrasting management systems; and (b) Tiller removal. Experiments evaluating effects of fallowing and residue management are described on pages 372 through 375.

## Soil-Moisture Use Patterns And Grain Yield Under Contrasting Management Systems

### Objectives

A field experiment was conducted at N'Dounga to study the response of millet varieties to plant densities, planting date and soil moisture. The objectives of the experiment were 1) to quantify soil moisture under millet stands throughout a growing season; 2) to evaluate the effects of soil moisture and climate on the growth and yield of three millet varieties; 3) to evaluate water use patterns; and 4) to evaluate the effect of planting densities and dates on the growth and yield of millet.

### Procedures

The experimental design was a factorial in a randomized complete block design with planting densities and varieties split on planting date. There were five replicates for each treatment. Soils samples were taken for chemical and physical analyses. A saturation and drainage study was performed to determine infiltration rates and hydraulic conductivity.

Soil moisture was monitored with a neutron probe to a depth of 1.80 m for the first planting date, and to 2.80 m for the second date. Weather data were recorded with a simple weather station. They included daily air temperature, air humidity, wind run, rainfall, solar radiation and pan evaporation.

Several plant measurements were made during the growing season, including tillering and plant counts. At harvest, data recorded consisted of poquets/plot, plants/poquet, height of plants, number of internodes per plant, number of heads per poquet, length and weight per head, grain and dry matter yield. Root counts were performed after harvest.

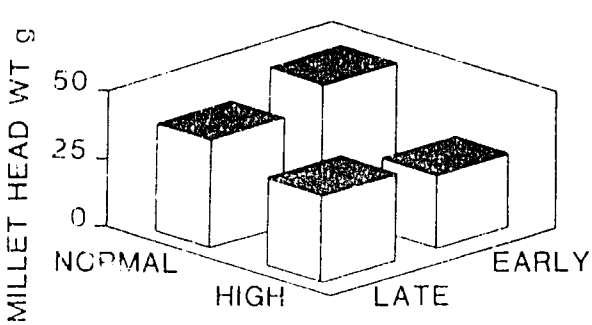


Figure 1. Effect of date of planting and planting density on weight of heads (g) in millet.
$D_1$: Early Planting (June 17)
$D_2$: Late planting (July 7)
N.Dn: Normal plant density, 10,000 poquets/ha, three plants per poquet
H.Dn: High plant density, 40,000 poquets/ha, three plants per poquet

### Results

The information gathered from this experiment is being analyzed and interpreted by Mr. M. Gandah. Total rainfall for the season was 377 mm from which 347 mm fell from planting to harvest for the first planting date, and 313 mm for the second planting date. There was only one dry period affecting the first planting date, and none for the second. This dry period was July 22 (12 mm) to August 4 (22 mm).

Preliminary data indicate that planting date had a significative effect on several yield components including height of plants, weight per 1000 grains, and grain yield. Interactions were recorded with plant density and varieties (Figures 1 and 2). Plant density results were mixed due to different thinning intensities: three plants per poquet in the normal density, and two plants per poquet in the high density. Density did not affect the height of the local millet variety, however; the local variety showed significantly taller plants at high density. Within the normal density, early planting produced heavier heads (Figure 1). Also within the normal density, HKP and ZONGO were not significantly different but both produced heavier millet heads than CIVT. No differences among varieties were recorded for the high plant density treatment (Figure 3).

Differences in dry matter production were only significant for varieties and planting dates. The local variety, with its high tillering capacity, produced more dry matter than the improved varieties. There was no

significant difference in dry matter production between the two improved varieties.

Grain yield was greater at high plant density but only for the first planting date (Figure 1). This high plant density apparently did not reach the level where plant competition for nutrients, light and water would affect grain yield. No differences were recorded between varieties for the second planting date.

## Tiller Removal

Many tillers are produced during the growth cycle of millet plants; the mean number depends on the particular genotype. It seems that traditional millet varieties in Niger have been selected for high tillering capacity, probably because 1) millet residue is used for housing and village industry, and as animal feed at the end of the season; 2) the semi-erect leaves function as rainfall harvesting surfaces; and 3) the tillers provide additional surface for photosynthesis, thus compensating for the short growing period. Whether these rationalizations are factual or not can only be decided by future research. However, it seems safe to assume that tillers, only a small percentage of which produce fertile heads, play an important role in growth, development and grain yield.

From a water-conservation viewpoint, tillers transpire water, and, if not productive, they increase the ratio of water used per unit of grain yield.

### Objectives

The specific objectives of this experiment were 1) to study the effect of tiller removal on growth and yield of several millet varieties under different soil-water conditions and levels of fertilization; 2) to investigate the effect of tiller removal on soil moisture use efficiency; and 3) to determine varietal differences and interactions with soil moisture content and fertilizer levels.

The results of this experiment will indicate whether tiller removal has potential as a low-input technique for soil-water management. If proven successful, it will increase the resiliency of the millet grower by helping him to tailor his crop biomass to the varying local rainfall pattern. Yields may be stabilized, and, in addition, tillers removed may be used as animal fodder.

### Procedures

An experiment was conducted in a factorial design to study the effect of four levels of tiller removal, three millet varieties, and two fertility levels on millet growth, yield and water use. The experiment was completed during the 1986 season.

### Results

Preliminary results data show a significant effect of tiller removal on grain yield under rainfed conditions. However, more information is needed, and it would be premature to extract general conclusions on the usefulness or practicability of this technique.

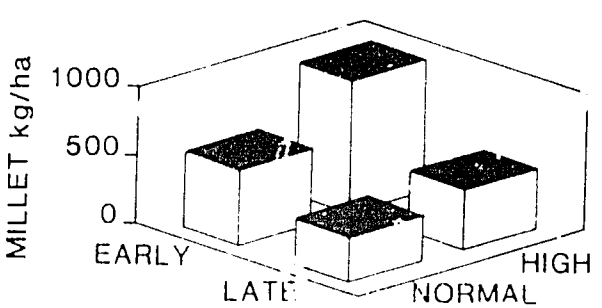


Figure 2. Effect of planting date and planting density on grain yield (millet, kg/ha).

$D_1$: Early planting (June 17)
$D_2$: Late planting (July 7)
N.Dn: Normal plant density, 10,000 poquets/ha, three plants per poquet
H.Dn: High plant density, 40,000 poquets/ha, three plants per poquet

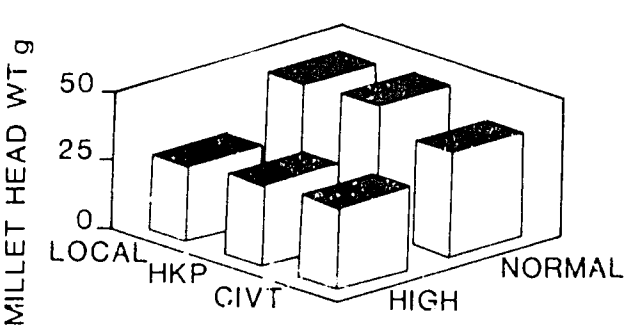


Figure 3. Head weights for three varieties of millet and two planting densities.

LOCA: Local, long cycle variety
HKP: Improved, short cycle variety
CIVT: Improved, long cycle variety
N.Dn: Normal plant density, 10,000 poquets/ha, three plants per poquet
H.Dn: High plant denstiy, 40,000 poquets/ha, three plants per poquet

# Modification of Agroclimate, Growth, and Yield of Cereals Between Rows Of Neem Tree Windbreaks

*Naraine Persaud, Texas A&M University*
*Steve Long, Texas A&M University*
*Mamadou Ouattara, INRAN*
*Mohamadou Gandah, INRAN*
*F. Borison, Yale University*

The neem tree, introduced from India, is now ubiquitous in the zone south of the 250-300 isoyet in Niger. In 1975, C.A.R.E. International, with cooperation from local residents, initiated a systematic planting of neem trees in the Maggia Valley of South Central Niger. To date, about 360 km of trees have been planted in double rows 100 m apart, oriented approximately north/south across the long axis of the valley. These plantings provide an opportunity for studying the role of shelterbelts and windbreaks in Niger for improving crop growth and yield in millet.

The government of Niger is interested in extending these plantings. Motivation may be due mainly to the villagers' acceptance of this soil- and water-conservation practice. Farmers may not perceive effects in moisture conservation, crop growth or yields. But they do perceive increase in comfort and protection for themselves, their dwellings and animals as a result of being shielded from high winds and dust. They are also interested in harvesting wood from these trees.

Careful studies are needed to understand the effects of the present windbreak rows on the physical environment of the crop and to relate these effects to crop growth and yield. Such studies will provide a rational basis for further plantings and, thus, optimize benefits from expended time, money, efforts, and from land removed from production. It is also necessary to study various wood-harvesting procedures to decide the optimum method of economically obtaining wood yields without significant reduction in the protective efficiency of the windbreak rows.

## Objectives

The objectives of this project are 1) to determine if and how climate and cereal growth and yield are modified when alley-cropped between neem tree windbreak rows, and 2) to investigate the influence of several possible wood-harvesting methods on wind protection between the windbreaks rows.

## Procedures

*Effects on microclimate and crop yields*

A field study was conducted during the 1984 and 1985 growing seasons to evaluate the response of millet and sorghum to shelter from double-row Neem

Table 1. Effect of protection and fertilizers on millet gain yield, above-ground dry matter and average grain weight per head.

| Treatment | Grain yield kg/ha | Dry matter kg/ha | Ave. wt./ head gm |
|---|---|---|---|
| Protected | 488.0 | 3510.5 | 13.0 |
| Non-protected | 396.5 | 2092.5 | 11.6 |
| | *** | * | *** |
| Fertilized | 487.5 | 2861.5 | 13.4 |
| Non-fertilized | 397.0 | 2741.5 | 11.1 |
| | ** | *** | ** |

* Means are significantly different at 95% level
** Means are significantly different at 99% level
*** Means are not significantly different

Table 2. Effect of distance from the windbreak row on millet grain yield, above-ground dry matter and average grain weight per head.

| Distance from row (H=10.54m.) | Grain yield kg/ha | Dry matter kg/ha | Ave. wt./ head gm |
|---|---|---|---|
| 0.5 H | 327 a | 2179 a | 12.2 a |
| 2.0 H | 593 b | 4211 b | 14.5 a |
| 4.0 H | 572 b | 3858 b | 14.5 a |
| 6.0 H | 566 b | 3971 b | 13.7 a |
| 8.0 H | 447 ab | 3661 bc | 11.3 a |
| 9.5 H | 424 ab | 3183 c | 12.8 a |

Means followed by different letters are significantly different at the 95% level using Duncan's new multiple range test.

windbreaks. It included evaluation of effects of fertilization and distance from the windward row. Fertilizer treatments were zero and 22.5 kg of $P_2O_5$ and 45 kg of N per hectare. Distances were 0.5, 2.0, 4.0, 6.0, 8.0 and 9.5 times the mean tree height (H) of the windward row. A local millet variety, GR-P1 (Guerguera), was planted at a density of 10,000 poquets per hectare. Meteorological variables such as windspeed at five heights above ground, wind direction, air temperature, relative humidity, pan evaporation and insolation were continuously monitored both inside and outside the windbreak rows to determine the mechanisms by which shelter affects the growing environment. Periodic gravimetric soil moisture sampling was done to estimate moisture storage in the soil profile throughout the growing season. Yield data were gathered in field plots located inside and outside windbreaks.

*Effects of wood harvesting methods*

Four methods of wood-harvest were compared: (a) Complete pollard: all trees in 100 m of a double row pollarded (the pollarding consisted of removing all wood more than 2.5 m above the ground); (b) One-row pollard: all trees in 100 m of the easter row pollarded; (c) One in four pollard: one in every consecutive group of four trees in 100 m of a double row pollarded such that cut trees were never adjacent and there were always three uncut trees between cut trees in either row; and (d) Partial poliard: removal of the branches overhanging the alleys from both sides of the double crown formed by trees. The effects of these treatments were compared to an uncut control. All cuts were made between June 2 and June 5, 1985. Average height of trees measured on a sample of 80 trees was 19.7 m.

Wind-monitoring instrumentation consisted of five anemometers mounted on towers at 108, 317, 572, 811 and 1151 cm above the ground. One such tower was set up outside the trees and another positioned at five times the height on the eastern side of the treated row as appropriate for each treatment. A wind direction sensor was mounted on the outside tower. Observations of windspeed were made simultaneously inside and outside the plantation at 60-second intervals with automated data-logging equipment. Average of these observed values were output at half-hourly intervals.

## Results

Data in Table 1 show that protection by the windbreak rows significantly increased dry matter production. There was a 23% (488 vs. 396 kg/ha) (statistically non-significant) increase in millet grain yield in millet. Data presented in Figure 1 show that grain and dry matter yields were significantly reduced near the windbreak rows.

Fertilizer application significantly increased grain

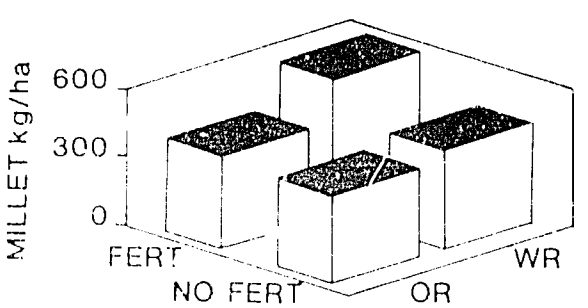


Figure 1. Effects of wind protection and fertilization on millet grain yield.

WR = Within neem rows
OR = Outside neem rows
NO-FERT = No-fertilization
FERT = 22.5 kg $P_2O_5$/ha and 45 kg N/ha

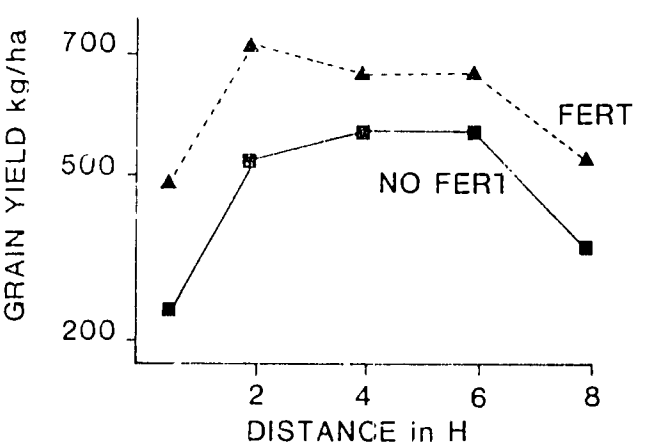


Figure 2. Millet grain yield within neem tree windbreaks as influenced by distance from the windward neem row, for two fertilizer levels.

H = Tree height
NO-FERT = No-fertilization
FERT = 22.5 kg $P_2O_5$/ha and 45 kg N/ha

yield and average head weight but did not affect dry matter production. Fertilizers increased grain yields regardless of distance from the windward row (Figure 1).

Reduction in average windspeed at crop height in the center of the field compared to that outside the windbreaks was between 29% and 41%. Average daily maximum and minimum temperatures were not significantly affected by the windbreaks. Maximum daily air temperature was 1-2° C higher inside the windbreaks. Average daily relative humidity was nearly 6% higher and pan evaporation was 1.4 mm/day lower within the windbreaks.

Partial pollarding proved to be the best harvest method, with the least loss of efficiency. As expected, the complete pollard considerably lowered the protection from winds for all directions, especially from the SW, which was the prevalent wind direction. Reduction with partial pollarding for most combinations of height and direction was as good as the uncut control. Except for winds from the NW, the "one-row" and "one-in-four" pollards significantly reduced wind protection compared with the uncut control. Partial pollarding may not yield as much total wood as the other methods but reduction in prevailing windspeeds greater than 30% can be maintained between the rows.

**Table 3. Influence of wood-harvesting method on averaged ratios of inside to outside half-hourly mean windspeeds sampled at different heights above the ground for main prevailing mean wind directions.**

| Wood-harvesting method | Height above ground cm 108 | 317 | 572 | 811 | 1152 | No. values in sample |
|---|---|---|---|---|---|---|
| A. Mean wind direction interval = SW ± 22.5 degrees | | | | | | |
| Uncut control | 0.58a | 0.59a | 0.68a | 0.74a | 0.83a | 89 |
| Complete pollard | 0.92b | 0.85b | 0.94b | 0.93b | 0.95b | 49 |
| One-row pollard | 0.73c | 0.72c | 0.79c | 0.82c | 0.87a | 75 |
| 1-in-4 pollard | 0.85d | 0.81d | 0.87d | 0.92d | 0.98bc | 56 |
| Partial pollard | 0.66e | 0.56a | 0.59e | 0.64e | 0.76d | 45 |
| | * | * | * | * | * | |
| B. Mean wind direction interval = W ± 22.5 degrees | | | | | | |
| Uncut control | 0.41a | 0.44a | 0.51a | 0.59a | 0.67a | 46 |
| Complete pollard | 0.81b | 0.73b | 0.80b | 0.81b | 0.81b | 30 |
| One-row pollard | 0.64c | 0.63c | 0.77c | 0.70c | 0.74c | 60 |
| 1-in-4 pollard | 0.66cd | 0.63cd | 0.67d | 0.70cd | 0.77cd | 63 |
| Partial pollard | 0.58e | 0.50a | 0.50a | 0.54a | 0.64a | 45 |
| | * | * | * | * | * | |
| C. Mean wind direction interval = NW ± 22.5 degrees | | | | | | |
| Uncut control | 0.55a | 0.54a | 0.63a | 0.73a | 0.79a | 14 |
| Complete pollard | 0.82b | 0.72b | 0.88b | 0.76a | 0.76a | 16 |
| One-row pollard | 0.65a | 0.63a | 0.65a | 0.67a | 0.70a | 14 |
| 1-in-4 pollard | 0.65a | 0.61a | 0.66a | 0.68a | 0.72a | 24 |
| Partial pollard | 0.47a | 0.44c | 0.48c | 0.52b | 0.59b | 14 |
| | * | * | * | * | * | |

* F-statistic significant at 99% level
Means not followed by same letter are significantly different at 95% level.

**Implications**

Tree windbreaks, by modifying the influence of hot, dry, desiccating winds in Niger serve as a semi-permanent method for soil-water conservation and as a practice against wind erosion. The trees, if rationally harvested, can provide much-needed fuel wood without seriously impairing their wind protective efficiency.

Results from this study show the usefulness of the trees in term of modification of the physical environment and crop growth. Such information is indispensable in planning layout of future plantings and their subsequent management.

# Rooting Pattern Studies On Sorghum and Millet

*Lloyd R. Hossner, Texas A&M University*
*Jessica Davis-Rainey, Texas A&M University*
*Andrew Manu, INRAN-TropSoils*
*Naraine Persaud, Texas A&M University*

Low agronomic production in the Sahel has been attributed to lack of water and/or nutrients. Both water and nutrients are taken up by the roots; therefore, if a soil factor exists which limits root growth, this limiting factor could be the cause of water and/or nutrient stress in the plants grown on such soils. The identification of the factor or combination of factors which limits root growth is necessary for the development of management practices that would overcome this limitation. Subsequently, the uptake of water and nutrients would be increased, and enhanced productivity would follow.

## Objectives

The objectives of this project are 1) to describe the root systems (depth, extent, density), water uptake patterns, plant growth, and yield of sorghum and millet varieties on soils of Niger; 2) to quantify the variability (laterally and vertically) of several physical and chemical soil variables within soil pedons; 3) to identify the primary limitations to root growth in two contrasting soils in western Niger, and to determine the level at which these variables are limiting; and 4) to determine the effect of soil amendments on the chemical properties of the soil, seedling emergence and survival, and millet root growth and composition.

## Procedures

Post-harvest 1986 root studies on three millet varieties and three sorghum varieties were carried out in two locations in western Niger (Kolo and N'Dounga). Root-trench profiles were excavated for each of these varieties. A 1 m x 1 m grid with 10 cm x 10 cm squares (100 squares/grid) was laid over the side of each trench with a plant stem in each of the upper corners. Soil samples were taken from each grid square for the measurements of available P, pH, exchangeable acidity (Al and H), exchangeable bases (Ca, Mg, K, Na), and extractable soil Fe, Mn, B, and Zn. The pit face was smoothed, one centimeter of soil washed off with a water spray, and root number

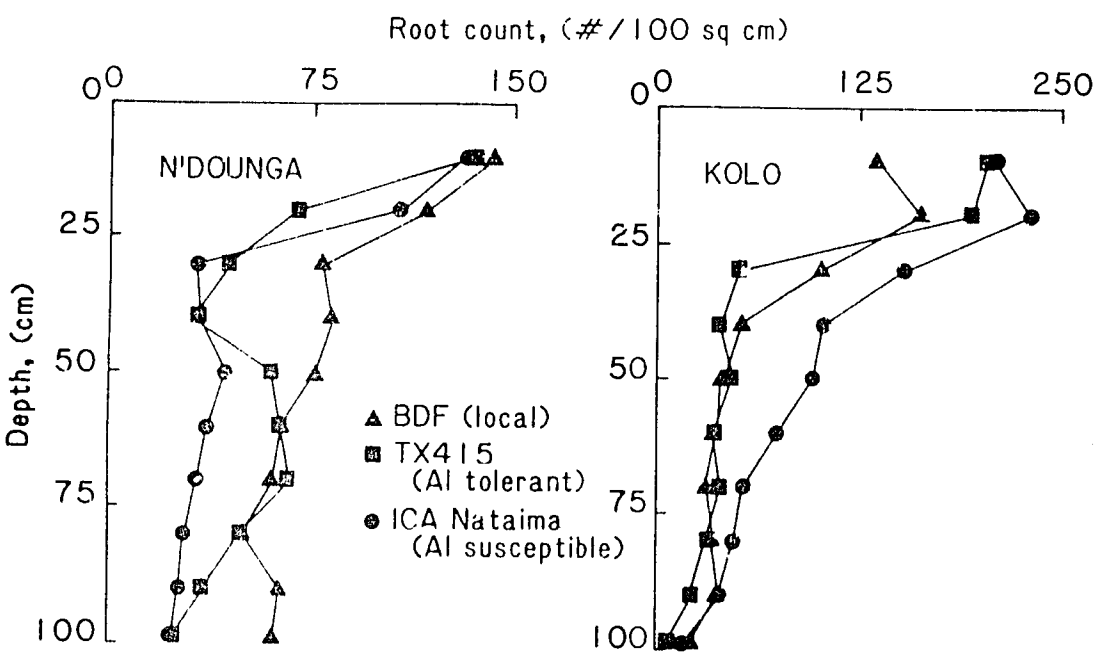


Figure 1. Sorghum root distribution with depth for three cultivars at N'Dounga and Kolo in 1986.

within each square was counted. The laboratory work and statistical analyses are currently underway. The laboratory analyses are being accomplished in cooperation with Dr. Andrew Manu of the AID/INRAN Laboratory Support Project.

## Results

The dramatic effect of soil properties on root growth of sorghum and millet is shown in Figures 1 and 2. The root growth patterns of the three millet varieties are similar in both locations, but the actual numbers of roots are markedly different. Sorghum root systems show a much steeper decline in root number with depth than do millet root systems. However, in Kolo, the Al-susceptible variety had the greatest rooting density of the three varieties, whereas in N'Dounga the local variety exhibited the greatest rooting density and the Al-susceptible variety had the lowest rooting density. These data will be related to the soil properties at these locations when the laboratory analyses have been completed.

## Implications

This research is designed to provide information and stimulus for the development of management practices that will diminish the detrimental effects of those soil factors which limit root growth and water and nutrient uptake. Correction of soil chemical or physical properties that have an adverse effect on sorghum and millet rooting would be one strategy. Selection of improved varieties with tolerance to adverse soil properties would be a second possibility.

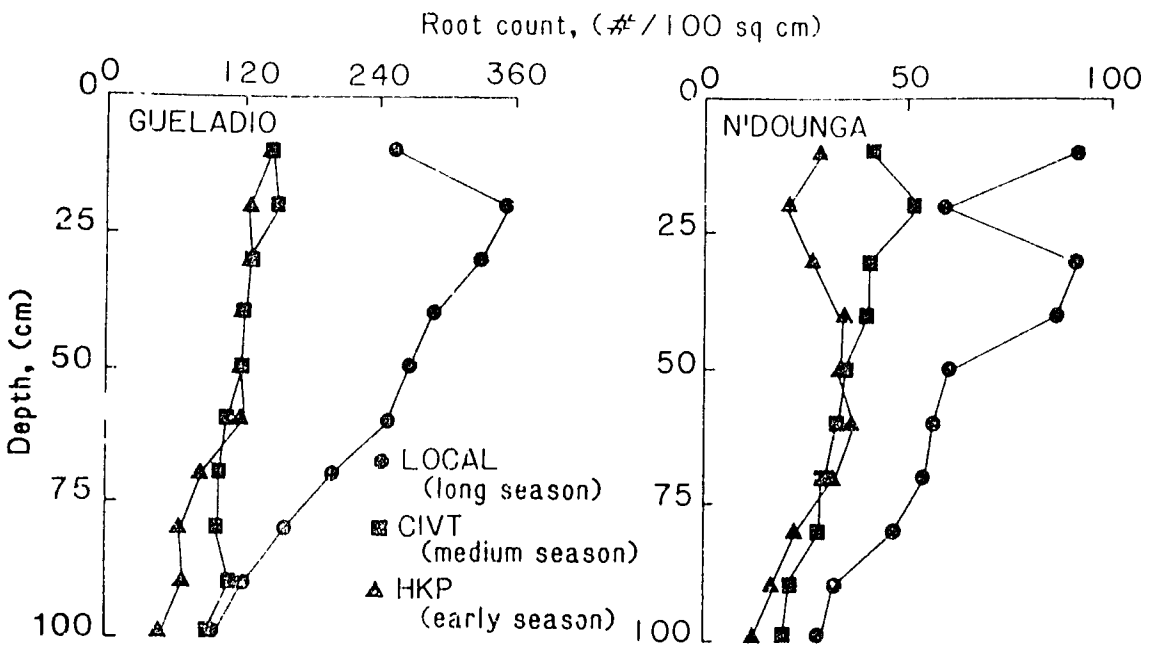


Figure 2. Millet root distribution with depth for three cultivars at Gueladio and N'Dounga in 1986.

# Water-Use Efficiency and Soil Fertility Relationships

*Arthur B. Onken, Texas Agricultural Experiment Station*
*Charles W. Wendt, Texas Agricultural Experiment Station*

Research has shown that nutrient deficiencies under rainfed conditions result in poor utilization of available water in both the African Sahel and Texas High Plains. It has been shown that five-fold increases in forage production can result from proper N and P fertilization. Water-use efficiencies (biomass/ET) have been increased 8% under dryland conditions at Lubbock, Texas, with proper fertilizer practices. While research tends to indicate that biomass/unit of water transpired changes only in cases of severe nutrient deficiencies, research is lacking concerning plant nutrition requirements necessary to obtain maximum dry-matter production per unit of water when water is limiting. It is well recognized that nutrient deficiencies, particularly N and P, greatly inhibit crop production in Sahelian Africa. Further information is lacking relative to fertility level-water level interactions and the role newly identified nutrient use efficient cultivars might play in water-use efficiency.

## Objectives

The objectives of this project are 1) to enhance water-use efficiency of crops with applied plant nutrients and cultivar selection, and 2) to improve soil physical and chemical properties through use of fertilizers and soil amendments.

## Procedures and Results

*Water-fertility studies*

Studies in minilysimeters (75L) in rainout shelters and differentially drip irrigated field plots were conducted to determine the effects of amounts of available water and soil fertility level on water-use efficiency (WUE, kg of grain/mm of water ET) of sorghums. Grain sorghum cultivars (SC630 and MB9-41), identified in previous research as differing in grain production at low N and P availability under rainfed conditions, were grown at five N levels and two water levels in minilysimeters in a rainout shelter. The minilysimeters were sealed to prevent evaporation. Dry-matter production was a linear function of transpiration, Figure 1. At the high water level, (100% T replaced weekly) there was no difference between lines in dry-matter production (tops and roots) per unit of water transpired. However, at the low water level (60% T replaced weekly), MB9-41 produced more dry matter per unit of water transpired. Water-use efficiency was influenced by water level, N fertility, total N in the plant tissue and sorghum genotype, Figures 2 and 3. At low available water and all levels of fertility, MB9-41 was most water-use efficient. MB9-41 was most N-use efficient at all levels of N fertility. This shows that in order to increase water-use efficiency through soil fertility, efficient and responsive cultivars must be identified and used.

For the yield study, three water levels and three N rates were imposed on a commercial hybrid with good yield potential (NK 2778). Water-use data were obtained for the growing season and plant growth measurements were made at head initiation, 50% bloom and black layer. Soil and plant samples were analyzed for N and P. Leaf-water potential and photosynthesis measurements were made on all plots at two dates after visual water stress was evident in the low-water treatment. At head initiation, plant weights and leaf area were greatest for the low-water treatment. By 50% bloom, leaf areas were similar

**Table 1. Water-use efficiency (kg of grain/mm of water ET) as affected by water and N fertilizer.**

| Water level | Nitrogen treatment | | |
|---|---|---|---|
| | ——kg/ha—— | | |
| | 0 | 20 | 80 |
| | kg grain/mm of water ET | | |
| W1 | 4.34 | 3.62 | 3.16 |
| W2 | 6.07 | 6.34 | 7.40 |
| W3 | 5.25 | 5.88 | 6.08 |

W1 - preplant irrigation only
W2 - preplant irrigation + 50% of ET weekly after July 10
W3 - preplant irrigation + 100% of ET weekly after July 1

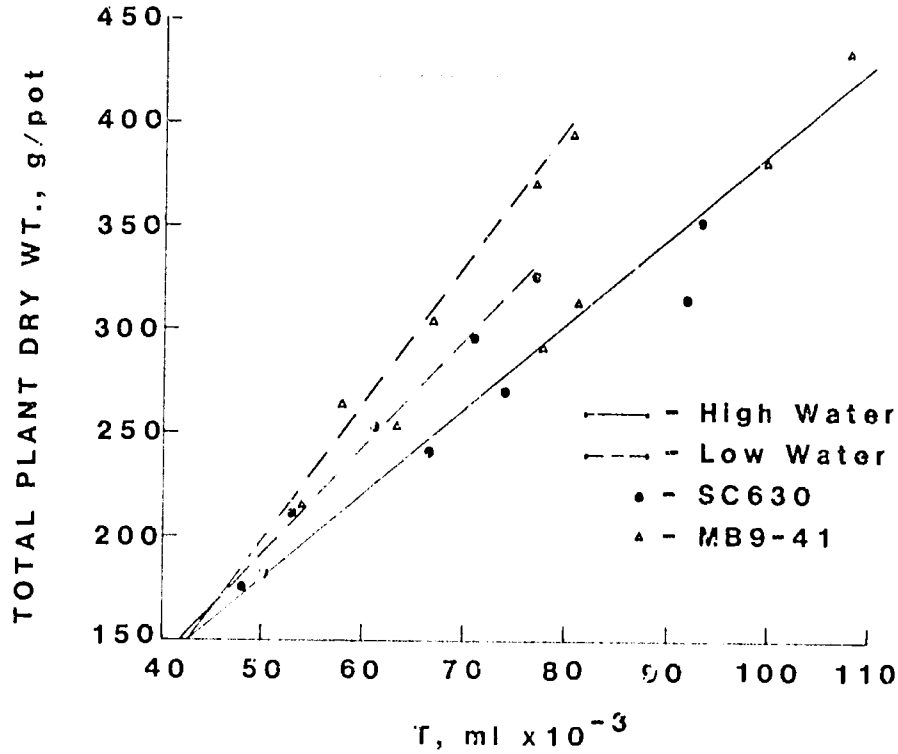


Figure 1. Relationship of total plant dry matter and transpiration (T) for two grain sorghum genotypes grown at two water levels and five nitrogen levels.

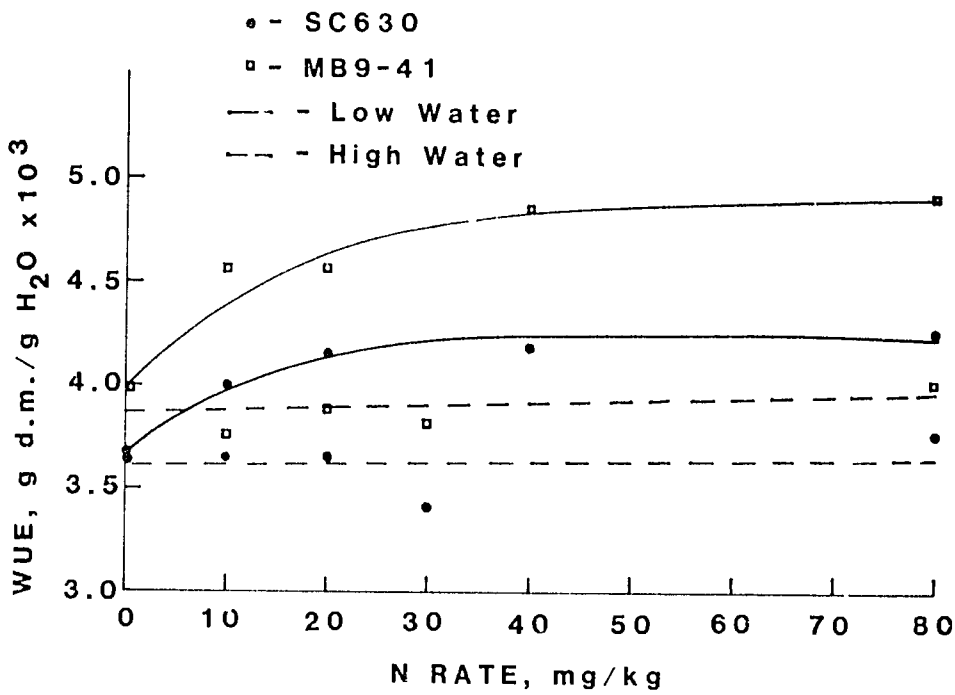


Figure 2. Effect of N rate on water-use efficiency (WUE - grams of dry matter produced per gram of water transpired) of two grain sorghum genotypes grown at two water levels.

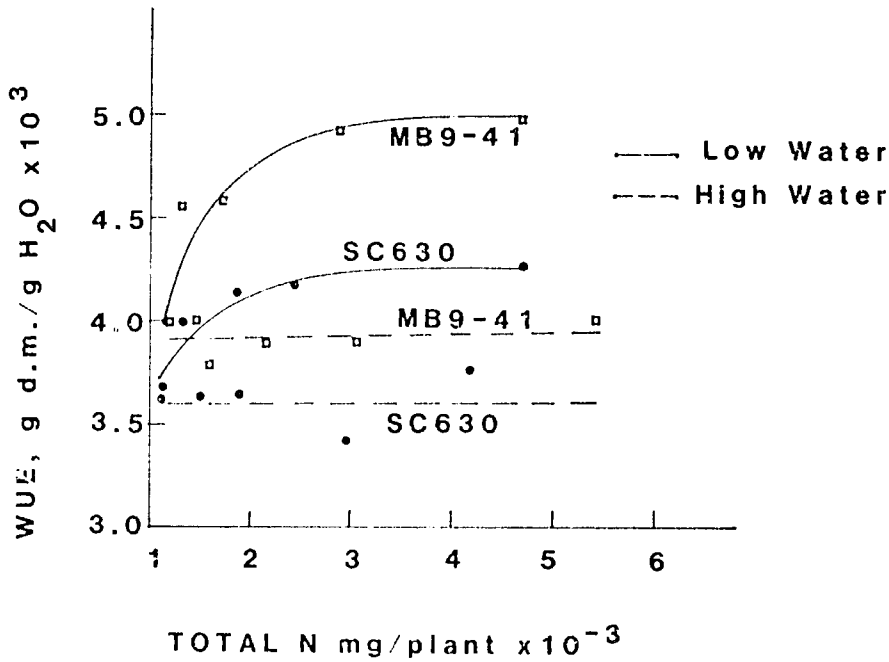


**Figure 3. Effect of total plant N on water-use efficiency (WUE = grams of dry matter produced per gram of water transpired) of two grain sorghum genotypes grown at two water levels and five N levels.**

between water treatments, but plant weights were still higher for the low-water treatment. At maturity, both plant weights and leaf area were least for the low-water treatments. At 50% bloom and maturity, plant heights were greatest at the high-water treatment. Measured plant parameters were more affected by water treatment than by fertilizer application. Grain weight per acre was decreased by fertilizer N at the low-water level and increased by fertilizer at the two higher water levels. Tillering was greatest at the high-water level. Water use efficiency was increased by N application when N increased yield and was decreased by N when applied N resulted in a decrease in yield (Table 1). Increased available water increased ET, whereas, N rate had no effect on ET. Water level had a significant effect on leaf-water potential, but N rate had no effect. At the second date of measurements the medium- and high-water treatments had higher leaf-water potentials than the low-water treatment. Photosynthesis, at both sampling dates, was a better indicator of water stress than leaf-water potential, showing a decrease before a change in leaf-water potential could be measured.

*Soil studies*

Samples from sixteen profiles of a toposequence of soils from the Cinzana Experiment Station in Mali were analyzed for particle size, water pH, 1.0 N KCl pH, exchangeable acidity, exchangeable aluminum, cation exchange capacity, anion exchange capacity, exchangeable calcium, magnesium, potassium and sodium and soil test phosphorus. With only a few notable exceptions, these profiles contained large amounts of sand (>70%) and small amounts of clay (<20%). Cation exchange capacities were generally low (<4 meq/100 g), particularly in the surface, indicating low buffering capacities. These soils were generally acid (pH < 6.0) with exchangeable acidity ranging from 10 to 40%. Several samples contained significant amounts of exchangeable aluminum. Exchangeable calcium and magnesium were frequently present in about equal quantities and occupied about 50% of the cation exchange capacity. Amounts of exchangeable potassium indicated potential deficiencies of this element. No sodium hazard was indicated. Anion exchange capacities were low (<0.3 meq/100 g) and generally 30% or

less of the cation exchange capacity. Soil test phosphorus was extremely low and indicated a deficiency of this element in every sample measured with the exception of one profile.

Nitrogen rates of 0, 20, 40, 80, 160, 320 and 640 x $10^{-6}$ g/gram of soil (equivalent to 0, 40, 80, 160, 320, 640 and 1280 lbs/A) as urea were added to a surface soil from the Cinzana Experiment Station in containers, moistened to field capacity, and incubated in an oven at 30° C. Samples were removed and pH measured at weekly intervals. The initial effect of the urea was to raise the soil pH due to ammonium release. Subsequent conversion of ammonium to nitrate resulted in pH depression. Due to the low buffering capacity of this soil (CEC of 1.4 meq/100 g), significant depressions in pH occurred with additions of urea. Equilibrium conditions had not been reached except at the 20 ppm rate, due to termination of the experiment. However, the results indicate potential problems of applying acid-forming fertilizers to these acid soils with low buffering capacity. Telemsi rock phosphate obtained from Mali was evaluated for use on six of the surface soils from the Cinzana Experiment Station, which were previously characterized and discussed. The method suggested by Chien (SSSAJ 44:260-279) was used. Results show that the method of Chien (perhaps with some modification) may be useful in evaluating Malian soils for potential use of rock phosphate and not all of the soils used are suitable for use of rock phosphate even though they were all acid.

**Conclusions**

Strong interactions exist among level of available water, cultivar and soil fertility in efficient use of available water, measured in terms of both ET and T. These relationships and associated mechanisms should be carefully delineated in order that specific cultivars can be identified and appropriate treatments defined to most effectively utilize available water resources in semiarid areas.

The nitrogen and phosphorus studies indicate the need for extensive research into the reactions and fate of fertilizer materials added to these soils and correlation studies with crop response. It may be necessary to modify or develop analytical procedures for use on these acid soils in the semiarid tropics.

**Implications**

It is clear that soil fertility and genotype have large effects on utilization of available water. The soils of the semiarid tropics of West Africa are extremely deficient in N and P. Soil management practices to increase the amount of the water resource available to crops will be economical only when N and P deficiencies are corrected along with the use of responsive genotypes. Controlled studies are needed before the general use of fertilizer is advocated and amounts to be applied selected. The research reported here indicates potentially harmful effects if fertilizers are misused.

# Increasing Crop Yield And Available Soil Water Through Tillage and Fertilization

*Charles W. Wendt, Texas Agricultural Experiment Station*
*Naraine Persaud, Texas A&M University*
*Zoumana Kouyate, Institut D'Economie Rurale*
*Arthur B. Onken, Texas Agricultural Experiment Station*
*William A. Payne, Texas A&M University*
*R. Louis Baumhardt, Texas Agricultural Experiment Station*

It is common knowledge that the Sahel has a deteriorating ecosystem, as is manifest in widespread famines. Inefficient use of limited water supplies is a major factor in this deterioration. In developed countries tillage techniques, engineering structures and cropping systems have been developed to increase soil water storage and stabilize or increase crop yields. Problems common to the semiarid areas of Africa and the United States include soil water evaporation, crusting, runoff and wind erosion. It may be possible to transfer mechanical concepts developed in West Texas to solve these problems to the Sahel.

Other factors in the deteriorating ecosystem of the Sahel are the soil chemistry (low pH, Al toxicity) and fertility (low N and P) problems. In some cases these problems are so severe that the crops and rangelands cannot use limited amounts of water efficiently. Chemical amendments and fertilizers should be applied judiciously, because of the fragile nature of Sahelian soils.

Because the costs of tillage, soil amendments and fertilizers are high, it is important to find what combinations of practices are economically feasible to increase crop yields in West Africa.

### Objectives

The general objective of this project is to develop appropriate tillage and fertilizer techniques to increase available soil water and crop yield under rainfed conditions. Specific objectives are 1) to compare several techniques of soil preparation, alone and in combination with fertilizer application, and evaluate their effect on water-use efficiency and yield of sorghum; 2) to determine the water balance and millet yield on different locations with similar physical and hydrological properties but different amounts of rainfall; and 3) to compare the effects of different tillage treatments and cultural practices on infiltration and soil water storage.

## Evaluation of Tillage and Fertilization In Water-Use Efficiency and Grain Yield

### Procedures

On a previously fallowed loam soil at Cinzana, Mali, a study involving the influence of deep plowing, ridging, and tied ridges with and without fertilizer on sorghum growth and yield was implemented. Appropriate chemical and physical analyses were made. Measurements of soil strength, plant growth and yield, water use, and potential evapotranspiration were made. From these measurements the influence of the treatments on water-use efficiency was investigated.

### Results and Conclusions

The data obtained show the importance of fertilization and deep plowing in the loam soils in Mali. Deep plowing decreased bulk density and soil strength. These were probably factors contributing to better rooting, yield and water-use efficiency (Table 1). Since root data were difficult to obtain, not all treatments were sampled. Plots with deep plowing plus ridging had significantly higher root weights. In the ridged treatments, fertilization increased rooting but no more water was used. The fertilizer increased yield and the water-use efficiency almost 50 percent. This increase was much more than the increase in efficiency due to deep plowing (24%).

The importance of fertilization and deep plowing is further emphasized at the bottom of Table 1. Fertilization increased sorghum yields almost 700 kg/ha, while deep plowing increased sorghum yields over 300 kg/ha. The increases due to fertilization were independent of deep plowing. Considering the cost of energy to deep plow, fertilization may be more practical because a response can be obtained without plowing.

**Table 1. Summary of tillage and fertilization effects on rooting, yield and water-use efficiency.**

| Tillage technique | Fertilization* | Root weight | Depth of rooting** | | Effective ET | Grain yield | Water-use efficiency |
|---|---|---|---|---|---|---|---|
| | | (g/cm3) | (cm) | (cm) | (cm) | (kg/ha) | (kg/mm) |
| No-till | F0 | | 26c | 61a | 372 | 1311b | 3.52b*** |
| | F1 | 13.5e | | | | 2055a | |
| Deep Plowing | F0 | | | | | 1811b | |
| | F1 | 23.3bc | | | | 2266a | |
| Ridging | F0 | | 32b | 67a | 395 | 1451b | 3.67b |
| | F1 | 22.3c | 41a | 70a | 396 | 2145a | 5.42a |
| Deep Plowing Ridging | F0 | | | | | 1629b | |
| | F1 | 24.3b | | | | 2454a | |
| Tied Ridges (BC1) | F0 | | | | | 1580b | |
| | F1 | 20.7d | | | | 1934a | |
| Deep Plowing | F0 | | | | | 1514b | |
| Tied Ridges | F1 | 26.4a | 34a | 68a | 390 | 2623a | 6.72a |
| Fertilization | | | | | | | |
| | (F0) | | | | | 1549b | |
| | (F1) | | | | | 2246a | |
| Plowing | | | | | | | |
| | Shallow | | | | | 1746b | |
| | Deep | | | | | 2050a | |

* F0 - No Fertilizer, F1 - Fertilized with 100 kg/ha of 18-46-0 and 50 kg/ha of 45-0-0

** Intensity rooting (IR) and Maximum Rooting (MR)

*** Means not followed by the same letter in the same column are not significantly different at the 95% level of probability.

## Water Balance and Millet Yields In Different Agroecological Regions

### Procedures

Three sites with contrasting average rainfall were selected in Niger at Chikal, Kala Pate and N'Dounga. At each site the soil was classified according to Soil Taxonomy and appropriate measurements to estimate potential evapotranspiration and water balance were made. Millet yield was determined at the end of the season. Following harvest, the influence of mulch on post-harvest water loss was determined.

### Results and Conclusions

The soils were classified as follows: Chikal--Ustic Torripsamment; N'Dounga--Psamentic Paleustalf; and Kala Pate--Alfic Ustipsament. Potential evapotranspiration (PET) as determined by the modified Penman equation varied from 4 mm in January to 9 mm in April and May. The PET at all locations was similar except for the period prior to the beginning of the rainy season in June. At this time the northern site had significantly lower PET (5 mm at Chikal) than the southern site (9 mm at N'Dounga).

The soil water and yield are presented in Table 2. Rainfall in the growing season varied from 219 to 392 mm. Storage of rainfall in the bare plots ranged from 4 mm at Kala Pate to 81 mm at N'Dounga. Thus, bare soil fallow is not a very efficient method of storing soil water.

In the cropped areas yields varied from 330 kg/ha at Chikal to 1170 kg/ha at N'Dounga. Kala Pate, which received the most rainfall and had the highest evapotranspiration, did not produce the highest yield. This indicates that water was not the primary factor limiting yield at this site. This is further emphasized in the water-use efficiency calculations (kg grain/inch ET). Kala Pate had the lowest efficiency (1.38 kg/ha) followed by Chikal (1.54 kg/ha) with N'Dounga having the highest efficiency (4.27 kg/ha).

Throughout the world mulches are proposed to protect the soil surface and decrease evaporation. Mulch was applied at the rate of 25 tons/ha to plots 2 m x 2 m at all locations. The results obtained (Table 2) show that the mulch did not affect the amount of water stored after the growing season was over.

**Table 2. Rainfall, evapotranspiration, yield and water use efficiency data from the Nigerien water balance study.**

| Site and Rainfall (mm)* | Treatment | Growing season ET | Yield (kg/ha) | Water use efficiency (kg/mm) | Post harvest water loss** (mm) Bare | Mulched |
|---|---|---|---|---|---|---|
| Chikal | Cropped | 214 | — | 1.54 | 9 | 3 |
| 219 | Bare | 172 | 330*** | — | 55 | 62 |
| Kala Pate' | Cropped | 321 | — | 1.38 | 63 | 63 |
| 392 | Bare | 317 | 443 | — | 55 | 61 |
| N'Dounga | Cropped | 273 | — | 4.27 | 45 | 41 |
| 308 | Bare | 192 | 1170 | — | 67 | 67 |

* 10mm, 36mm, and 33 mm fell at chikal, Kala Pate' and N'Dounga respectively prior to planting.

** Dates of measurement were as follows: Chikal - 10/16/85 to 3/24/86; Kala Pate' 10/2/85 to 5/3/86; and N'Dounga - 9/25/85 to 4/10/86.

*** Estimated yield from adjacent plots - Plots at Chikal were harvested by local farmers.

## Effect of Tillage Treatments and Cultural Practices on Infiltration And Soil Water Storage

### Procedures

Infiltration was determined on various tillage treatments and cultural practices with a rainfall simulator in Lubbock, Texas. Tillage treatments which were imposed on an Olton loam soil included chiseling and furrow diking, on both crusted and uncrusted soils. On an Acuff loam soil various cultural practices including continuous cotton and sorghum under conventional and reduced tillage, wheat, and fallow were evaluated.

### Results and Conclusions

In the initial studies with the rainfall simulator, infiltration was determined on chisel-and-tied ridge treatments with and without crust. Tied ridges and the absence of a crust significantly increased infiltration during a one-hour period (Table 3). Chiseling did not significantly influence infiltration.

There were no significant differences in infiltration due to cultural practices. The relatively high L.S.D. values indicate variability between treatments. Infiltration was significantly lower in the fall than the spring due to the differences in soil water content at the time the studies were conducted.

### General Conclusions

1. Both tillage and fertilization increased root weight and intensity in Mali.
2. Grain sorghum yields were increased by both tillage and fertilization in Mali. Fertilization was more effective than tillage.
3. Rainfall is not the primary factor limiting yield at Kala Pate, Niger.
4. Mulches are not an effective method of conserving soil water between growing seasons in Niger.
5. Tillage had more effect than cultural practices on infiltration at Lubbock, Texas.

### Implications

The site at Cinzana was a previously fallowed loam soil. The significant increase in sorghum yield due to fertilization was therefore unexpected. The yield increase due to fertilization (700 kg/ha) was twice the increase from deep plowing (300 kg/ha). Due to the high cost of energy to deep-plow, fertilization appears to be a more practical option to increase sorghum yields.

The fact that something besides rainfall is limiting yields at Kala Pate supports other findings in Niger. Other research indicates that on some sites chemistry-fertility problems are much more limiting to yield than water.

The importance of using tied ridges and minimizing crusting to increase infiltration was pointed out in the Lubbock studies. Since the soils of Mali and Lubbock are similar in many physical parameters it is probable that similar results will be obtained when infiltration studies are initiated in Mali.

**Table 3. Infiltration (mm) data from tillage and cultural practice study, Lubbock, Texas, 1986.**

| Tillage practice | Total Infiltration (mm/hr) | | |
|---|---|---|---|
| | Crust | No crust | Mean |
| Tied Ridge | 18 | 22 | 20a* |
| No Tied Ridge | 15 | 18 | 17 b |
| Chisel | 16 | 22 | 19 a |
| No Chisel | 17 | 19 | 18 a |
| Mean | 16 a | 20 a | |
| **Cultural practice** | **Spring** | **Fall** | |
| Wheat | 51 (8) | 12 (20)** | |
| Fallow | 43 (13) | 13 (25) | |
| Conventional Cotton | 48 (12) | 12 (21) | |
| Reduced Till Cotton | 48 (12) | 14 (22) | |
| Conventional Sorghum | 51 (12) | 10 (26) | |
| Reduced Till Sorghum | 33 (13) | 13 (26) | |
| L.S.D. | 19 (3) | 9 (6) | |

* Means followed by the same letter are not significantly different at the 95% level of probability.

** Numbers in parenthesis are the volumetric water contents at the time of infiltration was determined.

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