TropSoils

TECHNICAL REPORT 1985 - 1986

■ SOIL MANAGEMENT

■ COLLABORATIVE

■ RESEARCH SUPPORT PROGRAM

TropSoils

TECHNICAL REPORT 1985 - 1986

Edited by
Neil Caudle, TropSoils Editor, Department of Agricultural Communications, North Carolina State University

Charles B. McCants, Director, TropSoils Management Entity, North Carolina State University

Published June, 1987

TropSoils is one of the Collaborative Research Support Programs (CRSPs) created to implement Title XII, "Famine Prevention and Freedom From Hunger" of the Foreign Assistance Act. Primary funding is provided by the U.S. Agency for International Development under grant no. DAN-1311-G-SS-1083.

Copies of this report may be obtained by writing TropSoils Management Entity, Box 7113, North Carolina State University, Raleigh, N.C. 27695-7113, U.S.A.

Contents

The Humid Tropics, North Carolina State University

The Humid Tropics, University of Hawaii

The Acid Savannas, Cornell University

The Semi-Arid Tropics, Texas A&M University

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 "agro-ecological zones," are the basic units of TropSoils' organization.

This document reports the progress of TropSoils research in three agro-ecological 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
Dept. of Agronomy & Soil Science
University of Hawaii
Honolulu, HI 96822

Lloyd Hossner
Dept. of Soil and Crop Science
Texas A&M University
College Station, TX 77843

Douglas Lathwell
Department of Agronomy
Cornell University
Ithaca, NY 14853

Collaborators, N.C. State University

INIPA (Instituto Nacional de Investigacion y Promocion Agraria—Peru)

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuaria—Brazil)

IVITA (Instituto Veterinario de Investigacion del Tropico y Altura)

UEPAE-Manaus (Unidade de Execucao de Pesquisa de Ambito Estadual de Manaus)

IICA (Instituto Interamericano de Cooperacion para la Agricultura)

PEPP (Proyecto Especial Pichis-Palcazu)

CPAC/EMBRAPA (Centro de Pesquisa Agropecuaria dos Cerrados)

Universidad Nacional Agraria, La Molina, Peru

Center for Soils Research, Indonesia

CIAT (Centro Internacional de Agricultura Tropical)

University of Hawaii

University of Georgia

Wageningen University, The Netherlands

Institute of Development Studies, Finland

Reading University, United Kingdom

Cornell University

U.S. Agency for International Development

Collaborators, University of Hawaii

Center for Soil Research, Indonesia

Institute Pertanian Bogor, Nutrition Department

Andalas University, Padang

U.S. Agency for International Development

North Carolina State University

Collaborators, Cornell University

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuaria—Brazil)

CPAC/EMBRAPA (Centro de Pesquisa Agropecuaria dos Cerrados)

U.S. Agency for International Development

North Carolina State University

Collaborators, Texas A&M University

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics)

ILCA (International Livestock Center for Africa, Ethiopia)

CARE (Cooperatives for American Relief Everywhere)

INTSORMIL (USAID Collaborative Research Support Program on Sorghum and Millet)

IRAT (Institut de Recherches Agronomiques Tropicals, France)

INRAN (Institut National de Recherche Agronomique du Niger, Niger)

University of Niamey, Niger

IFDC (International Fertilizer Development Center, U.S.A.)

University of Wageningen, The Netherlands

FLUP (Forest and Land Use Planning Project, Niger)

USAID/NIGER (U.S. Agency for International Development, Niger Mission)

USAID/Mali (U.S. Agency for International Development, Mali Mission)

OICD (Office of International Cooperation and Development, USDA)

SAFGRAD (Semi-Arid Food Grain Research and Development, Burkina Faso)

ICARDA (International Center for Agricultural Research in the Dry Areas, Syria)

IFRSC (Institute Francais de Recherche Scientifique et Cooperation former ORSTOM—France)

SMSS (Soil Management Support Services, USDA/AID)

I.R.E. (Institut d'Economie Rural, Mali)

AGRHYMET (Centre Regional de Formation et d'Application en Agrometeorologie et Hydrologie Operationnelle, Naimey, Niger)

Humid Tropics
North Carolina State University

Traditional shifting cultivation with slash-and-burn clearing has been singled out as a major contributor to deforestation. This deforestation has raised concern world-wide over the prospect of economic and ecological disaster in the tropics. The pressure for new clearing arrises in part from the nature of tropical-rainforest soils, which are typically acid and infertile. Lacking the capital and technology to overcome these soil constraints, shifting cultivators slash and burn the forest, raise one or two marginal crops in its fertile ash, then move on to clear a new field. Many hectares of cleared land are abandoned after only one or two years of use.

The objective of North Carolina State University's TropSoils program in the humid tropics is to develop and transfer, together with national institutions and other universities, improved soil-management technologies that are agronomically, economically and ecologically sound for productive and sustained farming systems in the humid tropics and acid savannas. The program has been rooted in the premise that a stable, productive agriculture is the best means for conserving tropical forests and improving the living standard of farm families in developing countries. The emphasis in on relieving the pressure for new clearing by increasing and stabilizing the production of lands already cleared.

Rather than advocate a single solution for the humid tropics, the program seeks to provide a series of management options to farmers in the process of transition from shifting cultivation to settled agriculture. These management options cover the principal soils, landscape positions and levels of infrastructure development in the humid tropics, and include low-input cropping, continuous cultivation, agroforestry, legume-based pastures, paddy-rice production, and reclamation of humid tropical steeplands.

The program's primary research site is the Yurimaguas Experiment Station in Yurimaguas, Peru. Research is also conducted in Indonesia (supporting TropSoils work in the Sitiung transmigration settlements); at Manaus, Brazil; in the Cerrado of Brazil; and at Pucallpa and Pichis-Palcazu, in the Selva of Peru. These sites represent a range of environments. Soils and climate at Manaus, for example, are intermediate to Yurimaguas (loamy Ultisols and a weak dry season) and the Cerrado (clayey Oxisols with the strong dry season). Pichis-Palcazu has a perudic soil-moisture regime (3400 mm rainfall, Ultisols and Dystropepts), and Pucallpa a near-ustic regime (1500 mm). Technologies showing promise at one site are tested and adapted at others, and are introduced to other countries through a research network, so as to improve the transfer and application of results.

Some of the work reported here is complete; some is only beginning to produce results. While the research is presented as individual projects, most projects were conceived as parts of broader investigations supported by many collaborating scientists and institutions sharing a common goal: to increase food production while conserving natural resources in developing countries in the tropics.

CONTENTS

Low-Input Cropping Systems

Because it is unlikely that many farmers in the humid tropics can abruptly switch from traditional shifting cultivation to a fertilizer-based agriculture with continuous cropping, an intermediate system of low-cost, "low-input" technologies might be useful as a transitional agriculture that could produce ample food while reducing the need to clear more forest land. The emphasis of this low-input approach is on adapting plants to the soil, rather than correcting soil constraints to meet the plants' needs.

Previous research and interviews with farmers have led to an experimental low-input system largely based on traditional farming practices, with innovations introduced in stages. The strategy developed at Yurimaguas includes slash-and-burn clearing, aluminum-tolerant cultivars, a rotation of upland rice and cowpeas, zero or minimum tillage, chemical weed control, modest rates of fertilizers, and crop-residue management. As soil fertility and crop yields decline with time, the system would shift to such options as continuous cropping, pastures, tree crops or managed fallows.

The low-input system is considered transitory, but has remained productive considerably longer than expected. In the central experiment, seven continuous crops in three years have yielded a total of 13.8 t/ha of rice and cowpea grain, without application of lime or fertilizers in a soil with pH 4.4 and 68% Al saturation. Studies presented here indicate that soil fertility is not the major constraint in this system, as crop yields remain high with only small amounts of phosphorus and potassium after the second year.

As predicted by farmers during the interviews, weeds are a primary constraint to sustained production. Results are not yet available from a study of weed control in low-input systems, but preliminary observations suggest that, without tillage, weeds will limit the system's useful life to about six crop cycles. Research is planned to develop practical weed-control strategies that will prolong the productivity of the low-input system and increase its appeal as a soil-management option in the humid tropics.

Central Low-Input Experiment

José R. Benites, N.C. State University
Marco A. Nureña, INIPA
Pedro A. Sanchez, N.C. State University

A central experiment was established at Yurimaguas, Peru, to determine the potential of a low-input, crop-production system based on a rotation of upland rice and cowpeas, and to determine how long the system might remain productive. A one-hectare plot of a ten-year-old secondary forest fallow was cleared by slash and burn in July, 1982. In August, a study was established consisting of upland rice and cowpea with two treatments: one-half hectare fertilized at the rate of 30 kg N, 22 kg P and 48 kg K/ha per rice crop, beginning with the second rice crop, and the other half-hectare not fertilized. The traditional upland rice variety was sown with a planting stick (*tacarpo*) at the wide spacing common to the region; a post-emergence herbicide was used to control broad-leaf weeds. After the first rice harvest, at the time farmers typically abandon the field, several practices were introduced:

1. All the rice straw was cut and spread evenly.
2. "Africano Desconocido," an acid-tolerant, improved rice cultivar, was planted with *tacarpo* at 30 x 50 cm spacing.
3. Rice was followed by an acid-tolerant cowpea (cultivar Vita 6 or Vita 7), also planted with *tacarpo*.
4. After threshing, all the rice straw or cowpea stover was spread evenly on the field.
5. The rotation continued for 34 months, fertilizing only the rice crops in the fertilization treatment.
6. Pre-plant application of 2-4 D (1.5 L/ha) and Paraquat (2.5 L/ha) were used for weed control.

Table 1. Productivity of a low input system during the first 34 months.

Crop and Cultivar	Planting Date	Grain Yields	
		Not Fertilized	Fertilized*
	Month	t/ha	
Rice, Carolino	Sept. 82	2.4	2.4
Rice, Africano	Feb. 83	3.0	3.1
Cowpea, Vita 7	Sept. 83	1.1	1.2
Rice, Africano	Dec. 83	2.8	3.2
Cowpea, Vita 7	May 84	1.2	0.9
Rice, Africano	Sept. 84	1.8	2.0
Rice, Africano	Feb. 85	1.5	2.5
Total	34 Months	13.8	15.3

* 30 kg N/ha, 22 kg P/ha, 48 kg K/ha to Aficano rice crops.

Crop Yields

Yields of both rice and cowpea were high. Table 1 shows the yields of seven continuous crops harvested within three years after the experiment began. A total of 13.8 t/ha of rice and cowpea grain was produced during this period without any addition of fertilizer or lime. These results contrast sharply with those from the continuous-cropping system, in which yields approached zero without fertilizers within a year. The use of Al-tolerant cultivars, maximum residue return and zero tillage are believed to be responsible for this difference. The first six rice crops showed no response to the fertilizers applied. A sharp yield response to fertilizer was observed in the seventh crop, indicating a fertility decline in the check plots, and modest NPK applications became important at the end of the third year.

Table 2. Topsoil (0-15cm) fertility dynamics within the first 34 months of the low input cropping system at Yurimaguas.

Months after Clearing	Fertilized[1]	pH	Exchangeable Al	Exchangeable Ca	Exchangeable Mg	Exchangeable K	ECEC	Al Sat.	Avail. P	OM
			c mol/L					%	mg/kg	%
3	No	4.4	1.10	0.30	0.09	0.13	1.62	68	20	2.12
14	No	4.6	1.46	0.92	0.28	0.19	2.85	51	13	2.06
	Yes	4.7	1.14	0.97	0.27	0.19	2.58	45	18	2.07
34	No	4.6	1.65	1.00	0.23	0.10	2.99	53	5	1.92
	Yes	4.6	1.23	1.16	0.20	0.16	2.76	44	16	1.77
CV%[2]		6	46	46	41	43	9	37	39	20
LSD.05[2]		0.1	0.25	0.17	0.04	0.03	0.20	7	2	0.15

[1] Cumulative amount over 34 months: 120 kg N/ha, 88 kg P/ha as OSP, 192 kg/ha as KCl.
[2] Comparisons do not include sampling at three months after clearing.

Soil Properties

Topsoil chemical properties (Table 2) improved during the period three to 14 months after clearing, in response to the fertilizer value of the ash, which increased the base status. From 14 to 34 months, there was little change in pH, organic matter and exchangeable bases, and a more favorable Al saturation level was maintained. It is noteworthy that soil organic matter decreased only slightly, a sharp contrast to the 25% decrease observed in similar soils under a continuous-cropping system. Apparently this was due to the residue return and absence of tillage.

The check plots showed a pattern of declining soil fertility less drastic than results from continuous-cultivation experiments. Available P and exchangeable K decreased below the critical levels (12 ppm for P and 0.15 cmol/L for K). The small P and K additions in the fertilized treatment were apparently sufficient to offset this decrease.

Conclusions

It seems reasonable to assume that this low-input system could be sustained by modest fertilizer applications. The crucial limiting factor is a gradual buildup of grassy weeds, particularly during the rice crops. The effect of fertilizer application on weed growth does not appear to be important. The studies on weed control for low-input systems show that much needs to be learned about how to control these weeds economically by herbicides, and, as a consequence, avoiding tillage does not help, either. It is possible to control the weeds with hand labor economically, or with herbicides at a prohibitively high cost. Consequently, we have reached a crossroads in this transition technology. For the low-input system to succeed, effective and affordable weed control measures are needed to bridge the gap between year two and year five.

Results are promising for the low-input strategy as a transition from shifting agriculture to a more permanent system of management. With relatively simple practices farmers can grow seven crops where they were able to grow only one. This system cannot be considered stable at this time, and is viewed as a transition technology.

Tillage-Phosphorus Interactions Under Low-Input Croppirg Systems

Mwenja P. Gichuru, N.C. State University
Pedro A. Sanchez, N.C. State University

This experiment was begun in May 1982 to study the management of phosphorus in the low-input cropping system being developed on an Ultisol at Yurimaguas, Peru. Its objectives were to study the effect of no-till versus rotovation on continuous cropping without liming, using acid-tolerant crops, and to determine efficient rates and sources of phosphorus for a rotation of acid-tolerant upland rice (*Oryza sativa* L.) and cowpea (*Vigna unguiculata*).

Relevant soil chemical properties at the initiation of the experiment are shown in Table 1. The main plot treatments were tillage methods: 1) no-till, with broadcast fertilizers, and 2) rotovation before each crop, with fertilizers broadcast and incorporated to a depth of about 8-10 cm. Subplot treatments were phosphorus sources, ordinary superphosphate and Sechura phosphate rock. The sub-subplot treatments were 0, 25, 50, 100 and 200 kg P_2O_5/ha. Crop residues were left on the surface.

Tillage Effects

Figure 1 shows the influence of tillage on relative yields of five consecutive crops (relative yield is a percentage of maximum absolute yield). The first crop produced significantly more grain in rotovated treatments compared with no-till plots. The better growth in rotovated plots is probably due to improved soil physical properties and a better distribution of nutrients from the ash left by slash-and-burn.

The second and third crops' grain yields showed no differences due to tillage treatments. The advantage of rotovation in terms of improved physical properties may have disappeared, probably due to constant traffic during weeding and harvest. Rotovation followed by human traffic is likely to result in greater soil compaction and poorer crop performance, compared with no-till.

In the fourth and fifth crop dramatic yield reductions occured in rotovated treatments compared with no-till plots. Rotovated treatments produced 80% and 76% relative yields, respectively, in the fourth and fifth harvests (Figure 1). The reason for this sudden negative response to tillage is not clear. Bulk density measurements in the 0 to 7.5 cm depth, taken immediately after harvesting the fifth crop, showed high

Table 1. Relevant soil chemical properties at the initiation of the tillage-phosphorus experiment.

Soil Depth	pH	Exchangeable Acid	Ca	Mg	K	Effective CEC	Al Sat.	Avail P (Mod. Olsen)
cm		c mol/L					%	mg/kg
0-15	4.5	1.9	1.3	0.4	0.15	3.7	53	14
15-30	4.3	3.9	0.5	0.1	0.11	4.6	84	4
30-45	4.3	4.1	0.4	0.1	0.09	4.7	88	3

bulk density values both in rotovated plots (1.46 g/cc) and in no-till treatments (1.42 g/cc). These high values are believed to be mainly due to human traffic.

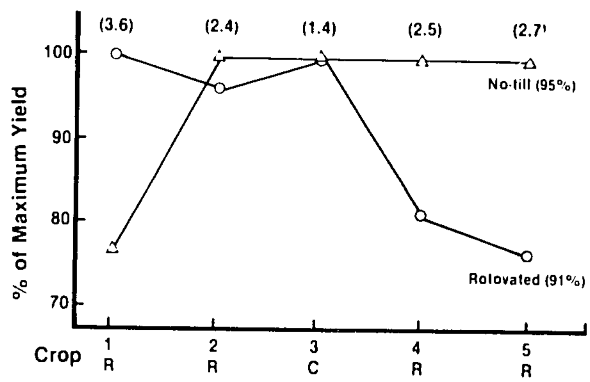


Figure 1. Relative yields of five consecutive crops as influenced by tillage. Numbers in parenthesis at the top are maximum yields in tons/ha, and numbers to the right are average yields of five crops. R = rice; C = cowpea.

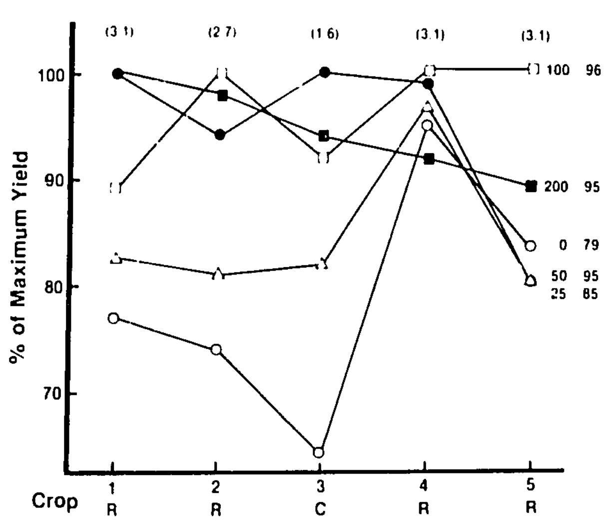


Figure 2. Relative yields of five consecutive crops as influenced by phosphorus application. Numbers in parenthesis are maximum yields in tons/ha, and numbers to the right are P rates (kg P = 2O = 5/ha) and average relative yields, respectively.

Phosphorus Effects

The grain yields ranged from a low of 1.41 t/ha to a high of 3.26 t/ha among the five crops. However, no significant differences were found between the phosphorus sources in any of the crops. Thus, phosphate rock was comparable to ordinary superphosphate in supplying P.

The data in Figure 2 show that, in general, only the control produced less than 80% relative yield in the first three consecutive harvests. The first P increment produced slightly over 80% while higher rates generally produced over 90% relative yields during the same period. The absence of a strong P response is believed to be due to the initially favorable P status in the soil, as shown in Table 1.

The fourth crop showed vigorous growth, probably due to N fixed by the cowpea crop, but severe lodging occurea during the grain-filling stage. All treatments produced yields over 90% of the maximum yield, but the grain quality was very poor; it had a high percentage of half-filled grain because of the lodging. The fifth harvest produced yields at least 80% of maximum, with the 100 kg P_2O_5/ha rate producing the maximum yield.

Conclusions

1. The effect of tillage appears to follow a trend in which rotovation is superior to no tillage during the first crop, about equal for the second and third crops, and inferior during the fourth and fifth rice crops. A combination of initial tillage followed by no-till appears advantageous, but firmer conclusions require additional data.

2. Rock phosphate at the rate of 50 kg P_2O_5/ha, applied to the surface, was sufficient to produce 95% of the maximum yields in the low-input system, based on crop varieties highly tolerant to aluminum. A total of 12.9 t/ha of rice and cowpea grain was produced by five crops on an Ultisol with pH 4.5 and no lime application.

3. The data show no significant interaction between tillage and phosphorus.

Calcium and Magnesium Movement In Low-Input Cropping Systems

Mwenja P. Gichuru, N.C. State University
Pedro A. Sanchez, N.C. State University
José R. Benites, N. C. State University

This experiment was initiated in May 1982 to study the effect of small additions of dolomitic limestone or gypsum on the downward movement of Ca and Mg as part of the low-input, crop-production strategy under development at Yurimaguas. A second objective was to determine the effect of tillage methods on the rates at which these cations moved into the subsoil.

Main plot treatments were a combination of tillage methods and nutrient incorporation: 1) no-till and broadcast fertilizers with no incorporation; 2) strip-tillage, with fertilizers applied in strips 15 cm wide (about one-third the total area) and incorporated with a hoe to a depth of approximately 8 to 10 cm, and 3) rotovator tillage with fertilizers broadcast and incorporated to rotovator depth (about 8 to 10 cm). Subplot treatments were calcium sources (dolomitic limestone and gypsum). Sub-subplot treatments were 0, 33, 100, 300 and 600 kg Ca/ha. Treatments with gypsum as the Ca source were supplemented with Mg from $MgSO_4 \cdot 7H_2O$ in amounts equivalent to that supplied by dolomitic limestone. The crop rotation was rice (*Oryza sativa* L.), rice, cowpea (*Vigna unguiculata*), rice, rice, cowpea.

Exchangeable Ca

Strip-tillage resulted in higher initial levels of exchangeable Ca in the topsoil because the calcium was applied to about a third of the soil surface area, but there were no significant tillage effects at other depths, and the effect on the topsoil had disappeared at twenty months.

The pattern of exchangeable Ca distribution appears nevertheless to be influenced by tillage treatments. Generally, seven months after application, dolomitic limestone resulted in significantly higher exchangeable Ca in the topsoil compared with gypsum treatments. The lower exchangeable Ca in the topsoil of gypsum-treated plots was due to downward movement, as indicated by higher exchangeable Ca at lower depths compared with the check and dolomitic-limestone treatments. Downward movement of Ca was more pronounced when gypsum was incorporated than when it was applied to the surface, as indicated by a larger bulge at the 15 to 16 cm depth in both strip tillage and rotovated treatments compared with no-till treatments (Figure 1).

The effect of gypsum on downward movement of Ca was still measurable 20 months after application. However, the exchangeable Ca bulge at the 15 to 45 cm layer had slightly shrunk despite a substantial decrease in exchangeable Ca in the above layers.

Slight increases in exchangeable Ca were found at 100 cm, suggesting that some Ca from gypsum had moved beyond the sampled depth. The application of

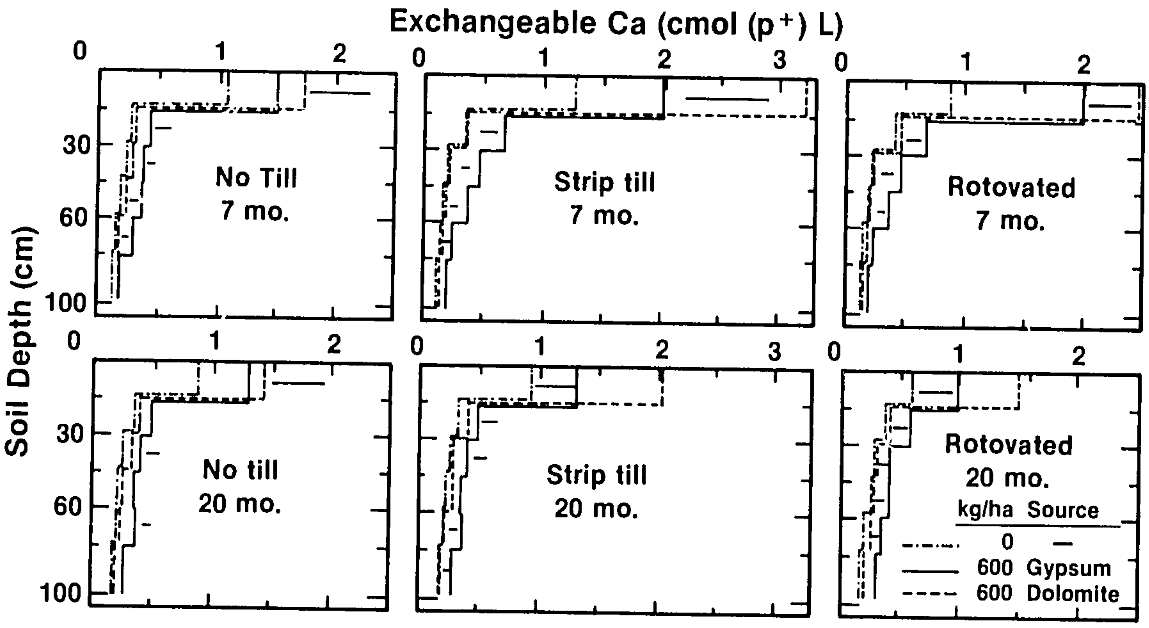


Figure 1. Exchangeable Ca as influenced by Ca source and rate under three tillage systems.

Table 1. Exchangeable Mg as influenced by the application of dolomitic limestone and gypsum.

Calcium Applied	No—Till		Strip—Till		Rotovated	
	Dol[1]	Gyp[2]	Dol	Gyp	Dol	Gyp
kgCa/ha			c mol/L			
			7 Months After Application			
0	.21	.28	.27	.26	.22	.20
33	.27	.25	.35	.29	.30	.20
100	.31	.17	.75	.23	.37	.39
300	.67	.23	1.03	.24	.55	.23
600	.56	.12	.98	.16	.90	.18
Rate LSD (.05)	.25	NS	.45	NS	.19	NS
Source LSD (.05)	0.09		0.14		0.08	
			20 Months After Application			
0	.15	.17	.18	.20	.11	.13
33	.17	.15	.19	.21	.14	.10
100	.17	.17	.47	.20	.20	.24
600	.58	.26	.97	.41	.53	.29
Rate LSD (.05)	.14	NS	.25	.16	.10	.11
Source LSD (0.05)	0.06		0.08		NS	

[1] Dol = dolomitic limestone
[2] Gyp = gypsum

300 kg Ca/ha showed a similar trend (data not presented here), but the magnitudes were smaller compared with the application of 600 kg Ca/ha. An exception was observed in no-till treatments, where the calcium bulge was comparable to that of the 600 kg Ca/ha rate in the rotovated treatment.

Exchangeable Mg

Statistical analysis of exchangeable Mg data revealed that treatments had little or no significant effect below the 0 to 15 cm layer. This was probably due to the initial variability of exchangeable Mg in the soil (coefficients of variation of 42, 87, 108, 55, 67 and 59% at increasing depth intervals, respectively). Exchangeable Mg status of the topsoil, however, was improved by the application of dolomitic limestone (Table 1). But little or no change in exchangeable Mg occured in gypsum treatments after seven months, although they had received supplemental Mg in equivalent amounts supplied by dolomitic limestone. The high solubility of the Mg source may have resulted in rapid leaching beyond the sampled depth. A similar trend was observed 13 months later, except that the highest rates of gypsum produced some increase in exchangeable Mg. In these high rates of gypsum the supplemental magnesium was split over the cropping cycles and applied at planting.

Conclusions

1. The applications of 300 or 600 kg Ca/ha as gypsum resulted in substantial downward movement of Ca in less than two years, whereas dolomitic limestone application resulted in little or no change in exchangeable Ca below the 0 to 15 cm depth. However, it was difficult to detect the effect of rates lower than 300 kg Ca/ha, probably because of variability in the field, which had recently been cleared by slash and burn.
2. Rotovation resulted in greater and more uniform downward movement of Ca, compared with surface application.
3. Gypsum application will result in subsoil enrichment with Ca in a short time.
4. The data from this experiment suggest that, 20 months after application, some Ca had moved downward beyond the sampling depth.

Results of this study indicate that relatively low rates of gypsum can promote a significant movement of calcium into the subsoil.

Legume-Based Pastures

Pastures are good news and bad news for soil management in the tropics. Well-managed, they 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. Many thousands of 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, Peru has been closely integrated with the Tropical Pastures Program of 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 has for the most part concentrated on the relationships among soil fertility, pasture quality, pasture persistence, grazing, the transfer of N from legumes to grasses, and the recycling of nutrients. Several promising grass-legume pastures have produced stable pastures and animal weight gains many times greater than those on the typical humid-tropical farm. After years of sustained production at Yurimaguas, the best of these associations and management techniques are being tested at extrapolation sites.

Some of these extrapolation studies have been initiated near Pucallpa, Peru, but are not reported because they are still in the establishment phase. Two projects are examining the N contribution of legumes to mixed pastures, and determining the optimum schedule for herbicide application during pasture establishment.

Central in the work reported here is the role of legumes in pasture associations. Legume-based pastures have not been studied extensively in humid tropical environments, and the information about their response to such management variables as fertility, grazing pressures and establishment methods are expected to be of use throughout the humid tropics.

Legume-Based Pastures: Central Experiment

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

The central experiment with pastures, begun in 1980, has sought to develop a practical management system for improving tropical pastures with stable mixtures of acid-tolerant legumes and grasses. Since its initiation, the experiment has evolved in response to new information gained from companion experiments and from collaboration with the International Center for Tropical Agriculture (CIAT) and its Tropical Pastures Network. Work so far has shown that proper management of some grass-legume associations can greatly improve the stability and productivity of previously degraded tropical pastures, while conserving the soil-resource base.

The objectives of this experiment are 1) to measure pasture and animal productivity on 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. Table 1 shows the species, animal management and years of evaluation for each association.

Animal Production and Botanical Composition

Changes in animal production are shown in Figure 1. During the first year, most associations yielded above 600 kg/ha/yr of liveweight gains. However, only *C. pubescens* and the *Brachiaria*-based pastures were able to maintain that level of productivity beyond the first year.

A remarkable performance by *Centrosema pubescens* 438 has been observed. After the first year, *A. gayanus* disappeared from this mixture because of establishment

Table 1. Grazing trial mixtures with starting dates of continuous and alternate grazing. (Planting dates: March to July, 1980 for first four, February, 1982 for fifth and October, 1984 for sixth mixture.)

Treatments: Grass/Legume	Initiation of Continuous Grazing	Grazing Days	Initiation of Alternate Grazing	Grazing Days Through Sept. 1985
B. decumbens/D. ovalifolium 350	Nov. 15, 1980	238	Oct. 7, 1981	370
P. maximum/P. phaseoloides 9900	Nov. 20, 1980	238	Oct. 6, 1981	1005
A. gayanus/S. guianensis 134-186	May 15, 1981	57	Oct. 6, 1981	1370
C. pubescens 438	—	0	Oct. 7, 1981	1370
B. humidicola/D. ovalifolium 350	—	0	Oct. 10, 1982	1056
A. gayanus/C. macrocarpum 5056[1]	—	0	May 1985	120

[1] Replaced Pm/Pp.

Table 2. Nutrient levels of grass and legume mixture components and tannin content of legumes May, 1983.

Species	N	P	K	Ca	Mg	S	Zn	Tannin
	%						ppm	%
Legumes:								
Centrosema pubescens 438	4.46	0.26	1.30	0.93	0.26	0.18	31	2.5
Desmodium ovalifolium 350	2.69	0.16	0.72	0.83	0.21	0.12	10	21.0
Stylosanthes guianensis 136	3.89	0.22	0.32	1.13	0.32	0.16	37	4.0
Pueraria phaseoloides 9900	3.90	0.22	1.30	0.45	0.32	0.12	25	4.0
Grasses:								
Brachiaria decumbens 606	2.38	0.24	1.57	0.42	0.42	0.11	14	—
Brachiaria humidicola	1.70	0.21	1.66	0.28	0.27	0.10	16	—
Androgogon gayanus	2.11	0.17	1.05	0.36	0.14	0.11	10	—

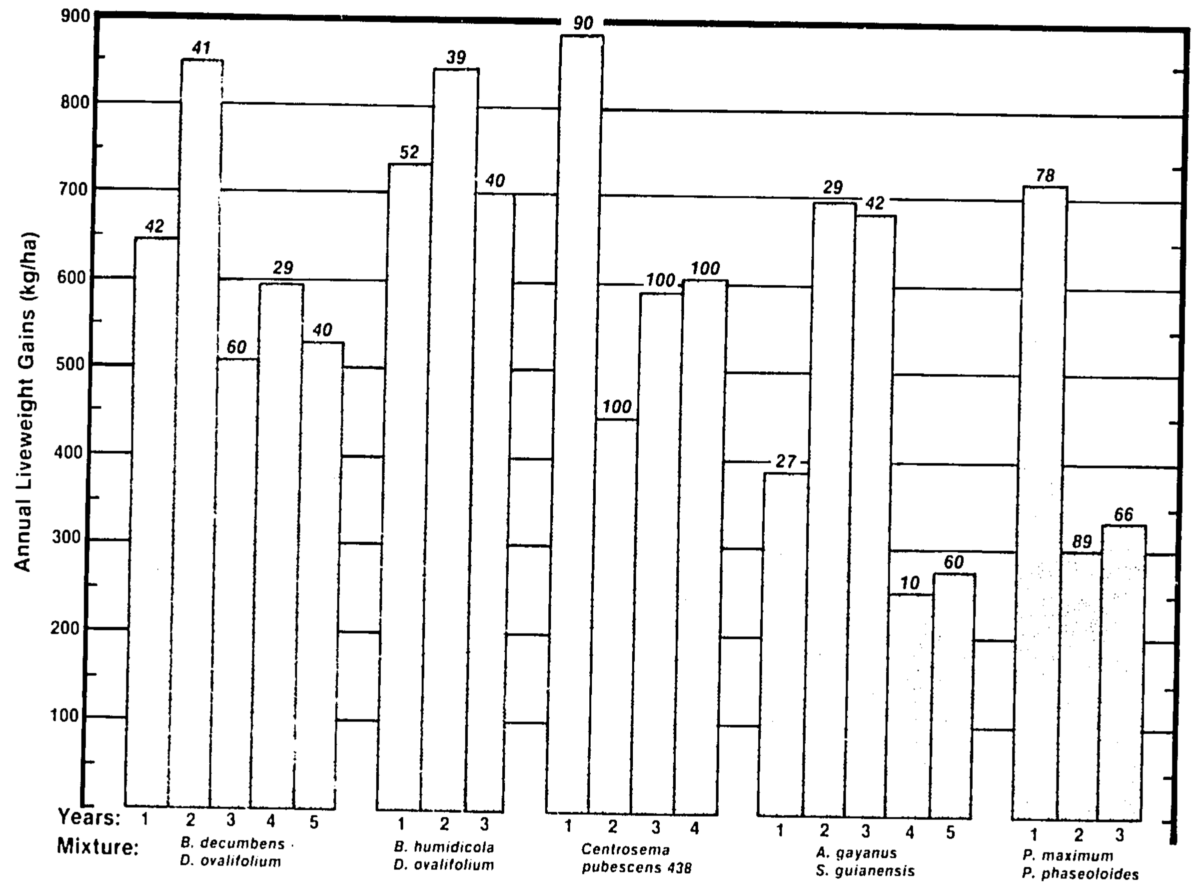


Figure 1. Changes in animal production from grass-legume pastures with time in Yurimaguas. A number at the top of a bar is an average annual percentage of legume in the mixture.

problems. In spite of this, the legume has persisted and maintained high levels of production. This must be related to the high quality of the species (excellent palatability and high nutritional content) in comparison to the other legumes in the experiment (Table 2).

The change from continuous to alternate grazing has favored the presence of grass in the mixtures of *B. decumbens* + *D. ovalifolium* and *B. humidicola* + *D. ovalifolium* (Table 2). This has resulted in sustained animal gains based mainly on consumption of the grass, since the legume is of low palatability (Figure 1). Levels of *D. ovalifolium* in the mixture with *B. decumbens*, however, decreased sharply in May 1984. This was related to an unusual intake of legume and a rejection of the grass during a short drought at that time. In the mixture of *A. gayanus* + *S. guianensis* the annual animal performance was closely related to the content of legume in the association (r^2 = 0.75). The legume almost disappeared in the same period as indicated for *D. ovalifolium* with *B. decumbens*.

Poor animal gains were observed in *P. maximum*

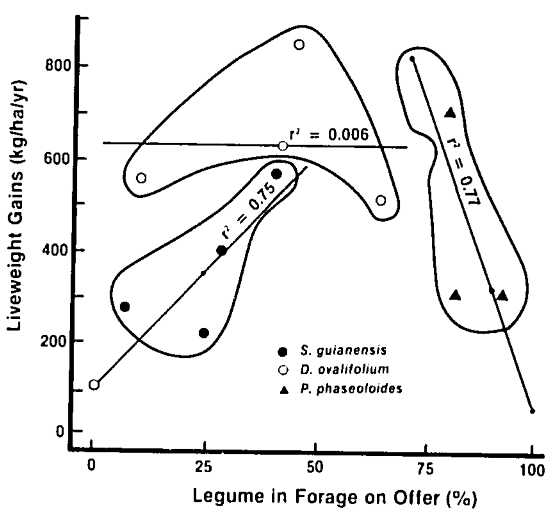


Figure 2. Effect of the content of legume in the forage on offer on animal gains in three grass-legume pastures growing in an Ultisol of Yurimaguas. (% legume expressed as annual mean value.)

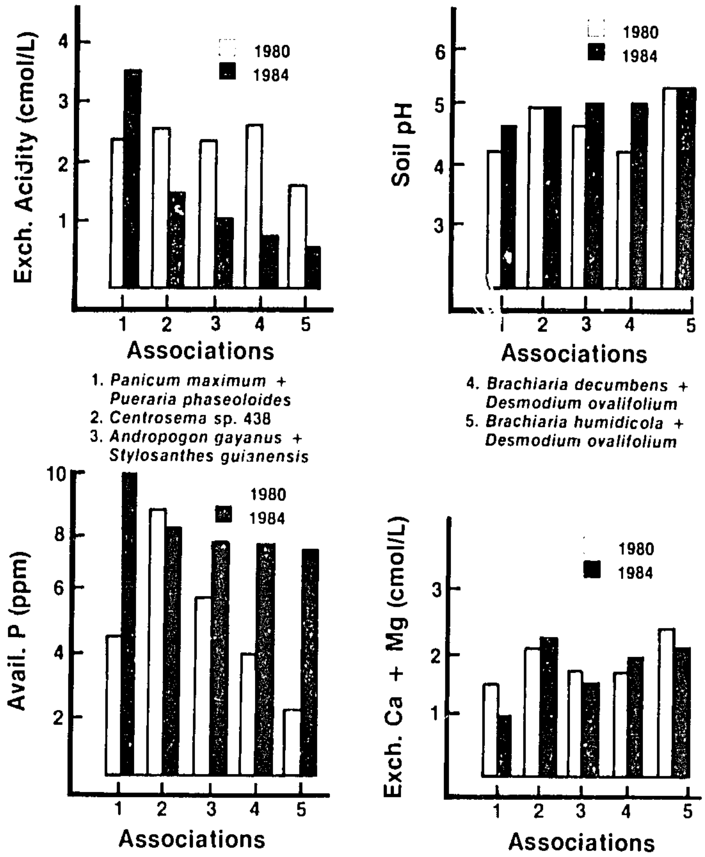


Figure 3. Changes in the topsoil chemical properties in five grass-legume associations after four years of grazing.

+ *P. phaseoloides* after three years of evaluation. This appears to be related to the increasing content of *Pueraria*. The negative effect of this legume on animal gains is reflected in a negative correlation coefficient of -0.77 (Figure 2).

Centrosema pubescens 438 as a pure legume and the *B. humidicola* + *D. ovalifolium* mixture were the best pastures in terms of individual animal gains and kg/ha

Table 3. Average annual productivity of five associations under grazing. Stocking rate 4.4 animals/ha.

Association	Years of Grazing	Liveweight Gains	
		kg/ha/yr	g/an/day
B. humidicola/D. ovalifolium	2	691	429
B. decumbens D. ovalifolium	4	626	379
Centrosema pubescens 438	3	619	459
A. gauanus S. guanensis	4	467	357
P. maxim/P. phaseoloides	3	455	296

weight/ha (Table 3). The association of *B. humidicola* + *D. ovalifolium* performed well but had only two years of evaluation.

Changes in Soil Chemical Properties

In order to follow the changes in the soil properties as a function of time in these pastures, the treatments were sampled in 1980 (before grazing, and six months after fertilization for establishment) and in 1983 and 1984. Figure 3 shows that some of the properties have changed in the 0-20 cm depth in several pastures. It is interesting to observe that exchangeable acidity has decreased in all associations except *P. maximum* + *P. phaseoloides* and that pH has increased to 5.0 in *B. decumbens* + *D. ovalifolium*. Phosphorus levels have increased in all associations, probably due to maintenance applications of phosphorus (25 kg P ha/yr). Most changes have occurred in the 0-20 cm depth.

Progress in 1985

Several changes have been introduced in the management of the associations. *D. ovalifolium* and *S. guianensis* were replanted in their respective associations in order to investigate the effects of different grazing-management procedures.

Grazing periods were reduced from 42 to 28 days, and stocking rates were increased from 4.4 to 5.5 animals per ha during the rainy season, and maintained at 4.4 during the dry season, in pastures of *B. decumbens* + *D. ovalifolium* and *B. humidicola* + *D. ovalifolium*. These changes more efficiently use the high levels of available forage and prevent losses in the quality of the grass when the pasture remains ungrazed for longer periods.

The *C. pubescens* pasture is being maintained with the same 4.4 animals/ha and 28-day grazing and resting periods. Stocking rates for the associations *A. gayanus* and *S. guianensis* and *A. gayanus* and *C. macrocarpum* have been adjusted to 3.3 animals/ha and 20 to 28 days of grazing.

The new management has produced positive results in *B. humidicola* and *D. ovalifolium*. In seven months of grazing, animal gains passed the annual gains for the previous two years. Furthermore, individual gains are excellent at this time, and if this trend continues for the remaining four months of the year, it will be possible to reach levels up to 900 kg liveweight per year in this pasture. The sward is in excellent shape with a 40% legume intimately mixed with the grass.

The *Brachiaria decumbens* and *D. ovalifolium* pasture

Table 4. Preliminary results of animal production levels in five associations under grazing until Sept., 1985, Yurimaguas, Peru.

Associations	Stocking Rates		Animal Gains		Legume
	Rainy season	Dry Season	Kg/live weight/ha	gm-head/d	%
Brachiaria humidicola + *D. ovalifolium*[1]	5.5	4.4	697.6	597.6	40
B. decumbens + *D. ovalifolium*[1]	5.5	4.4	530.2	470.3	40
Centrosema pubescens 438[1]	4.4	4.4	399.4	419.8	100
A. gayanus + *C. macrocarpum* 5066[2]	3.3	3.3	387.2	751.4	20
A. gayanus + *Stylosanthes guianensis*[2]	3.3	3.3	282	641.8	60

[1] Grazing from January—September
[2] Grazing from May—September

is once again showing the problems observed in 1984. Although the grass appears to be doing well, the animals are grazing only the legume and making little use of the grass. This seems to indicate that this grass is very sensitive to drought stress normally occurring during the dry season. As a result, digestibility probably falls to levels preventing its consumption. Measurements will be conducted to test this statement.

Centrosema appears likely to maintain the animal productivity observed in 1984. The other two pastures have only six months of evaluation and it is too early to make any conclusions. *A. gayanus* + *C. macrocarpum* 5065 is well established with a 15% legume base.

Conclusions

1) To date, *Centrosema pubescens* 438 as a pure legume and the *B. humidicola* + *D. ovalifolium* mixture have provided the best pastures in terms of individual animal gains and kg/ha weight/ha.

2) The association of *B. humidicola* + *D. ovalifolium* performed well but had only two years of evaluation.

3) Exchangeable acidity has decreased and soil P levels have increased in most of the pastures during the course of this study.

4) Adjustments in stocking rates and grazing periods have improved the quality of grasses and made more efficient use of available forage in several of the grass-legume associations.

Potassium Dynamics In Legume-Based Pastures

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

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. Its objectives were 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.

The grazing experiment was a factorial of three annual rates of K fertilization (0, 50 and 100 kg K/ha) by two grazing pressures (11 and 7.8 kg green forage dry matter/100 kg liveweight), with three repetitions. Two additional experiments were established on 3 x 4 m plots with K rates of 0, 25, 50, 75, 100, 150, and 300 kg K/ha/yr. The first, 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

Table 1. Effect of cummulative rainfall on exchangeable K status of 0-5 cm layer in bare and clipped plots.

	Bare Plots		Clipped Plots	
	Cumulative Rainfall, mm		Cumulative Rainfall, mm	
K Rate	25	150	25	150
kg/ha	Exchangeable K, cmol/L			
0	0.07	0.06	0.07	0.07
25	0.16	0.09	0.10	0.07
50	0.26	0.12	0.15	0.16
75	0.28	0.14	0.17	0.18
100	0.32	0.18	0.18	0.19
100	0.42	0.29	0.25	0.24
300	0.78	0.47	0.61	0.48
LSD .05	0.09	0.28	0.09	0.28

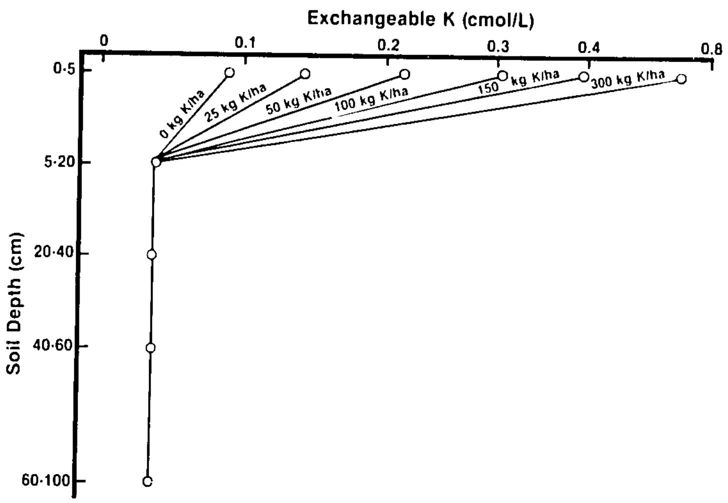


Figure 1. Effect of application of potassium on the distribution of exchangeable K in the profile of a sandy loam Ultisol, following 25 mm of rain.

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. Potassium distribution in the soil with depth was 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.

Exchangeable K Dynamics

The Ultisol in the experimental area was characterized as having a sandy loam topsoil texture, Al saturation of 74% and K contents of 0.06 cmol/L, far below the critical range of 0.15 to 0.20. Most of the K applied to the bare soil, however, remained in the top 5 cm, even though 25 mm of rain fell during application (Figure 1). After an additional 159 mm of rain, topsoil exchangeable K levels remained constant, except in plots receiving 300 kg K/ha, which lost 0.13 cmol K/L (Table 1). In the clipping plots, where the grass-legume mixture was growing rapidly, this decrease at the 300 kg K/ha rate was more pronounced (Table 1).

Pasture Response

Results of the first cut of the mixture growing in the small plots are presented in Table 2. Total dry matter was not affected by the potassium rates, although the content of the grass in the mixture tended to increase with K rate. Foliar K in the grass in-

Table 2. Effect of seven K rates on dry matter yields and uptake of Brachiaria humidicola and D. ovalifoliumb growing in association in an Ultisol of Yurimaguas, Peru (first cut).

K Applied	Dry Matter	Grass Component	Plant K Content		Total Uptake	
			Grass	Legume	*B.humidicola*	*D.ovalifolium*
kg/ha	g/m²	%	% K		kg/ha	
0	196.6 a	54	0.96 c	0.74 d	1.32	0.54
25	217.8 a	61	2.21 b	0.91 d	1.83	0.74
50	219.5 a	62	1.51 b	0.90 d	2.29	0.66
75	183.6 a	63	1.62 b	1.31 ab	1.80	0.93
100	201.5 a	51	1.65 b	1.06 bcd	1.72	1.04
150	229.3 a	59	2.19 a	1.24 abc	3.00	1.12
300	268.0 a	71	2.56 a	1.58 a	4.95	1.18
LSD	67.5	14				

Table 3. Effect of K applications on dry yields and botanical composition in a pasture of B. humidicola and D. ovalifolium before grazing.

K Applied	Dry matter Yield	Grass	Legume	K in Grass	K in Legume
kg/ha	t/ha	%			
0	2.51	53 a	47 a	0.98	1.02
50	3.03	65 b	35 b	1.51	1.29
100	2.95	68 b	32 b	1.72	1.38

creased with potassium applications, and the highest application rate multiplied foliar K 2.6 times the level found in grass with no K applied. Compared to the grass, the legume accumulated less foliar K in response to K fertilization.

The relation between the potassium content in leaves and dry matter yield was not consistent in either species, suggesting a high luxury consumption by the grass. Only at 300 kg K/ha was there an increase in dry matter of *B. humidicola*.

The effect of K fertilization on the growth and K content of leaves before grazing is shown in Table 3. As observed in the clipping plots, grass composed a larger share of the forage mixture when the pasture was fertilized with K. This was true under grazing, as well.

Animal Behavior

Grazing has shown an expected animal preference for the grass, regardless of the potassium level. Little consumption of the legume was observed, even at the higher grazing pressure. However, grass recovery after grazing was excellent, especially when potassium was present. After 86 days of grazing there was an overall increase of 36 kg per animal. Individual gains appear to be slightly better in the 50 kg K/ha treatment.

Conclusions

The first stages of this continuing study yield the following initial conclusions:

1) Rainfall did not significantly reduce exchangeable K in the topsoil except on plots with the highest rate of K fertilization (300 kg K/ha).

2) Plots receiving K showed an increased percentage of grass in the forage mixture.

3) Foliar K levels increased sharply with K fertilization in grass, but only slightly in the legume.

Pasture Germplasm Evaluation and Agronomy

Rolando Dextre, INIPA
Miguel Ayarza, N.C. State University
José M. Toledo, CIAT
Mario Calderón, CIAT
Jill Lenné, CIAT
Esteban Pizarro, CIAT

Twenty-three species of grasses and legumes have been tested for their adaptation to Yurimaguas conditions according to the methodology suggested by CIAT for regional trials type B. The objectives of these studies are 1) to introduce new acid-tolerant grass and legume accessions through regional trials and seed production, and 2) to evaluate tolerance to spittlebug in grasses and to anthracnose in legumes.

Species are harvested at four cutting intervals (three, six, nine and 12 weeks). Cover and resistance to pests and diseases are also recorded.

Yields at Cutting Interval

Figure 1 presents the effect of four intervals of cutting on four legumes and three grasses growing on an Ultisol at Yurimaguas. At the 12-week cutting interval, *Brachiaria dictyoneura* produced yields similar to those of *B. decumbens* and *Andropogon* species. Ground cover ability and vigorous growth of this species make it a promising grass for further evaluation under grazing. Among legumes, the *Centrosema macrocarpum* 5065, 5062, and 5452 appear to have potential for the Yurimaguas areas. Stable yields during dry and wet periods is an important attribute for their selection. *Centrosema pubescens* 5189 produces yields similar to those from the 438 ecotype, which is the most successful legume at present under Yurimaguas conditions. New *Desmodium* accessions have not shown superior yields to the 350 ecotype.

These species seem to require a minimum of six weeks to recover from cutting.

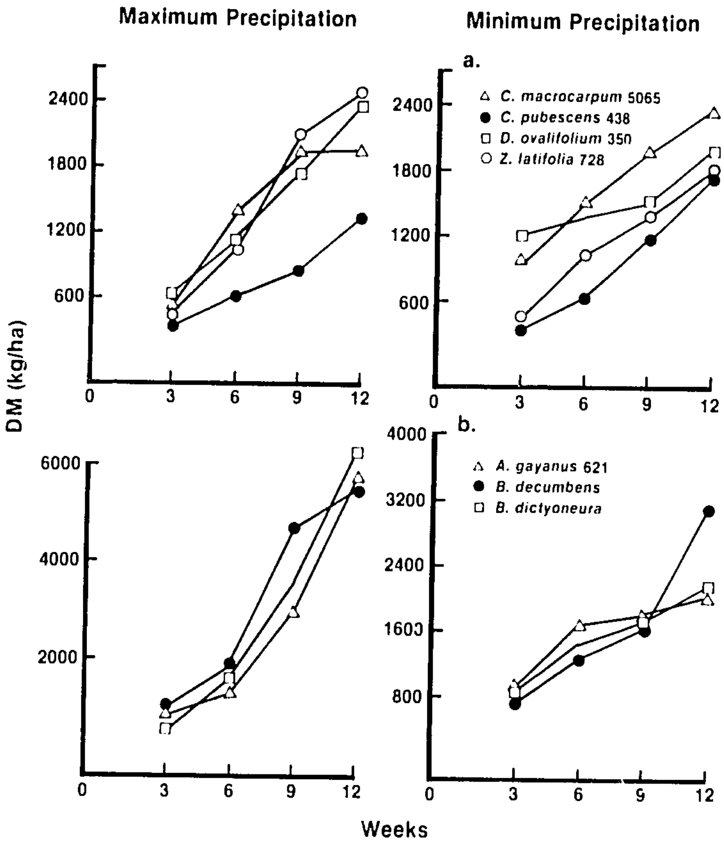


Figure 1. Effect of four intervals of cutting on four legumes (a) and three grasses (b) growing in an Ultisol of Yurimaguas. (Mean of two years.)

Seed Production of Promising Forage Species

Four grasses and five legumes, drawn from the most promising accessions described above, are under evaluation for their potential to produce seed, an important attribute of a good forage species. All grasses except *A. gayanus* have to be propagated vegetatively, as they do not produce viable seed under Yurimaguas conditions. Between four and five hectares could be planted with the available material of the *Brachiaria* accessions. Relatively good yield potential was observed for *Centrosema* accessions 5713 and 5452.

Tolerance to Pests and Diseases

Twenty-six accessions of *Stylosanthes guianensis* have been studied for tolerance to anthracnose and 26 ecotypes of *Brachiaria* have been studied for tolerance to spittlebug. Results after two years of observation indicate a wide range of tolerance to anthracnose in most *S. guianensis* species. Although the disease is present, it seriously affects only five accessions: 97, 1091, 1017, 1951 and 1893. *S. guianensis* 136 and 184 are the most tolerant accessions to this disease. Spittlebug does not appear to be a major problem in any of the species of *Brachiaria* under testing. High levels of infestation can be observed in *B. humidicola* pasture under grazing; however, there is no apparent damage.

Animal Preference

A new criterion was added to the *Brachiaria* accessions. Animal preference was tested in March, 1984 (rainy season) for a period of 18 hours using four animals. The entire area was fenced and the animals were left to graze after spending a night without food. The number of times the animal grazed each accession was recorded every 15 minutes and the total period of time the animals grazed each species are illustrated in Figure 2. Results indicate a difference in preference not only among species but also within species. *Brachiaria decumbens* 6009, *B. hybrid* 6298 and *B. humidicola* 629 were among the most preferred species. It is interesting to observe the low preference for *B. dictyoneura* accessions. A new evaluation is proposed for the dry season next year.

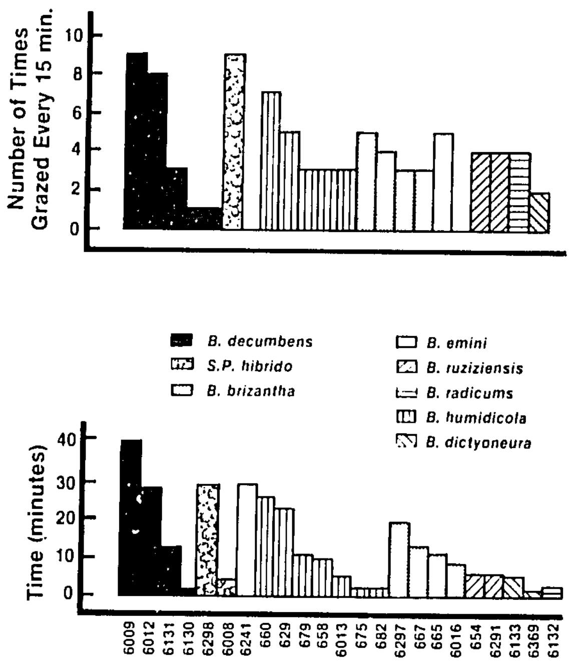


Figure 2. Animal preference for 26 brachiaria accessions ranked by number of times grazed every 15 minutes in 18-hour period, and by time animal spent grazing in 18 hours.

Pasture Reclamation in Steeplands

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

There is a substantial area of pasture land in the humid tropics that has very low productivity because of poor soil management, overgrazing or badly adapted forage species. The purpose of this project is to develop a simple technique for reclaiming degraded pastures in Ultisol steeplands.

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 forage crops grow). The only fertilizer was Bayovar rock phosphate, applied at the rate of 50 kg P/ha in the hole or furrow.

New-Project Update

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

Although data are not yet available, visual evaluation of the effect of treatments on the replacement of the native species (*torourco*) can be summarized as follows: The grasses, *Brachiaria humidicola* and *B. decumbens*, which are planted by vegetative propagation, are both well established, but *B. humidicola* appears to be better in the zero-tillage treatment. Both grasses have almost replaced the *torourco* between furrows in the minimum-tillage treatment.

The legumes tested, which were planted by seed, initially did not compete as well with the *torourco*. *Centrosema pubescens* 438 is doing better than *D. ovalifolium*, but both require some tillage before planting, in order to diminish competition for light and nutrients in the early stages of growth.

Evaluation of biomass production and percent cover of native grass is planned at four and eight months after planting. The information gathered so far suggests that some tillage is required to establish grass and legumes successfully.

Agroforestry Systems

Anyone regarding the luxuriant growth of a rainforest might gather that trees are the natural vocation of the humid tropics. Because a variety of commercially valuable species can succeed in this environment, agroforestry, the production of trees alongside crops or pastures, is an important soil-management option. In many cases, annual crops may be the wise choice for alluvial sites and soils with a high base status, while trees might be better suited to rolling, upland sites, where they require relatively little maintenance, tolerate acid soils, and afford long-term protection against erosion. Even so, most of the data available on tropical tree production are from areas with fertile soils. Collection and screening of the wide variety of germplasm available for use on acid soils have only begun.

Agroforestry projects at Yurimaguas are focused on tree-soil relationships on well-drained, acid soils. This work has been linked to agroforestry programs supported by INIPA, the International Council for Research in Forestry (ICRAF) and the International Development and Research Center of Canada (IDRC), and the principles being tested are expected to be applicable in the humid tropics world-wide.

The studies presented here have explored three general areas: 1) the selection and production of trees and shrubs valued for fruit and timber production or soil improvement; 2) the integration of trees and annual crops in systems such as alley-cropping; and 3) the role of secondary forest fallows in the improvement of soil properties. Because trees require months or years to become established and productive, these experiments are long-term, and some are in the earliest phases.

Trees as Soil Improvers In the Humid Tropics?

Pedro A. Sanchez, N. C. State University

It is commonly believed that trees are the best option for producing food and fiber on a sustained basis in the humid tropics. Because tree plantations resemble the natural ecosystem more closely than do annual crops, tree management might be expected to require fewer inputs. The accumulation of large amounts of biomass on acid, infertile soils, seemingly due to rapid and efficient nutrient cycling, suggests that tropical forests function in a fundamentally different way than do annual crops and pastures. It is not known if the same conditions exist in production-oriented tree crops. The objective of the activity reported here was 1) to bring together reliable information on the effects of deliberately planted tree crops on soil properties in the humid tropics, and 2) to develop working hypotheses for agroforestry research.

Available information on the effect of deliberately planted tree crops on soil properties in the humid tropics was compiled, examined, and, whenever possible, compared to alternative systems such as native forests, annual crops, pastures or fallows. Only data sets meeting a set of soil uniformity criteria were used in the analysis. A complete report has been published. (See publications list.)

Working Hypotheses

The main conclusions or working hypotheses are:

1. Tree crops make the soils initially more vulnerable to runoff and erosion than annual crops or pastures because of their lower rate of canopy development during the establishment phase.
2. The degree of changes in soil properties during the tree establishment phase depends largely on land-clearing methods.
3. Protection of the soil surface with well-managed leguminous covers during the tree-establishment phase can largely prevent deterioration of physical and chemical properties.
4. When trees close their canopy, they begin to exert four major positive effects on soil properties: (a) soil-surface protection with a double layer (canopy and litter); (b) opening soil pores via root expansion and decomposition; (c) capture of nutrients and storage in biomass, and (d) recycling nutrients back to the soil.
5. Closed tree canopies provide virtually complete protection against erosion unless the trees are deciduous, and provided the litter layer is not removed or burned.
6. Closed tree canopies tend to improve soil structure and decrease topsoil bulk density, but this effect varies substantially with tree species.
7. Closed tree canopies do not increase topsoil organic matter contents. In most cases, soil organic matter is maintained relative to pre-clearing levels. When products such as rubber or oil palm are harvested, soil organic matter decreases and then reaches a new equilibrium level.
8. Some tree species tend to increase topsoil Ca and Mg by mechanisms not clearly understood. The effect is marked with *Gmelina arborea*, which appears to be a calcium accumulator in Nigeria and Brazil. Exchangeable K often decreases to very low levels and may trigger deficiencies. Tree species differ in their ability to alter soil acidity.
9. Leaching losses occur mainly during the tree-establishment phase. When well managed tree plantatins develop a full canopy, leaching losses are as low as in undisturbed forests. The nutrient-cycling mechanisms of many perennial tree crops appear to be very efficient. Sometimes their efficiency is enhanced by fertilization.
10. Fertilization and other management practices are likely to be needed for second rotations of timber crops, as has been clearly demonstrated with perennial crops. Expectations are likely to be erroneous that sustained tropical forestry is possible in acid soils of the humid tropics without using fertilizers.
11. Trees, therefore, generally maintain or improve soil properties in the humid tropics after they have established a closed canopy. Maintenance can be initiated early with a leguminous cover. The main advantages of trees over annual crops or pastures seem to be related to the longer period of time during which they exert their influence on soil properties.

Alley-Cropping on Ultisols

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

In areas with increasing demographic pressure, traditional forms of shifting cultivation must be supplanted by production systems that yield more food on the available land. One technique, shown to be promising in Alfisols of West Africa, is the combination of rows of leguminous trees with annual crops grown between them. Prunings from the trees form a mulch that may aid in weed control and provide nitrogen and other nutrients, cycled from deep in the soil, to the crops. The use of such organic additions may prolong the productivity of the acid, infertile soils found in much of the humid tropics.

This study was conducted at the Yurimaguas Experiment Station. Its objectives were: 1) to assess the suitability of various leguminous trees or shrubs in an alley-cropping system, an assessment based on survival, biomass production, ability to withstand repeated prunings, and litter-decomposition characteristics; 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 stability.

Six leguminous species were chosen: *Inga edulis*, *Erythrina* sp. *Cajanus cajan*, and *Cedrelinga catenaeformis* were obtained locally while *Leucaena leucocephala* and *L. diversifolia* were obtained from the Nitrogen Fixing Tree Association (NFTA) in Hawaii. *Cedrelinga* was replaced in late January, 1985 by *Desmodium gyroides*, direct-seeded.

Most species were raised from seed in the nursery and after four to six months were transplanted (October 1984) to a field that had been slashed, burned and planted with rice.

An experiment was established with variable alley spacings, using a randomized, complete-block design and four replications. Three rows of trees were planted in 9.5 x 23 m plots; the middle tree row was periodically staggered to provide six different intervals between adjacent tree rows. These intervals accommodate two to seven rows of annual crops (Figure 1). All the trees in each plot received one of three fertility treatments: 1) none, 2) two tons lime/ha or 3) two tons lime + 100 kg P/ha, which were applied once, on an equivalent-area basis, only to the 1 m wide tree rows. In March, 1985, some of the trees showed signs of K deficiency. Therefore, 100 kg K/ha was applied on an equivalent-area basis to the 1 m wide tree rows in the lime + P treatment in both experiments. The alley crops receiving K were *Cajanus*, *Inga*, and *Erythrina*.

Food crops were grown between the tree rows, without direct fertilization and at a constant spacing within and between rows. The checks were two additional treatments of crops grown without trees — "sole" crops, with and without fertilization. Soil chemical properties were monitored after each crop harvest.

Trees were pruned before each planting or soon thereafter, and during crop growth as needed. Pruning biomass was measured and subsamples taken to measure dry matter and nutrients. Prunings from the plot were divided into six equal parts; each part was spread over one spacing interval. Therefore, the amount of prunings per area varied with each spacing.

Weed biomass was measured approximately two weeks before every crop harvest. Crop yield was initially recorded by row position and fertility level. Subsequently, yield data were obtained by spacing interval, row position and fertility treatment.

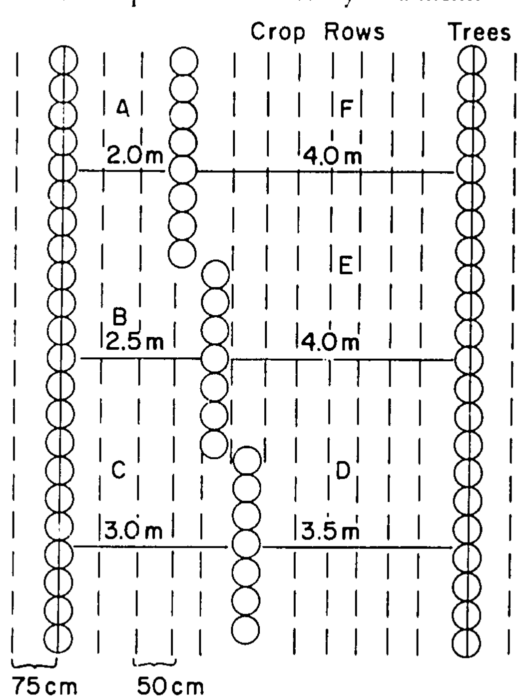


Figure 1. Plot design, variable spacing plots of alley-cropping experiment. Capital letters identify spacing treatment.

The first rice crop was harvested in February 1984. Most of it was severely infected with rice blast caused by *Pyricularia oryzae* and was left in the field.

Pruning of *Cajanus* began in March 1984; of *Inga* in August 1984; and of *Erythrina* in April 1985. *Cedrelinga* was eliminated in January 1985 and replaced with *Desmodium gyroides*. By April 1985, biomass production and growth of the two *Leucaena* species were poor. At this time, the average tree height per plot was estimated, all plants were pruned 1 m above the soil, pruning yields were measured, and the prunings were placed around the trees.

L. leucocephala yielded 576, 667, and 859 kg of dry prunings per hectare for the no-input, lime, and lime + P treatments, respectively; *L. diversifolia* prunings averaged 481, 384, and 438 kg/ha for the same treatments. While in some cases vertical growth was good, reaching over three meters, the majority of the plants appeared spindly, without much foliage. The *Leucaenas* have subsequently been eliminated from the experiment.

By mid-August 1985, *Cajanus* had been pruned four times; four crops (corn, cowpea, rice, and rice) were harvested from these plots. *Inga* had been pruned four times also; three crops were harvested (cowpea, rice, and rice). *Erythrina* had been pruned once and one rice crop was harvested.

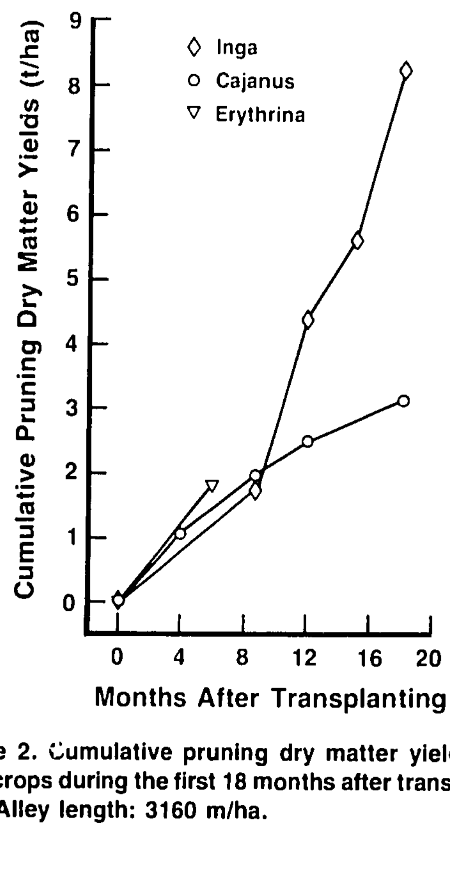


Figure 2. Cumulative pruning dry matter yields of alley crops during the first 18 months after transplanting. Alley length: 3160 m/ha.

Pruning Yields

Cumulative pruning yields of the alley-crop species, averaged over fertility treatment and replications, are shown in Figure 2. Yields, based on 3160 m of tree-row length per hectare, are 8.3 tons of dry matter per hectare for *Inga* and 3.1 t/ha for *Cajanus*. *Erythrina* has been pruned only once, producing slightly higher biomass than *Inga* and *Cajanus* at six months of age.

There was no response to lime additions, but the lime + P treatment, in comparison with the no-input treatment, yielded approximately 8% more prunings in *Inga* and 6% for *Cajanus*. *Erythrina* appears to respond to P. The lime Ca + P treatment yielded 625 kg or 38% more prunings than either the no-input or the lime treatment. In addition, there appears to be a positive response to increases in the clay content of the topsoil in all alley-crop species.

The rate of biomass production by *Inga* appears fairly constant over time and averages 8.7 t/ha/yr after the first pruning. In contrast, *Cajanus* production averages 1.8 t/ha/yr and appears to decline with time. Much of this decrease is due to plant senescence. By January 1985, only about 65% of the original *Cajanus* plants were still alive, indicating the need for continual replacement. Because of different establishment practices, some species were ready for a first pruning before others.

The decomposition characteristics of the prunings differ by species. *Erythrina* prunings decompose rapidly; few last longer than one month. A significant proportion of the *Inga* prunings, on the other hand, can still be observed after three months. The decomposition rate of *Cajanus* prunings is intermediate to those of *Erythrina* and *Inga*.

Weed Control and Biomass

Weeds were controlled by herbicide use prior to planting and hand weeding during the crop, as needed. Herbicide application before planting was the only form of weed control used in the corn and cowpea crops. Weeds in the first rice crop following cowpea were controlled with preplant herbicides and two hand-weedings; in the subsequent rice crop, all treatments received preplant herbicides and one hand-weeding. In addition, the *Cajanus* and control plots required a second hand-weeding.

Due to the weed-control regimens used, and the different lengths of time plots have been in cultivation, the most appropriate comparisons of weed-biomass data are within alley-crop species.

A comparison of weed biomass by spacing subplot for the most recent sampling (7/85) shows surprisingly little relation between subplot and weed biomass (Table 1). It might be expected that weed levels would be lowest at the closest spacing due to shading and a greater mulch concentration, especially in the case of *Inga*, which has a long-lasting mulch. The data, however, do not appear to support this hypothesis.

There is a suggestion that weed biomass decreases with closeness to the tree rows and that the reduction is likely due to shading. The effect appears to be less pronounced in the *Cajanus* than in the *Inga* treatments, presumably due to less biomass and less shade production in the former.

For each alley-cropping species, there appear to be significant differences in weed biomass among replications, but the pattern over time is variable and difficult to explain.

In general, weed biomass is usually higher in the untilled, unfertilized control plots than in the alley-cropping treatments. It is also interesting to note that fertilization was related to decreased weed biomass in all sole-crop checks.

As might be expected, the effectiveness of weed control by the prunings is less pronounced in *Cajanus* than *Inga* due to the reduced quantity of *Cajanus* mulch produced. One should note that similar levels of weed biomass were measured for the *Inga* and *Cajanus* treatments (7/1985), despite an additional hand weeding in the *Cajanus* plots requiring approximately 60 man-hours of labor.

Soil Chemical Properties

In general, topsoil chemical properties degrade with time after burning. Exchangeable cations and available P decrease while acidity and exchangeable Al increase, for all treatments with the exception of the fertilized check. There are only minor differences between the unfertilized check, *Cajanus*, and *Inga* treatments. The *Inga* plots have slightly higher levels of Ca + Mg and K, but they have also been used for one less crop than *Cajanus*. Both *Inga* and *Cajanus* have slightly higher levels of soil organic matter than the unfertilized check.

In an attempt to further define whether mulch additions affect soil chemical properties, the soil was sampled in March 1985 by spacing sub-plot (six composited samples per plot) for the *Cajanus* and *Inga* treatments. Data for the closest and farthest spacings for each species are shown in Table 2. For *Inga*, the closest spacings, which have received 1.75 times more pruning dry matter than the widest spacings, have slightly higher levels of exchangeable Ca, Mg, and K. The closest spacing for *Cajanus*, on the other hand, has virtually the same soil nutrient levels as the widest spacing. The topsoil base status under *Inga* is higher than under *Cajanus*, and it appears that, at least in the case of *Inga*, there is some slight improvement in soil properties.

Crop Yields

Crop yields have been adversely affected by insects, disease and weather. Consequently, yields are low, bear

Table 1. Weed biomass as affected by alley crop species and by spacing sub-plot, July 1985.

Tree spacing	Alley crop species		
	Cajanus	Inga	Erythrina
m		g/m²	
2.0	40 ± 34	35 ± 39	87 ± 43
2.5	20 ± 26	42 ± 32	65 ± 55
3.0	37 ± 24	47 ± 30	48 ± 21
3.5	43 ± 42	40 ± 26	58 ± 23
4.0	39 ± 27	51 ± 33	57 ± 34
4.5	32 ± 15	36 ± 27	89 ± 61

Table 2. Effect of alley crop species and mulch application rate on topsoil chemical properties 18 months after planting tree crops (3/85).

Alley crop species	Alley spacing	Mulch added	pH	Exchangeable Al	Ca	Mg	K	ECEC	Al Sat.	Avail. P
	m	t/ha/18 mos.				cmol/L			%	ppm
Cajanus	4.5	2.6	4.5	1.6	0.64	0.16	0.07	2.47	65	8
	2.0	4.5	4.5	1.4	0.65	0.16	0.07	2.28	61	9
Inga	4.5	6.9	4.6	1.6	0.85	0.18	0.10	2.73	59	7
	2.0	11.8	4.6	1.5	1.03	0.23	0.13	2.89	52	8

little relation to treatments, and are probably not interpretable. In general, row position appears to have an effect on yield, but it is uncertain whether these differences are significant. The data suggest that, with rice and cowpea, yields increase with distance from the tree rows. It may be too early in the cropping sequence to identify meaningful patterns. Furthermore, since soil texture seems to affect yields, covariance techniques may be necessary to pick out trends in yield.

Conclusions

1. Of the six original leguminous trees or shrubs assayed in an alley-cropping system, *Leucaena leucocephala*, *L. diversifolia*, and *Cedrelinga catenaeformis* have been eliminated due to poor survival and low biomass production. *Cajanus cajan* is also unsuitable due to increased plant senescence and decreased productivity at about one year of age.

2. Both *Inga edulis* and *Erythrina* appear to have good survival and coppicing ability. *Inga* biomass production is high (8.3 t dry matter/ha/yr, based on 3160 m of tree-row length per hectare); *Erythrina* production must be assessed for a longer period. *Cajanus*, *Inga* and *Erythrina* production appears to respond to P fertilization.

3. *Inga* prunings resist decomposition, *Erythrina* prunings are readily decomposed, and *Cajanus* prunings are intermediate in their rate of decomposition.

4. Weather, insects and disease severely reduced crop yields and made them for the most part uninterpretable.

5. A correct comparison of weed levels can only be made among spacings within a given alley-crop species in this study. There appears to be little relation between weed biomass and spacing/mulching.

6. Soil chemical properties decline with time and are similar in all alley-crop treatments and in the unfertilized check. Soil chemical properties have improved in the fertilized check. Comparisons of the highest and lowest pruning-addition levels show increases in exchangeable cations at the highest mulching rates for *Inga* and no difference between rates for *Cajanus*.

New work in this project will investigate the effect of mulching, nutrient transfers between prunings and crops, the effects of different types of prunings, and competition between the trees and crops.

Peach Palm as a Soil Management Option on Ultisols

Jorge Perez, INIPA
Charles B. Davey, N. C. State University
Robert E. McCollum, N. C. State University
Beto Pashanasi, INIPA
José R. Benites, N. C. State University

The production of peach palm, *Guilielma gasipaes*, has several advantages as a management option for the Amazon Basin. It is indigenous and adapted to acid soils, does not require yearly tillage, has been known to remain productive for 20 years, and has potential as a source of fruit, heart of palm and lumber for parquet. Results from peach palm experiments established at Yurimagaus in 1980 indicate that the crop can produce fruit at the rate of 15 ton/ha/yr, beginning with the fifth year. At present prices (U. S. $0.17/kg fruit), gross proceeds from a peach palm plantation producing 15 ton/ha/yr would be about $2600/ha/yr. Although prices would vary with production and market conditions, the economic potential of peach palm appears to compare favorably with paddy rice production on alluvial soils, the most economically attractive option in Yurimaguas so far. Because of this potential, several projects related to peach palm production have been conducted at the Yurimaguas Experiment Station.

Collection and Propagation

The objectives of this work were 1) to collect and maintain a permanent collection of spineless-trunk and spiny-trunk peach palm germplasm from Amazonia nations in order to improve certain characteristics for higher agronomic value, and 2) to establish a phenological calendar for each accession.

Yurimaguas is a center of origin for spineless-trunk peach palm. Over 120 spineless accessions have been collected in the area, varying considerably in fruit characteristics. In addition, 80 spiney-trunk accessions in an international collection from Brazil, Colombia and Ecuador have been planted in an area sufficiently distant from the spineless collection to prevent cross-pollination.

Peach palm accessions have been planted in two agroforestry sequences. The spineless collection had an upland rice-cowpea rotation, while the spiny one was interplanted with cassava, which yielded 10-30 ton/ha. After the cassava harvest, a ground cover of *Desmodium ovalifolium*, was established.

The range in nutritional composition of fruits collected around Yurimaguas is shown in Table 1. It has higher mean protein content than sweet potatoes with comparable values. The range indicates the possibility of selecting fruits with very high protein or fat contents.

Nutritional Requirements of Peach Palm

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 (Table 2). 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 (Table 3). There was also a clear response to 2 kg Zn/ha the third year.

Cover Crops in Plantations

This project's objective was to observe the effect of different leguminous ground covers on peach palm development and production. Peach palms were planted in October, 1980 at 5 x 5 m spacing in a 0.7 ha plot. Four legume covers were planted in February, 1982, in strips without replications. The legumes were: *Pueraria phaseoloides* (kudzu), *Desmodium heterophyllum*, *D. ovalifolium* and *Centrosema* hybrid 438. Two of the legumes *D. heterophyllum* and *Centrosema* had disappeared, apparently because of drought and shade, despite the fact that sunlight passed through the peach palm canopy. The other two legumes were well adapted, and began invading adjacent areas. Each produced dry matter of about 800 kg/ha/yr.

Legume ground covers showed no significant differences in their effect on tree growth. After 28 months, peach palm trunk diameter breast height (DBH) ranged from 17.4 to 18.5 cm, and height ranged from 5.0 to 6.1 m.

Three-year topsoil samples show sharp increases in acidity and base depletion. No fertilizers or lime have been added to this field to date.

Table 1. Nutritional composition of peach palm fruits collected around Yurimaguas. Fresh-weight basis.

Parameter		Mean	Range		
Carbohydrate	(%)	33	23.4	-	42.6
Water	(%)	56	52	-	72
Protein	(%)	4.7	3.0	-	12.8
Fats	(%)	6.1	0.7	-	20.0
Ash	(%)	0.9	0.51	-	1.11
Fiber	(%)	1.0	0.56	-	1.02
Energy	(cal/100gr)	194	126	-	281
Ca	(mg/100gr)	45	27	-	86
P	(mg/100gr)	102	41	-	166
Fe	(mg/100fr)	2.8	0.7	-	8.0
Thiamin	(mg/100gr)	0.03	0.007	-	0.042
Riboflavin	(mg/100gr)	0.063	0.006	-	0.216
Niacin	(mg/100gr)	0.455	0.150	-	2.08

Table 2. Effect of applied N on the growth in height of peach palm.

	Applied N (kg/ha)			
	0	50	100	200
Tree age (years)	Tree height (m)			
One	0.6	1.0	1.2	1.2
Two	1.8	2.3	3.1	4.1
Three	2.6	5.5	7.1	7.4

Table 3. Effect of applied K on the growth in height of peach palm.

	K Applied kg/ha			
	0	50	100	200
Tree age (years)	Tree height (m)			
One	0.8	1.0	1.0	0.8
Two	2.2	3.4	3.4	3.2
Three	5.8	7.0	6.8	4.6

Gmelina arborea: Intercropping, Coppicing and Nutritional Requirements

Jorge Perez, INIPA
Charles B. Davey, N. C. State University
Robert E. McCollum, N. C. State University

Gmelina arborea is a promising, fast-growing timber species for the humid tropics. The first stand in Yurimaguas was planted in April 1981, and several experiments were conducted in order to evaluate *Gmelina*'s potential in agroforestry, including systems of intercropping. The objectives of the experiments reported here were 1) to observe the effects of ground covers on growth and coppicing behavior of *Gmelina arborea*, and 2) to determine this tree's response to applications of N, P, K, Mg, lime and Zn.

Effects of Understories

Gmelina planted at a 3 x 3 m spacing grew quickly and reached a height of over 7 m with a 10 cm diameter at breast height (DBH) in three and a half years (Table 1). *Gmelina* did not grow significantly less when pineapple, plantain, or a rotation of three annual crops were raised in its understory. Tree growth was retarded by cassava and the legume species, and stunted by the grasses. The effect of the *Brachiaria* was so severe that it may be allelopathic.

Table 1. Effects of understories on the growth of *Gmelina arborea* 3.5 years after planting.

Understory	Diameter at Breast Height	Tree Height
	cm	m
None	10.0	7.4
Pineapple	11.8	7.3
Corn-rice-soybeans	11.3	6.8
Plantain	9.1	7.0
Cassava	8.5	5.3
Pueraria phaseoloides	9.7	5.9
Desmodium ovalifolium	8.9	5.7
Desmodium heterophyllum	7.8	5.6
Brachiaria decumbens	7.9	5.8
Brachiaria humidicola	6.7	5.3

Soil Properties

This experiment was installed in an area which was limed to pH 5.5. With time, soil acidity increased and available P declined. Reports from other regions suggest that *Gmelina* is a topsoil-calcium accumulator. Although soil tests do not provide evidence of this happening up to this time, analysis of leaves reveals a very high Ca content, about triple that of pasture grasses and leguminous plants grown at Yurimaguas.

Coppicing Behavior

When the trees were five years old, they were cut and allowed to coppice. A cutting height variable was introduced but did not show any influence on the growth of sprouts. The remarkable aspect is the rate of regrowth—3 m in 60 days. An upland rice crop planted in the area grew so poorly that no yield was produced. Apparently the stump regrowth was too competitive for water and perhaps nutrients.

Nutritional Requirements

The *Gmelina* fertilization experiment was planted in November, 1982 on an Ultisol at pH 4.3 and 75% Al saturation in the top 15 cm. Trees were spaced at 3 x 3 m. During the first year, trees attained an average height of 4 m and a DBH of 3.6 cm. Eighteen months later, average height reached 9.7 m (a growth rate of 32 cm per month) and DBH reached 11.2 cm. By the third year, the canopy had closed, impeding the growth of weeds. Damage by leaf-cutting ants continues, but is not critical. *Gmelina arborea* is susceptible to dry periods greater than 60 days. Such droughts cause a general chlorosis and strong defoliation.

No significant responses to N, P, K, Mg, Zn and lime have been observed. Variability in growth is primarily related to areas that are poorly drained.

Contrasting Effect of *Pinus caribaea* and *Gmelina arborea* on Soil Properties

Pedro A. Sanchez, N. C. State University
Charles E. Russell, Institute of Ecology, University of Georgia

Reliable data are scarce on soil-fertility dynamics under fast-growing timber species in the humid tropics. This project was conducted to complement thesis research by Charles E. Russell of the University of Georgia, who sought additional soils data to quantify the influence of *Gmelina arborea* and *Pinus caribaea* plantations on soil properties of Typic Paleudults at Jari Florestal Agropecuária in the state of Pará, Brazil. The discussion that follows draws on his thesis and laboratory analysis conducted at N.C. State University.

Gmelina arborea significantly increased soil pH and exchangeable Ca in the top 1 m of this soil, while *Pinus caribaea* decreased these parameters as well as available P, exchangeable K, Mg and total N (Figure 1). A synthesis of the changes in total nutrient stocks during the course of plantation establishment and growth is presented in Figure 2. Total nutrient stock is defined as the sum of all the nutrients in the plant biomass (aboveground, litter, detritus, roots) plus total N, available P (by the Mehlich I method), and exchangeable K, Ca, and Mg in the top meter of the soil. This estimate, therefore, ignores the total P, Ca, Mg, and K contents of the soil.

Total plant biomass decreased to about 40 to 60% that of the virgin rainforest at the end of the first rotation of *Gmelina* or *Pinus*. Most of the losses are quantitatively accounted for by the newly planted trees and the dry matter extracted by harvest.

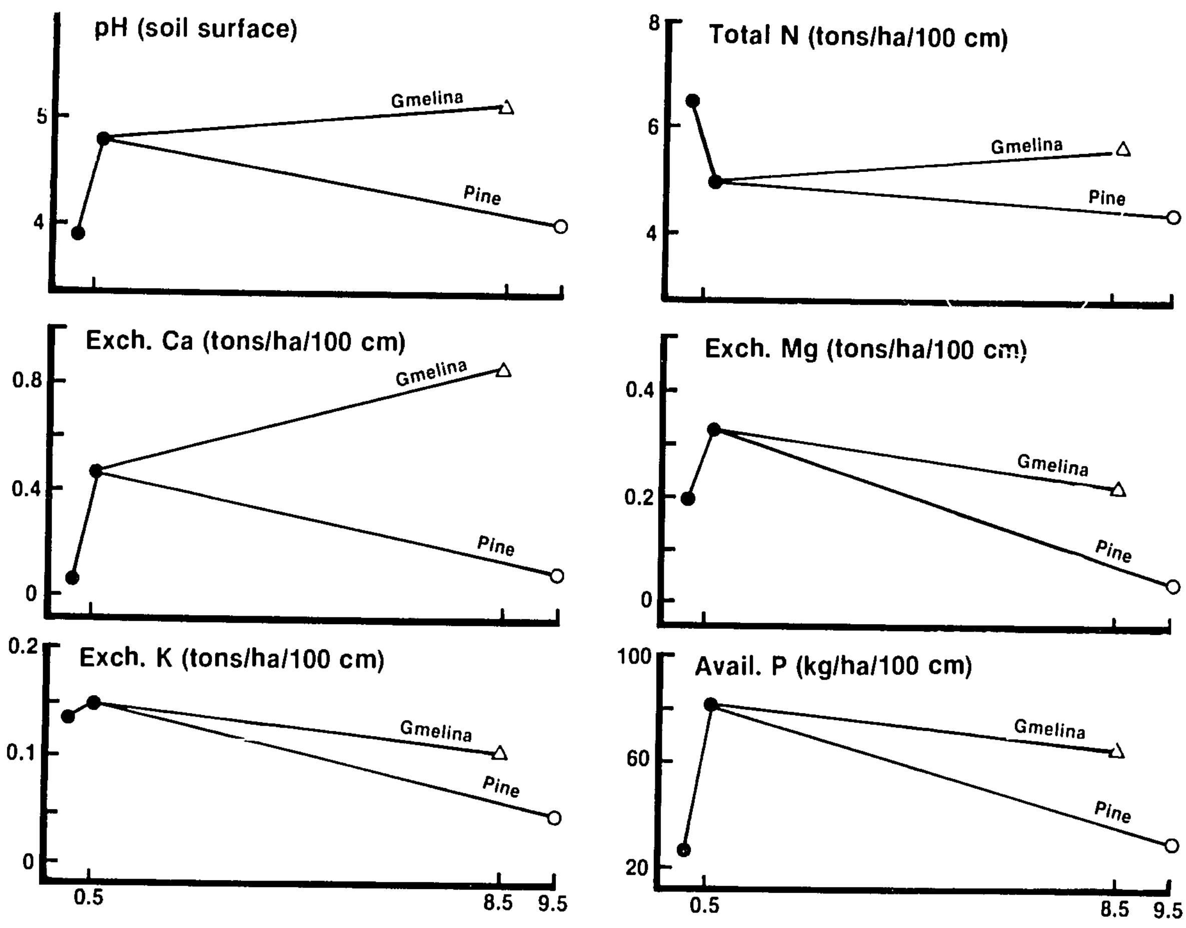


Figure 1. Effects of *Pinus caribaea* and *Gmelina arborea* plantings on surface soil pH and nutrient content of the top 1 m of a sandy Ultisol in Jari, Brazil.

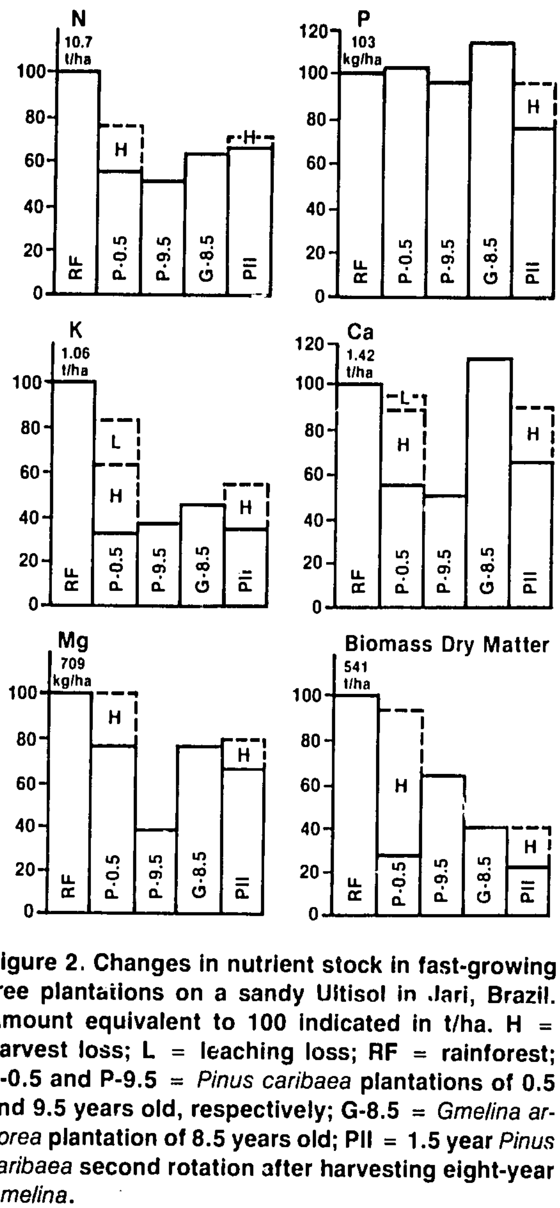


Figure 2. Changes in nutrient stock in fast-growing tree plantations on a sandy Ultisol in Jari, Brazil. Amount equivalent to 100 indicated in t/ha. H = harvest loss; L = leaching loss; RF = rainforest; P-0.5 and P-9.5 = *Pinus caribaea* plantations of 0.5 and 9.5 years old, respectively; G-8.5 = *Gmelina arborea* plantation of 8.5 years old; PII = 1.5 year *Pinus caribaea* second rotation after harvesting eight-year *Gmelina*.

Nutrient Stocks

The plantations, of all ages, contained approximately 60% of the total N stock of the rainforest. Most of the decrease in N occured at clearing. Because none of the plantation trees were legumes and no legume cover crops were used, no N buildup occurred. The ecosystem, therefore, lost 40% of its total N, and then reached a new equilibrium.

A remarkable conservation of P is shown in Figure 2. Nutrient stocks ranged from 76 to 116% of the rainforest values. The decrease in P at the second rotation is largely accounted for by the P removed in the first rotation harvest. These values reflect only the fraction of total P extracted by the Mehlich procedure. Calculations from total elemental analysis of soils of the Amazon by Marbut and Manifold in 1926 indicate an average total P content of the top meter on the order of 60 times the total P stock indicated in Figure 2.

Significant losses of K occur when rainforests are converted into tree plantations. Potassium stocks after clearing decreased to about 32% those of the native forest. Most of the losses are accounted for by the removal of harvested trees and the rapid leaching losses recorded during this period. After clearing, there were slight increases to about 40% of the rainforest value. The overall stocks and losses of exchangeable K presented in Figure 2 (1.06 t/ha), however, are small considering the total K content of these soils, estimated at 73 t/ha of K (Marbut and Manifold, 1926). It is not surprising that research on perennial crops such as rubber and oil palm on Ultisols shows rapid depletion of K and the need to fertilize the trees with this element.

The calcium nutrient stock decreased to about 56% of the rainforest value upon planting the first *Pinus* rotation. The losses were again accounted for by harvest and slight leaching. This level remained relatively stable with *Pinus* but increased to above pre-clearing levels with *Gmelina* (Figure 2). The second rotation started at a lower level, but much of the loss was related to the amount removed by *Gmelina* harvest. Losses were slight compared to the total Ca in the top meter, about 13.6 t/ha.

The magnesium nutrient stocks decrease with age of *Pinus* plantations, but mature *Gmelina* plantations maintained a steady level of about 75% of the level in the rainforest. The 25% loss appears to be related to the harvest of the rainforest. The overall losses are small relative to the total Mg content of these soils, about 14.4 t/ha of Mg at the 100 cm depth.

Improved Fallows

Lawrence T. Szott, N. C. State University
Charles B. Davey, N. C. State University
Cheryl A. Palm, N. C. State University
Pedro A. Sanchez, 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. The purpose of this project, which was conducted at the Yurimaguas Experiment Station, was to determine whether productivity in such fields might be regenerated more rapidly with the use of selected, high-biomass, nitrogen-fixing fallow species, and to measure the effects of these species on soil physical and chemical properties, weed supression, and, subsequently, crop yield.

A one-hectare, 15-to-20-year-old secondary forest on a loamy topsoil and clay loam subsoil was cut, burned, and planted with upland rice using traditional methods in August 1983. The rice was harvested in January 1984, and the following treatments were installed in 100 m² plots, with four replications, in a randomized complete block design: Natural purma (secondary vegetation); *Cajanus cajan; Inga edulis; Stylosanthes guianensis 136; Centrosema macrocarpum; Desmodium ovalifolium 350; Pueraria phaseoloides* (kudzu); high-input cropping check (fertilization and mechanization); low-input cropping check (without fertilization or mechanization).

Changes in soil and vegetation properties during the first 16 months after fallow establishment are reported. The experiment will be continued for at least 32 additional months, after which the plots will be prepared for low-input crop rotations. Crop harvest data will be used to assess fallow performance.

Discussion

Fallows may restore the productivity of abandoned agricultural land by one or more of the following: 1) enrichment of the topsoil-vegetation system by retaining nutrients added in rainfall, dust, or mineral weathering, or by direct contributions from N_2 fixation or the recycling of nutrients from the subsoil; 2) improvement in soil physical properties; 3) control of weeds.

Aboveground Living Biomass

The importance of possibility (1) can be ascertained through the construction of a nutrient budget for the topsoil-vegetation system. While complete soil and plant-tissue nutrient analyses are presently lacking, it is worthwhile to consider biomass accumulation, since nutrient immobilization is a function of both the quantity of biomass and its nutrient concentration. Consideration of the planted-fallow biomass only shows that there is little difference among treatments after 16 months. On average, living aboveground biomass approaches 7.5 t/ha; kudzu accumulation is about 2.5 t/ha lower, and that of *Desmodium* 2 t/ha greater (Figure 1). There are, however, differences in the rate of biomass accumulation. *Stylosanthes* and *Cajanus* production, for example, is concentrated in the first eight months; that of *Centrosema* and *Desmodium* appear linear with time; and a large part of the *Inga* and kudzu accumulation occurs between eight and 16 months.

Measurements of total living aboveground biomass (planted fallow plus other vegetation), on the other hand, show treatment-related differences (Figure 2). At 16 months, *Desmodium* has outperformed the natural purma, wile the *Inga* and *Cajanus* treatments are about equal to it. The biomass of the "spreading" type fallows (kudzu, *Centrosema*, and *Stylosanthes*) is much lower. The difference between the two groups is due to the presence of non-planted fallow vegetation, primarily trees, bushes, and lianas. This vegetation is naturally excluded from the "spreading" fallows, but has readily invaded the tree or bush fallows. It is noteworthy that at 16 months after establisment,

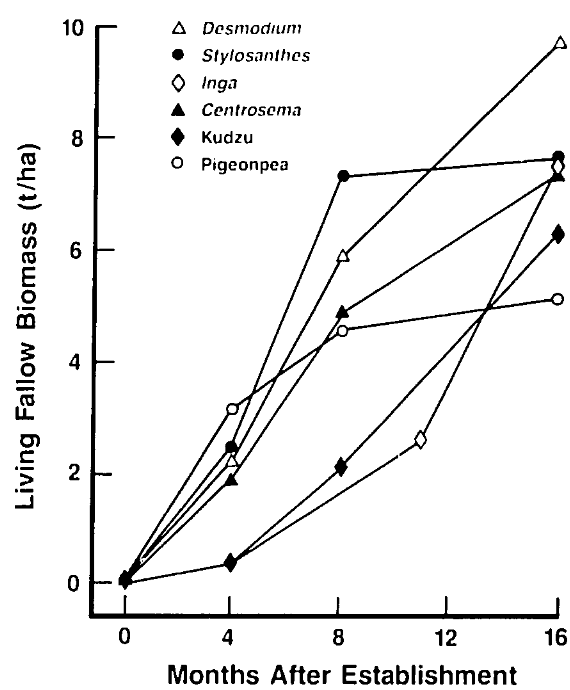
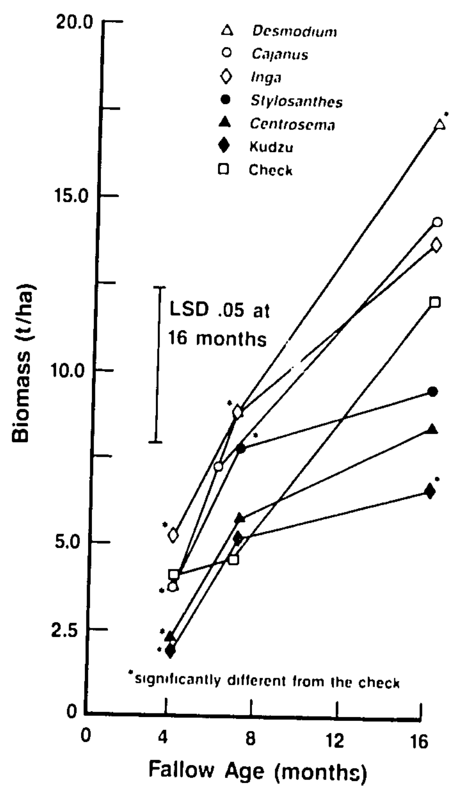


Figure 1. Living aboveground biomass of planted fallows.

weed (grass and broad-leaf herbaceous plants) populations are low in all treatments and are lower in the planted fallows than in the natural fallows.

Root Biomass

The pattern of root-biomass accumulation at 16 months parallels that of aboveground biomass (Table 1). No planted fallow has a greater root biomass than the natural purma, although the *Inga* and *Cajanus* fallows are similar to it. In general, the "spreading" type fallows have much less root biomass. Kudzu root biomass, for example, is only about 40% that of the natural purma. The large root biomass observed in the *Stylosanthes* treatment is due to the presence of a large root (>10 mm in diameter) remaining from the previous forest. If this root is discounted, root biomass for *Stylosanthes* is similar to that of the other "spreading" fallows.



ure 2. Total living aboveground biomass accumulation in fallow treatments.

The quantity and distribution of fine roots, most active in water and nutrient uptake, should also taken into account. Moreover, their presence in significant quantity in the subsoil may indicate nutrient "pumping," one means by which the topsoil-vegetation system may be enriched.

In general, fine root (< 3 mm in diameter) biomass comprises around 85% of the total root biomass, although this proportion is only 65% in the natural purma. Again, fine root biomass patterns parallel aboveground biomass—treatments with great aboveground biomass also have greater fine-root biomass. The majority of fine roots are found in the upper 15 cm of the soil for all species (Figure 3). Significant quantities (~ 700 kg/ha) of fine roots, however, are also found in the subsoil in the *Inga, Cajanus*, and natural purma treatments. The *Centrosema* and *Desmodium* treatments contain about 500 kg of fine roots per hectare, and the *Stylosanthes* and kudzu fallows approximately half that much. Hence, the possibility for recycling nutrients from great soil depths appears limited for the *Stylosanthes* and kudzu fallows.

Vegetation Structure

The speed of leaf-canopy development has a number of important consequences. The development of the photosynthetic machinery affects vegetative growth rates and concomitantly water and nutrient uptake, while canopy formation reduces rainfall impact and

Table 1. Total Root Biomass, by Treatment and Depth.

Soil Depth cm	Treatments kg/na						
	Centro	Stylo	Inga	Cajanus	Kudzu	Desmo	Check
0-5	1074ab	585 b	748 b	1268ab	949ab	998ab	2014a
5-15	576 b	1776a	1019ab	478 b	262 b	621 b	891ab
15-30	256	768	499	457	134	399	297 ns
30-50	234	383	543	515	110	170	563 ns

Treatments significantly different (0.05) from the check at given soil depths are shown by different letters.

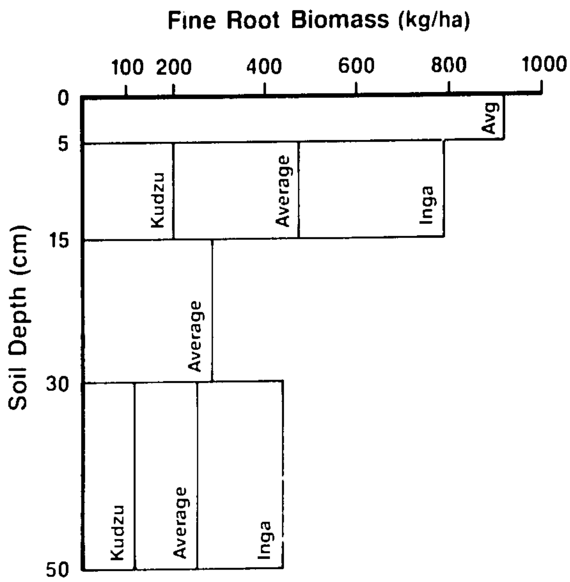


Figure 3. Fine root (less than or equal to 3 mm diam.) with soil depth. Treatments differing significantly (.05) in fine root biomass, at given soil depths, are shown. The average biomass is shown when there are no significant differences when comparisons are made across treatments.

the potential for erosion, as well as moderating the soil microclimate. Indicators of foliage development are the leaf-area index (LAI) and the percentage of ground cover.

In general, LAI correlates well with increasing biomass, although *Centrosema* and the natural purma have lower LAIs at 16 than at eight months, and ranges between four and eight at 16 months. It is also notable that all fallows develop a fairly high LAI (LAI = 5-6) and an almost complete ground cover within four to eight months after establishment for all fallows.

Soil Physical Properties

Soil physical properties are affected by vegetation growth and development and associated changes in the physical environment. Changes in soil physical properties are shown in Table 2. Bulk density, while increasing in the first eight months after field abandonment, appears to decrease to pre-cultivation levels by 16 months. Generally, the treatments with a high fine-root biomass (purma, *Cajanus*, *Inga*) have lower bulk densities than those with little fine-root production (kudzu). These differences are not statistically significant, however.

Field capacity (see Table 2) was measured in the field 24 hours after fairly heavy rainfalls. Depending as it does on the amount and intensity of rainfall and the initial moisture status of the soil, a comparison of field capacity over time may not have the validity of comparisons among treatments at a given time. For all fallows, field capacity at 16 months is greater than or equal to that measured at field abandonment. However, there are few treatment-related differences in the values at a given time. At 16 months, field capacity for *Desmodium* and *Inga* is lower, and higher for *Centrosema*, than that of the purma. Few differences among treatments are observed in infiltration rates measured at 16 months. Differences, if present, may be obscured by variability in the data. All planted fallows, with the exception of *Stylosanthes*, have infiltration rates that equal or exceed that of the natural purma.

Soil Chemical Properties

Soil chemical data for the first eight months after establishment indicate a reduction with time in exchangeable Ca + Mg and available P levels in the topsoil. Topsoil K, on the other hand, increases during the first four months, probably due to K release from the decomposition of 2 t/ha of rice straw. It soon declines to levels similar to those measured at fallow establishment. The reduction in topsoil nutrients can probably be attributed to plant uptake and immobilization in the biomass. The lack of significant differences among treatments in soil chemical properties can probably be attributed to all treatments having similar biomass at eight months, and the relatively short time span during which measurements were recorded.

There seems to be a direct relationship between topsoil organic matter and available P content. Both parameters increase after burning, drop precipitously during the first eight months of fallow, and increase afterwards.

Table 2. Representative values for topsoil bulk density, field capacity (0-15 cm) and infiltration rate at various times following fallow establishment.

	Months After Establishment 0	8	18
Bulk Density (g/cm^3)			
0 - 7.5 cm	1.16	1.19	1.11
7.5-15 cm	1.32	1.33	1.24
Field Capacity (% H_2O)	26	28	29
Infiltration Rate at 3 hrs (cm/hr)			19

Weed Control

As noted previously, all planted fallows are successful at controlling grasses and broad-leaf weeds (Figure 4). The best and quickest weed control is afforded by the "spreading" type of fallow. In effect, these fallows screen out almost all other types of vegetation. The bush- and tree-type fallows, while allowing a somewhat greater invasion of weeds, also permit the establishment of other bushes and trees, resulting in greater total biomass in those treatments. This may be advantageous in that more biomass may result in greater nutrient immobilization. Moreover, a mixture of vegetation types may exploit the soil more completely. Furthermore, as observed in the fine-root biomass data, treatments with significant quantities of tree, bush and liana biomass not only tend to have more fine roots, but also the roots are encountered at greater soil depths, thus raising the possibility of the recycling of nutrients from the subsoil.

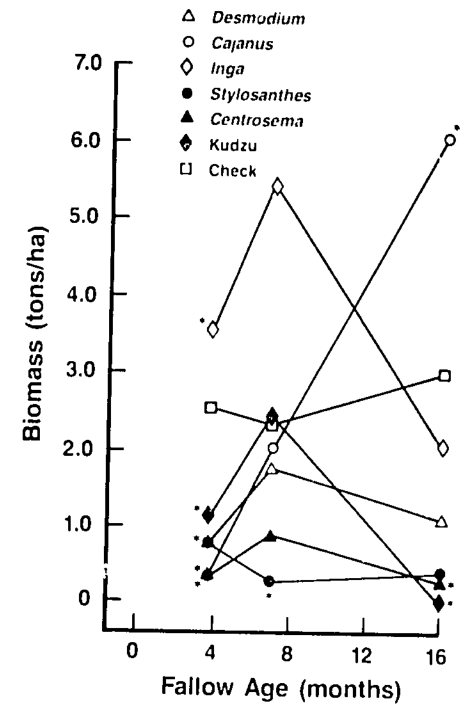
Comparisons With Continuous Cultivation

Grain yields for the mechanically incorporated fertilizer treatment are about double those from the unfertilized plots — 10 t/ha vs. 6.3 t/ha (Table 3). However, it is significant that the latter treatment continues to yield reasonable quantities of grain two years after clearing. Similar phenomena have been observed elsewhere at the Yurimaguas Experiment Station and suggest that factors other than the decline in soil fertility — weed control, for example — are critical to a farmer's decision to abandon his land.

In comparison with the fallows, soil chemical properties are more favorable to crop production in the continuous-cultivation treatments. This is expected in the fertilized treatment due to periodic nutrient additions. In the unfertilized, continuously cultivated treatment, the level of nutrient removal via harvest, which may be likened to long-term nutrient immobilization in the fallows, is likely to be much less. For example, only the nutrients contained in 6.3 t grain/ha have been removed from the cultivated plots vs. the nutrients contained in 8 to 17 t biomass/ha in the fallows. Furthermore, decomposition of soil organic matter and crop residues releases nutrients to the soil. With time, of course, soil nutrient levels in the cultivated, unfertilized treatment should approach or decrease below that of the fallows due to continued nutrient removal during harvests, a reduction in the quantity of nutrients recycled as plant production declines, and leaching losses.

Table 3. Grain yield from continuously cultivated plots included in the managed fallow experiment.

Crop	Date Harvested	Treatment	Grain Yield
			t/ha
Rice	01-14-84	None	2.82 ± .38
Corn	06-04-84	Fertilized	0.93 ± .32
		Unfertilized	0.44 ± .11
Cowpea	08-29-84	Fertilized	0.86 ± 0.31
		Unfertilized	0.48 ± 0.14
Rice	12-30-84	Fertilized	2.3 ± 1.0
		Unfertilized	1.0 ± 0.4
Rice	05-14-85	Fertilized	1.91 ± 0.45
		Unfertilized	0.82 ± 0.19
Cowpea	07-30-85	Fertilized	1.26 ± 0.58
		Unfertilized	0.76 ± 0.36
Total Grain Production		Fertilized	10.08
		Unfertilized	6.32



*significantly (.05) different from check treatment

Figure 4. Changes in weed biomass with time in fallow treatments.

Conclusions

Comparisons of the rates at which natural and improved fallows restore productivity can be based on soil physical properties, the quantity of nutrient stocks in both soil and biomass, the weed population, and crop yields after the fallow. Considering these factors, the following conclusions can be drawn:

1. Physical properties improve with time under all fallows, and there are few treatment-related differences in infiltration rate, field capacity or topsoil bulk density. Field capacity and topsoil bulk density improve with time, the bulk-density values at 16 months approaching those following clearing.

2. Available nutrient levels in the topsoil decrease with time in all treatments, except continuous cultivation, probably due to immobilization in the biomass. Biomass nutrient stocks are determined by the quantity of biomass present and the concentrations of nutrients in the tissues.

3. After 16 months of growth, total biomass accumulation is highest in the bush or tree fallows (approximately 14 t/ha) and lowest in the spreading types (approximately 7-10 t/ha). The natural purma biomass is 14.1 t/ha. High biomass in the bush or tree fallows is due primarily to the invasion of trees, since the planted-fallow biomass is similar in the majority of treatments at 16 months, about 7 t/ha. These differences in total biomass are accentuated with time.

4. Planted fallow biomass accumulation was greatest in *Desmodium* (9.7 t/ha) and least in *Cajanus* (5.1 t/ha). The difference between total and planted fallow biomass is due to the presence of other vegetation, primarily trees.

5. Foliage development and the establishment of an almost complete ground cover occur within four to eight months in all treatments.

6. Weed control is better than the natural purma except for *Cajanus cajan* in all planted fallows. Control is quickest and most effective with the "spreading" fallow types.

7. Based on biomass production, fine-root production and distribution, weed control, and changes in soil properties, *Desmodium* may serve as a good short-term (16-month) fallow. *Desmodium*, *Centrosema*, or *Stylosanthes* may be suitable for fallows of eight months.

Forest and Soil Regeneration

Lawrence T. Szott, N.C. State University
Charles B. Davey, N.C. State University
Jorge Perez, INIPA
Cheryl A. Palm, N.C. State University

The period of vegetative regrowth following the abandonment of agricultural fields has often been credited with the restoration of site productivity. Surprisingly, there have been few studies of soil and vegetation dynamics in shifting cultivation fallows, even though such studies are necessary for an understanding of how the most common agricultural production system in the humid tropics functions, and may point the way to potential improvements in the system. Therefore, two complementary projects, addressing different aspects of old field secondary succession, were undertaken. One compared secondary successional sites of different ages but similar soils (Udults), in order to determine how soil properties and vegetation structure and composition change over fairly long periods of time. The other project is a long-term study, at a single site, of the effects of different levels of soil fertility on secondary succession in an abandoned agricultural field.

The two studies are complementary in the sense that they address different aspects of old field secondary succession: how soil properties and vegetation change over fairly long periods of time, and how soil fertility affects these processes. They physically complement each other in that the non-fertilized control plots in the fertility study have been used to provide data points in the study of different-aged purmas.

Soil and Vegetation Dynamics In Shifting-Cultivation Purmas

Three purmas within approximately 1 km of one another were identified. According to their owners, all were previously farmed in the traditional manner and had suffered little disturbance since abandonment. The purmas were approximately three, seven and 11 years old. A fourth purma, nearby, used for the undisturbed check plots of the fertility study, was included to provide data for purmas of age zero (field abandonment) to 17 months. Soil texture in all the purmas appeared similar, and are classified as sandy loams. Further analysis revealed that the zero-year purma had a lower clay content, with a classification of loamy sand.

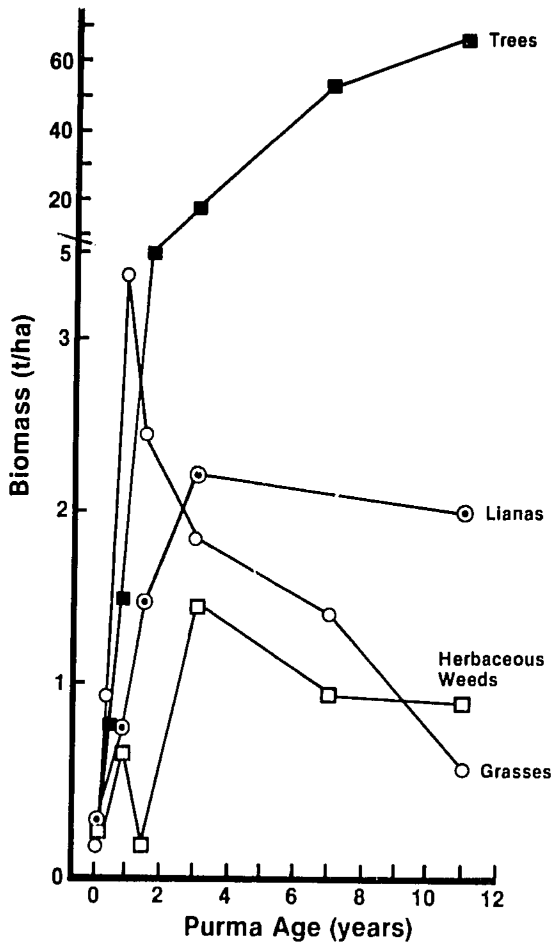


Figure 1. Changes in aboveground biomass with time by vegetation type.

Table 1. Changes in purma vegetation structure with time after adandonment.

Time After Abandonment	Average Dominant Height, m	Leaf Area Index	Cover, %
0	1.35 ± .28	1.4 ± .7	58 ± 17
4 mo.	2.28 ± .29	3.6 ± 1.1	93 ± 12
8 mo.	3.56 ± .47	6.3 ± 1.5	98 ± 5
17 mo.	4.04 ± .51	4.8 ± 1.3	98 ± 5
3 years	5.99 ± 1.52	not measured	
7 years	12.89 ± 1.39	not measured	
11 years	14.68 ± 2.24	not measured	

The older purmas were sampled during a two-month period. Soil properties measured included infiltration rate, bulk density, field capacity, pore-size distribution, organic-matter percentage, pH, exchangeable Al, and nutrient contents (exchangeable Ca + Mg, K, and available P). Biomass estimates of above-ground vegetation, litter, and roots to a 50-cm depth were also obtained. Subsamples of each vegetation component were taken for nutrient analysis and included tissue samples of all trees greater than 2.5 cm DBH (diameter 1.4 m above the ground), by species. Heights and diameters of all trees greater than 2.5 cm DBH were also measured.

Changes in Biomass

Changes in living above-ground biomass are shown in Figure 1. Biomass accumulation shows a typical growth curve with a decline after seven years. The average rate of biomass accumulation, 6 t/ha/yr, is a bit low for humid tropical forests, which average around 10 t/ha/yr. The seven-year-old purma, however, accumulated biomass at a rate of 8.3 t/ha/yr. In general, grasses dominate during the first year of succession and decrease thereafter, presumably due to shading by trees and other vegetation. The biomass of lianas appears to increase in the early years of succession, maintaining itself at around 2 t/ha thereafter. Tree biomass, while low during the first year, increases rapidly thereafter and composes the majority of the total biomass after three years. Recruitment of trees into the population, as represented by the understory (trees < 2.5 cm DBH) biomass, remains fairly constant with time (about 1.5 t/ha).

Root biomass, down to a 50-cm depth, is shown in Figure 2. Discounting roots having diameters greater than 10 mm, root biomass appears to increase with time. The large quantity of roots and the number of large roots found at abandonment likely represent remnants of the previous forest. It is generally cited that root biomass is usually about 20% that of the above-ground living biomass. Clearly that is not the case here, as root biomass declines from 39% at 17 months of age, to 21%, 10% and 9% at three, seven and 11 years of age, respectively. Root turnover, which may be rapid and hence contribute greatly to production estimates, was not measured.

The standing-crop biomass of fine roots—those most important in the uptake of water and nutrients—is also shown in Figure 2. In general, fine root biomass increases with time. This pattern is maintained to a soil depth of 30 cm; at greater depths, all purmas, regardless of age, have similar fine root biomass. In general, fine root biomass declines with depth. The majority of the fine roots are in the upper 15 cm of the soil, while very few are found at depths greater than 30 cm.

Changes in Vegetation Structure

Rapid changes in vegetation structure occur during the first 17 months (Table 1). Foliage development, as measured by the leaf-area index (LAI) and percentage of ground cover, occurs quickly. Within eight months there is almost complete ground cover and a fairly high LAI. The decrease in LAI between eight and 17 months is probably due to the senescence of grasses, herbs, and many of the dominant, short-lived trees. At the same time, early vertical growth of trees is extremely rapid (5.33 m/yr at eight months), eventually decreasing to an average growth rate of 1.33 m/yr at 11 years.

These changes have a number of important consequences. The development of a multi-layered canopy will tend to moderate soil temperature and humidity and buffer any changes in these environmental variables. Microbial activities and the decomposition of organic matter may also be affected. The development of a high photosynthetic potential also allows rapid growth to occur and, with it, a high demand for water and nutrients. Nutrients arriving at the roots, via water uptake and diffusion along concentration gradients, and their uptake in the biomass, are a conservation mechanism by which losses in leaching, runoff, or erosion can be reduced.

Diversity

The diversity of the purmas, i.e., the number of genera of trees greater than 2.5 cm DBH present, appears to decrease with time. The three-, seven- and 11-year-old purmas contained 60, 56, and 51 genera per sampling unit, respectively. Very few genera present in the three-year-old purma, however, are also found in the seven- or 11-year purmas, indicating a very rapid species turnover or nonhomogenous plant population distributions. The only genera in common to the three-, seven-, and 11-year-old purmas were *Cecropia* (cetico), *Inga* (shimbillo) and *Pollalestra* (yanavara), and these accounted for 60%, 62.5% and 39.2% of the individuals in the three-, seven-, and 11-year-old purmas, respectively. Apparently, although

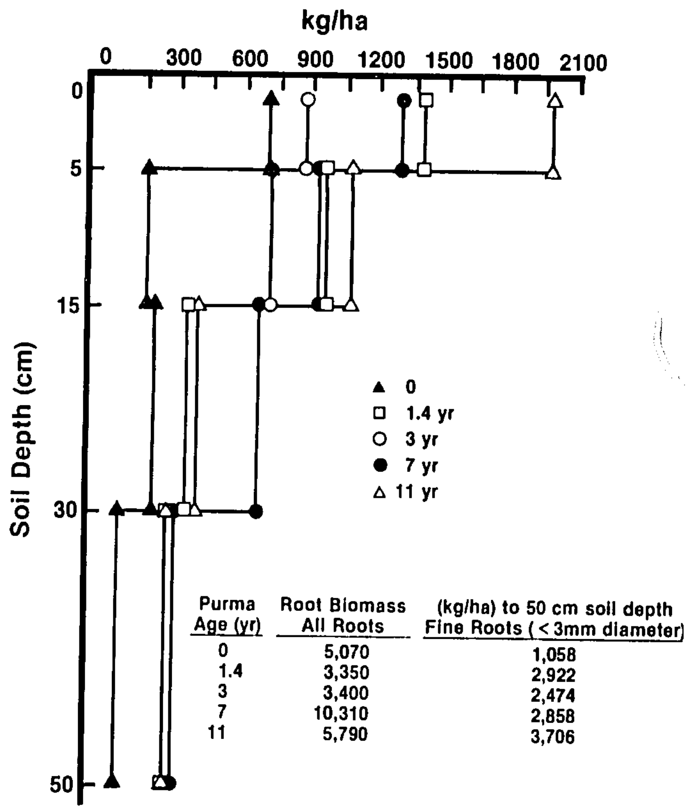


Figure 2. Distribution of fine-root biomass in purmas of different age.

Table 2. Effects of purma age on topsoil field capacity, infiltration rates and bulk density (g/cm³ using Uhland cores).

Purma Age	Field Capacity 0-15cm	Infiltration Rate at 3 hrs.	Soil Depth (cm) 0-7.5	Soil Depth (cm) 7.5-15
	%	cm/hr	g/cm³	g/cm³
0	14.0 ± 2.2	—	1.36 ± .07	1.53 ± .03
17 mo.	14.9 ± 1.9[1]	53.9 ± 8.4[1]	—	—
3 yrs	16.0 ± 0.8	22.2 ± 13.4	1.28 ± /10	1.48 ± .11
7 yrs	19.1 ± 2.7	29.9 ± 5.8	1.18 ± .05	1.35 ± .10
11 yrs	16.0 ± 1.3	24.8 ± 21.9	1.21 ± .13	1.42 ± .13

[1] Measured at 15 months.

the number of genera present may decrease with time, dominance also decreases.

Soil Physical Properties

Bulk density was measured using two different methods, Uhland cores and the excavation of a known volume of soil. Results obtained using Uhland cores suggest that topsoil bulk density decreases with time, the greatest change occurring in the first year or two. The bulk density in the seven-year old purma is a bit low and may be due to the lower sand content in this soil. The excavation method shows similar results. Bulk density at the 0-7.5 and 7.5-15 cm soil depths generally decreases with time, presumably due to organic-matter additions and root growth. At greater depths, however, soil bulk density is higher and does not appear to change significantly with time.

Topsoil field capacity, measured in the field approximately 24 hours after a heavy rainfall, appears to increase slightly with time (Table 2). Once again, the higher value for the seven-year-old purma may be due to the lower sand content and, hence, macropores in this soil. Infiltration rate was measured in the field using a double-ring infiltrometer. There are probably no significant differences in infiltration rates for the three-, seven- or 11-year-old purmas (see Table 2). The rate measured at 17 months is significantly higher and is probably due to the high sand and low clay content of this soil.

Soil Chemical Properties

In general, topsoil acidity, as measured by pH value, and exchangeable Al, both increase with time (Table 3). There is a suggestion that exchangeable nutrient cation levels in the topsoil decrease. A fairly large decrease in cation levels appears in the first year after abandonment. This is followed by a period (six to seven years) of little change in the exchangeable cation content of the topsoil before a subsequent decrease is observed in the 11-year old purma. A similar pattern is observed at the 15-30 cm soil depth, while little change with time occurs at depths greater than 30 cm.

A number of factors make the interpretation of this pattern rather difficult. It is unclear, for example, whether the changes observed in the purmas of different ages are, in fact, due only to the growth of the vegetation and passage of time, or whether there are significant differences in such things as site history and clay mineralogy. Additionally, there is a fair amount of variability in the data, especially in the results for the seven-year old purma, which obscures trends and makes interpretation difficult.

The decline in topsoil nutrients during the first year can probably be attributed to nutrient immobilization in living biomass (6.3 t/ha above ground) and leaching losses. After this decline, topsoil nutrients appear to change little for six years, while living above-ground biomass increases nine-fold during the same period. It is likely that the nutrients sustaining this growth are

Table 3. Changes in soil chemical properties with time after abandonment.

Parameter	Soil Depth	Months After Abandonment			Years After Abandonment		
		0	4	10	3	7	11
	cm						
pH	0-15	5.1 ± .2	5.0 ± .3	4.8 ± .1	4.8 ± .2	4.6 ± .1	4.5 ± .2
	15-30	4.4 ± .1	4.5 ± .1	4.6 ± .04	4.7 ± .1	4.4 ± .1	4.5 ± .2
	30-45	4.4 ± .1	—	4.6 ± .04	4.8 ± .1	4.5 ± .1	4.8 ± .1
Exch Al	0-15	0.2 ± .3	0.9 ± .3	0.8 ± .4	0.6 ± .1	1.8 ± .4	1.1 ± .3
(cmol L1)	15-30	1.3 ± .4	1.6 ± .4	2.0 ± .8	1.6 ± .4	3.4 ± .6	2.2 ± .7
	30-45	1.7 ± .3	—	2.5 ± .4	2.3 ± .4	3.3 ± .6	2.8 ± .6
Exch Ca*	0-15	1.3 ± .9	0.8 ± .3	1.0 ± .2	1.0 ± .2	1.2 ± 15	0.5 ± .2
(cmol L1)	15-30	0.5 ± .1	0.4 ± .1	0.5 ± .1	0.5 ± .1	0.5 ± .1	0.4 ± .1
	30-45	0.3 ± .1	—	0.4 ± .1	0.3 ± .1	0.4 ± .1	0.3 ± .1
Exch K	0-15	.10 ± .07	.07 ± .03	.09 ± .02	0.9 ± .02	.11 ± 01	.08 ± .01
(cmol L1)	15-30	.08 ± .05	.07 ± .03	.08 ± .03	.06 ± .01	.07 ± .02	.06 ± .02
	30-45	.06 ± .03	—	.075 ± .02	.06 ± .01	.07 ± .02	.05 ± .01
Avail P	0-15	14 ± 4	8 ± 2	7 ± 1	5 ± 1	5 ± 1	4 ± 1
(ppm)	15-30	7 ± 2	4 ± 2	4 ± 1	3 ± 0	2 ± 1	2 ± 1
	30-45	4 ± 1	—	3 ± 1	3 ± 1	2 ± 1	2 ± 1

* Values for exch Ca for 0 and 4 months are exch. Ca + Mg.

Table 4. Changes in soil organic matter with time.

Soil Depth	Months After Abandonment[1]				
(cm)	0	2		9	12
	% organic matter				
0-5	2.11 ± 1.00	1.25		1.34 ± .37	1.69 ± .50
5-15	1.50 ± .46	0.96		0.95 ± .17	1.20 ± .11
15-30	1.26 ± .18	—		—	—
Soil Depth	**Months After Abandonment**				
(cm)	**0**		**36**	**84**	**132**
0-15	2.07 ± .40		1.05 ± .13	1.67 ± .19	1.21 ± .20
15-30	1.26 ± .18		0.63 ± .06	0.84 ± .32	0.85 ± .23
30-45	—		0.44 ± .24	0.83 ± .17	0.50 ± .17
45-100	—		0.23 ± .29	0.65 ± .11	0.29 ± .10

[1] 0-12 month data were measured at the same site; 3-, 7-, and 11year-old data are from different sites.

provided by atmospheric inputs and the decomposition of organic matter in and on the soil, and retranslocation within the vegetation itself. A build-up in soil organic matter, presumably due to litter fall, between three and seven years is observed (Table 4). Changes in the biomass of the forest floor have been measured, but the data are not available at this time.

In any case, further analysis, including the contribution of atmospheric inputs and the construction of a nutrient budget, is needed.

Conclusions

1. Secondary succession is in general very dynamic. Pioneer vegetation quickly establishes its photosynthetic material and a soil cover. Photosynthesis and transpiration set up soil-water and nutrient gradients that enable rapid biomass accumulation and nutrient immobilization in the biomass.

2. Rapid vegetation growth affects soil properties through root growth and turnover, organic matter additions, vegetation-mediated changes in soil microclimate, and the canopy's ability to reduce the impact of rainfall on the topsoil, all probably contributing to the decrease in bulk density and improving the retention of soil moisture. It is interesting to note that where root biomass is similar, bulk density is also similar. And, while differences in sand content may influence the increase in field capacity over time, this increase during the first fifteen months agrees well with increases in soil organic matter over the same period.

3. Nutrients become impoverished in the topsoil over time, largely as a consequence of nutrient uptake and immobilization by vegetation.

4. It is unclear whether the higher biomass accumulation and productivity of the seven-year-old purma should be attributed to a growth phase common to this stage of succession, or to differences in sites. Data show that the site of the seven-year-old purma was less sandy and somewhat more fertile than the others.

5. A number of questions remain. The effect and importance of changes in soil physical properties on vegetation growth remain largely unknown, as does the effect of soil fertility on biomass production and vegetation composition. The relative importance of atmospheric inputs, N fixation, soil organic matter, and litter as sources of nutrients for developing vegetation is likely to vary according to soil type, and these factors also need further evaluation. It is important to conduct long-term studies at permanent sites, in order to avoid the problems created when site and time are confounded.

Effect of Soil Fertility On Shifting Cultivation Fallows

The purpose of this study was to answer some of the questions regarding the effect of soil fertility on secondary succession in abandoned agricultural fields. Specifically, the study was designed to quantify the size of potential or actual nutrient pools in an abandoned agricultural field, and to investigate the effects of soil chemical properties on secondary succession by manipulating soil fertility.

A 0.5 ha abandoned field that had been cropped with a rice-corn mixture was sampled on 24 plots of 64 m < 2. Analyses included total soil nutrients to a 1 m depth; exchangeable Al, Ca + Mg, K; available P contents in the upper 100 cm; and soil organic matter.

Biomass measurements and subsamples for nutrient analysis were obtained for litter, crop residue, and living vegetation. The leaf-area index (LAI), average heights of the five dominant individuals per plot, and percentage of cover were also measured.

Three rainfall collectors were installed, as well as six zero-tension leachate collectors. The lysimeters were placed in zones of textural change, usually between 15 and 20 cm depth.

Soil physical properties—texture, bulk density, field capacity, and pore size distribution—were also sampled.

After the initial sampling, four fertility treatments were established: 1) undisturbed controls, 2) litter removal, 3) litter additions (the equivalent of 3.25 t of rice straw and 17.4 t of wood per hectare) and 4) fertilization with 100 kg P/ha, 100 kg N/ha, 100 kg K/ha and and 50 kg Mg/ha.

Soil and vegetation dynamics were studied by means of periodic measurements. These included: topsoil organic matter approximately every two months; exchangeable Al, Ca + Mg, K; available P; pH at four, ten and 17 months after abandonment; topsoil bulk density at zero, ten and 17 months after abandonment; field capacity at 0 and 15 months; infiltration rate at 17 months; and pore size distribution at zero, ten and 17 months. The heights of the five dominant individuals per plot, LAI, % cover, and biomass (weight and nutrient concentration by vegetation type, i.e., grasses, lianas, herbs, and trees) were measured at zero, four, ten and 17 months. Root biomass down to a 50 cm soil depth was measured at one and 17 months. Rainfall and leachate samples were collected within two days after a rain, the quantity collected was measured, and a subsample was taken for chemical analysis.

Nutrient Pools

Soil total nutrient analyses are shown in Table 5. The increase in nutrients observed in the 15-60 cm horizon is due to an increased clay content. The relatively large amounts of total K and Mg reported may be due to the presence of vermiculite-like minerals having imperfect substitution or Al oxide minerals having K or Mg entrapped in the interlayers. These nutrients are, for the most part, probably unavailable. It has been reported that, after kaolinite, vermiculite is the next most common soil mineral in the Yurimaguas soils.

In general, the total quantity of nutrients in the soil appears sufficient to support more than one crop harvest. However, the slow release of minerals into plant available forms and the possibility of Ca deficiencies or Ca/Mg imbalances would probably negatively affect crop productivity. Moreover, available nutrient levels in the topsoil, while not high, generally appear sufficient, although K availability may be a limiting factor. The existence of large total nutrient pools deep in the soil profile, on the other hand, raises the possibility of nutrient "pumping" by deep-rooted plants.

Preliminary analyses of atmospheric inputs suggest that inputs may be sizeable for K, Na, and Ca, but may be within the range reported in the literature. An unexplained anomaly is the rainfall pH value of 6.9. Rainfall should have a pH of around 5.5. A higher pH value may indicate contamination. In any case, atmospheric inputs fall far short of supplying the nutrients needed for continual crop production. Additions over a ten-year period, however, may be sufficient to support one or two crop harvests, assuming total nutrient conservation and similar atmospheric input levels for all years.

The importance of large and small litter pools present at abandonment cannot be assessed at this time due to the absence of nutrient analyses of litter. Considering that litter biomass ranges between approximately three and 11 t/ha, litter decomposition may supply large quantities of nutrients to vegetation regrowth.

In comparison to nutrient additions, leaching losses appear relatively small. Losses were greatest for K, as might be expected based on its chemical characteristics. In general, leaching losses varied by treatment. Losses were greater in those treatments with larger quantities of available nutrients.

Table 5 Total soil nutrient stocks present at field abandoment (mean of three replications).

Depth (cm)	Kjeldahl	Ca	Mg	P	K
	kg/ha				
0-15	857	292	361	173	669
15-60	2410	67	1264	613	3507
60-100	1431	25	1041	505	2393

Vegetation Dynamics

In general, a great deal of within-treatment variability is observed in the measurements of living above-ground biomass (Table 6). In many cases, coefficients of variation are 100% or more. Such variation is due to the "clumpy" nature of vegetation distribution and the quadrat sampling techniques used. Such variability obscures trends and makes interpretation difficult.

Table 6. Changes in living aboveground biomass following field adandonment (kg/ha).

Treatment*	Grass	Broad-leafed Weeds	Lianas	Trees, <2.5cm dbh	Trees, >2.5cm dbh	Crop Remnants
			1 Month After Abandonment			
1.	28	43	214	108	0	2590
2.	28	35	447	821	0	2113
3.	204	34	249	234	0	2617
4.	210	203	99	272	0	2030
			4 Months After Abandonment			
1.	928	165	445	763	0	144
2.	520	361	421	531	0	511
3.	1029	477	894	825	0	147
4.	1006	449	1555	3243	0	72
			10 Months After Abandonment			
1.	3372	628	741	1539	0	0
2.	2085	89	382	720	625	0
3.	2190	54	241	1300	1475	0
4.	2394	549	315	1211	9150	0
			17 Months After Abandonment			
1.	2467	14	1481	1745	1841	0
2.	2775	177	287	2934	5562	0
3.	1072	72	616	872	5037	0
4.	456	346	638	2217	7038	0

* Key to Treatments: 1) Natural secondary succession control; 2) residue removed; 3) residue added; 4) fertilized.

A number of patterns in biomass accumulation are apparent, regardless of fertility treatment (Table 6 and Figure 3). Above-ground living biomass decreases during the first four months after abandonment as crop plants remaining after harvest senesce. The crop plants are quickly replaced by grasses and trees which are codominant for a while. The grasses eventually decrease in biomass as tree biomass continues to increase both absolutely and in relative importance. Herbaceous weeds and lianas, although present, are of much lesser importance. Their biomass generally peaks between four and eight months and decline thereafter.

There appear to be very few treatment-related differences in biomass accumulation. Up to ten months after abandonment, total above-ground living biomass is similar in the undisturbed check and the residue treatments. Biomass levels, considered by vegetation type, are also similar across these treatments. During this period, however, greater biomass levels were recorded in the chemically fertilized treatment, primarily due to a greater tree biomass. These differences may not be significant due to variability in the data.

Biomass measurements at 17 months show little difference between the check and residue-addition treatments, while the residue-removal and chemical-

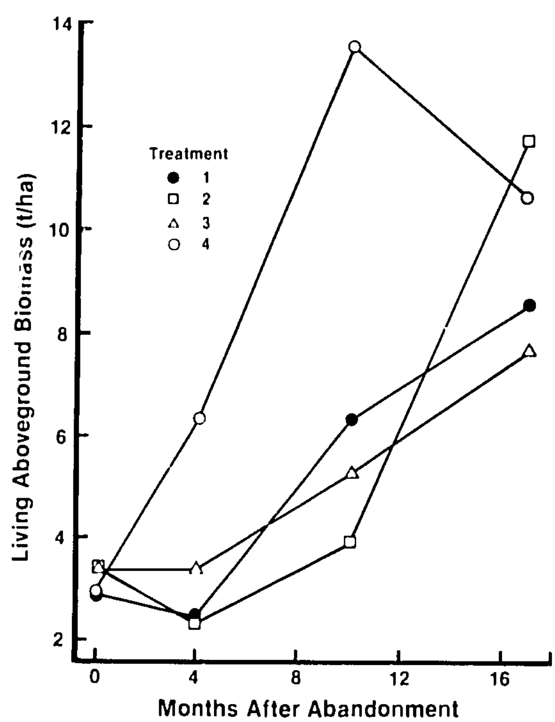


Figure 3. Changes in living above-ground biomass with time.

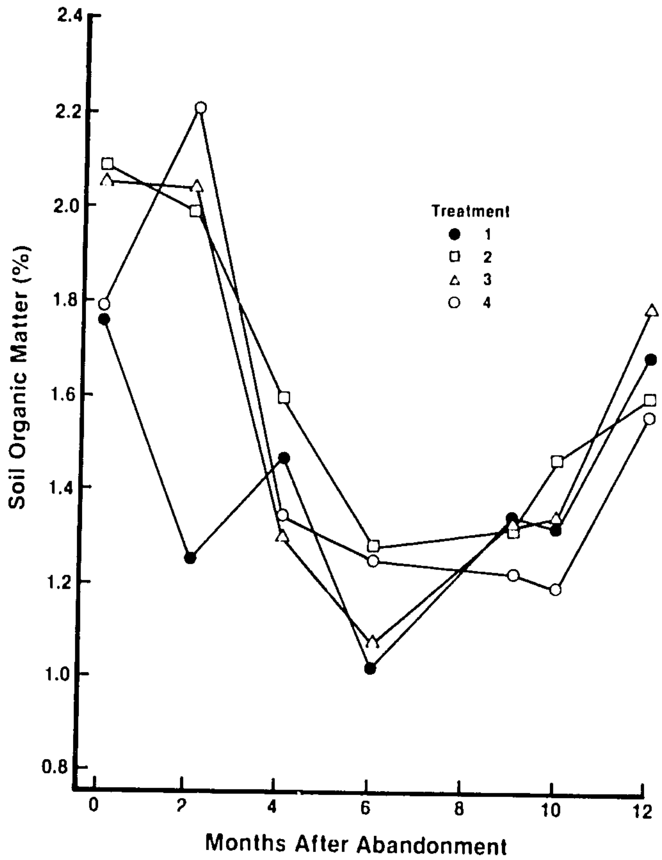


Figure 4. Changes in soil organic matter with time (0-15 cm).

ly fertilized treatments have similar levels of biomass, averaging 2-3 t/ha more than the check. The data suggest that tree growth responds quickly to chemical fertilizer additions. There is little difference among treatments in topsoil or subsoil chemical properties at ten months, with the exception of higher P levels in the chemically fertilized treatment. This suggests that the nutrients which were added were lost either in surface runoff or erosion, converted to an unavailable form, or immobilized in litter and biomass. The latter possibility, at least, can be investigated via nutrient-budget calculations.

Soil Organic Matter

Topsoil (0-5 cm) organic matter declined in the first six months after the field was abandoned, but increased from six to 12 months (Figure 4). There was no apparent effect of the different treatment. Similar but less marked changes were also observed in the 5-15 cm layer.

Conclusions

1. The recovery of vegetation in an abandoned agricultural field appears to respond to the application of 100 kg N, 100 kg K, 100 kg P, and 50 kg Mg per hectare. This response is mainly apparent in increased tree growth. Despite differences in tree growth, there was little effect of treatment on soil physical or chemical properties. This suggests the amounts of nutrients added or removed in vegetation residue is small relative to soil pools and that nutrients added via the application of fertilizers may only be available to the vegetation for a short period of time before they are taken up, leached, or converted to chemical forms unavailable to plants.

2. Further work is needed on the quantity and rate of release of nutrients from soil pools as well as inputs to and losses from these pools.

New-Project Update

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

Comparative Soil Dynamics

Julio C. Alegre, N. C. State University
Pedro A. Sanchez, N. C. State University
Luis Arevalo, N. C. State University
Jorge Perez, INIPA
Manuel Villavicencio, INIPA

This project, established on a tract of ten-year-old secondary forest at the Yurimaguas Experiment Station, compares the effects of various crop-management systems on changes in the physical, chemical and biological properties of an Ultisol upon clearing. The experiment consists of six management options as treatments, which are: 1) shifting cultivation, with plots contracted out to a farmer who planted upland rice intercropped with cassava and plantain; 2) mechanized continuous cropping, with corn and soybean, on a plot cleared with a tractor and straight blade, then logged, burned, disked and fertilized according to soil-test recommendations; 3) low-input technology, in which a rotation of two crops of rice followed by cowpea will be carried out until productivity declines; then it will be placed in managed fallow; 4) combined tree and crop production, with rice interplanted with tornillo (*Cedrelinga catenaeformis*), and *Inga edulis* planted between the *Cedrelinga*; 5) peach palm (*Gulielma gasipaes*), interplanted with the first crop in a sequence of rice, rice and cowpea; and 6) a forest fallow check, in which the plots were not disturbed.

Plots were sampled before and after clearing, and after burning. Soil chemical, physical and biological properties are being monitored intensively.

Collection and Propagation Of Agroforestry Species

Angel Salazar, INIPA
Jorge Perez, INIPA
Cheryl A. Palm, N.C. State University
Alwyn Gentry, Missouri Botanical Garden
Kenneth MacDicken, University of Hawaii

Most tree and shrub species used for agroforestry in the humid tropics are successful in high base status soils. This project seeks to identify species that can succeed on acid soils. There was progress during 1985 in several areas:

1) At Yurimaguas, seed of eleven legumes with potential in agroforestry were collected, identified and planted at the nursery.

2) Some 200 trees, shrubs and vines, collected around Yurimaguas during a survey by the Flora of Peru Project, are being identified.

3) A trial to evaluate trees for alley-cropping was established, with eight of twenty tree species planted. The trees will be studied for survival, growth rate, regrowth after pruning, biomass production and nutrient accumulation.

4) In collaboration with the Nitrogen Fixing Tree Association (Hawaii), a site was prepared for a trial designed to measure biomass production and N accumulation in species considered strong N-fixers on acid soils.

New-Project Update

Living Fences

Jorge Perez, INIPA
José Benites, N.C. State University

The objectives of this project are 1) to determine the most suitable tree species for use in living fences, and 2) to test the idea that living posts, sprouted from stakes or poles, could persist on acid soils, reducing the high cost of fence maintenance on farms in the humid tropics.

Research was begun at Yurimaguas with three promising species: mullohuayo (*Seca floribunda*), llambo pashaco (*Eslorabium* sp.) and huina caspi (genus and species unknown).

Mullohuayo

Sprouting percentage was determined with 0.5 or 1.0 m long mullohuayo stakes as a function of days of storage after cutting.

Over 80% sprouting was achieved with seven-day-old stakes of either size. Similar results were obtained with 2.5 m long stakes.

Llambo pashaco

For this species, 2.5 m stakes were used. Seven days after planting, 80% of the stakes had sprouts, but the vigor disappeared quickly and all stakes died.

Huina caspi

This species grows on upland soils. It is traditionally used as fencing material in the gardens of *pueblos jovenes* of Yurimaguas. The same experiment was carried out as with mullohuayo, using 0.5 m and 1.0 m stakes. Results were negative because the macroporosity of this species allows a very quick loss of its water content. Ninety days after planting the survival rate was 82%. At 180 days after planting, only 26% of the living plants were found. The causes of mortality are not known but sprouts began drying and fell from the trunks.

Further study will test ways to stimulate rooting and rapid growth. Native legumes with a high potential for vegetative propagation will also be tested in the living fences.

Continuous Cropping Systems

Continuous cropping is in many ways an attractive system to those in the humid tropics who seek to produce more food on less land, conserving natural forests while developing a more stable agricultural base. Research has shown that the effective use of modern fertilizers and lime can dramatically increase crop yields in the acid, infertile soils of the humid tropics. Before this technology can be applied successfully in developing nations, however, it must first be adapted to local economic, social and environmental conditions.

A stable system of continuous cultivation must overcome several soil-related constraints. The common humid-tropical weather pattern of intense rainstorms followed by dry periods promotes soil erosion and water stress in crops. Most of the available soils are acid and infertile, and are subject to nutrient leaching during heavy rains. Tropical weeds, which have traditionally been controlled by extended fallows and very brief periods of cropping, soon dominate food crops if they are allowed to establish themselves in the fields.

The reports that follow describe research aimed at managing each of these primary constraints. Most of the research has been conducted at the Yurimaguas Experiment Station in Peru. Several projects examine various tillage methods and their effect on soil physical and chemical properties. A second group reports experiments in fertilizer management, while a third deals with methods of weed control. The central continuous-cropping experiment incorporates information and methods generated by each of these experiments, so as to develop and refine a comprehensive soil-management program for the continuous cultivation of food crops in the humid tropics.

Land-Clearing and Post-Clearing Soil Management Practices

Julio C. Alegre, N. C. State University
D. Keith Cassel, N. C. State University
Dale E. Bandy, N. C. State University

In the humid tropics, large areas of cleared land have been abandoned because their soils were too compacted, eroded or infertile to support crops. Much of this damage has been blamed on the use of bulldozers with straight blades in land-clearing. There has been a need for information on alternatives to straight-blade bulldozing, as well as for soil-management practices that could improve the productivity of cleared land. The purpose of this project, which was conducted at the Yurimaguas Experiment Station, was 1) to determine the rate of change of selected soil physical properties resulting from alternative land-clearing and soil-management practices, and 2) to evaluate crop performance as affected by land-clearing and soil-management practices of a humid tropical Ultisol.

Soil Physical Properties

Clearing methods and burning and tillage treatments are shown in Table 1, along with bulk-density measurements for two depth intervals, taken 15 days before harvesting the first and last crops. Soils in the treatments were 8 to 10% clay, and particle-size distribution at the 0 to 15 cm depth was not altered by land-clearing. Topsoil removal and mixing of topsoil and subsoil are probably more a function of the bulldozer operator than of the clearing method itself.

Clearing tended to increase the variation in Db (Table 2), as indicated by the higher standard deviations. Compaction occurred for slash-and-burn clearing due to foot traffic during slashing and trunk removal. The greatest numerical increase in Db occurred for straight-blade clearing, but it was not significantly different from the shear-blade and slash-

Table 1. Mean bulk density and standard deviation (in parentheses) of Yurimaguas soil at two depths for two times as a function of land clearing methods, burning and soil tillage treatments.

Treatment	8 Months After Clearning		23 Months After Clearing	
	0 to 15 cm	15 to 25 cm	0 to 15 cm	15 to 25 cm
	Mg/m³			
Slash/burn	1.17*(±0.10)a**	1.37 (0.10) b	1.32 (0.04) c	1.38 (0.04)b
Straight blade/rototill	1.26 (±0.16)a	1.44 (0.19)ab	1.42 (0.06)ab	1.56 (0.15)a
Straight blade/chisel/rototill	1.25 (±0.09)a	1.49 (0.09)ab	1.46 (0.11)a	1.57 (0.07)a
Shear blade/burn/disk/rototill	1.18 (±0.11)a	1.45 (0.15)ab	1.34 (0.11) bc	1.52 (0.11)a
Shear blade/rototill	1.28 (±0.24)a	1.52 (0.12)a	1.32 (0.12) c	1.58 (0.04)a
Shear blade/disk/rototill	1.31 (±0.14)a	1.56 (0.16)a	1.33 (0.11) bc	1.57 (0.06)a

* Each value is the mean of nine measurements in cores of 76 x 76 mm.
** Means in a given column with the same letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

Table 2. Mean bulk density and standard deviaton (in parentheses) of Yurimaguas soil prior to and three months after land clearing.

Time	Clearing Method	Depth (cm)	
		0 to 15	15 to 25
		Mg/m³	
Before clearing*		1.16 (0.09)b***	1.39 (0.08)b
Three months after clearing**	slash/burn	1.27 (0.07)a	1.37 (0.10)b
	straight blade	1.42 (0.12)a	1.49 (0.12)a
	shear blade	1.28 (0.25)a	1.50 (0.15)a

* Each value is the mean of 36 measurements.
** Each value is the mean of 18 measurements.
*** Means in a given column with the same letter are not significantly different at the 5% level with the Waller-Duncan comparison test.

and-burn clearing methods. This lack of difference may be attributed to the high variability produced by the mechanical clearing methods.

Bulk density in the 15 to 25 cm depth increased for both types of mechanical clearing, but not for slash and burn. No differences were found at the upper depth before harvesting the first crop, but at the lower depth greater Db values were observed for some random treatments compared to slash and burn. After 23 months, Db of the upper depth for the slash-and-burn treatments was significantly lower than Db for two other random treatments. At the lower depth, all mechanized land-clearing treatments had greater Db's compared to the slash-and-burn treatment.

Water-Holding and Infiltration

The soil water characteristics for the 0 to 15 cm depth prior to clearing are shown in Figure 1A. The vertical bar through each point is two standard-deviation units long. The amount of water held between soil water pressures of -13 to -1,500 KPa was assumed to approximate the soil's capacity for holding plant-available water before clearing, and was equal to 0.187 m^3/m^3. The diameter of the largest pore neck that retained water at the applied soil water pressures is also shown in Figure 1A. Pores with neck diameters >23 μ m were drained at *in situ* field capacity.

The soil water characteristics at the 0 to 15 cm depth three months after clearing are presented in Figure 1B. Straight-blade clearing increased soil water content for soil water pressures < -2 KPa when compared to the slash-and-burn and shear-blade treatments. These higher water contents are attributed to destruction of macropores by compaction, which, in turn, increased the volume of micropores. Soil water characteristics for the 15 to 25 cm depth showed the same trend three months after clearing (Figure 1C). The soil water characteristics for the 0 to 15 cm depth for the three soil-management subtreatments eight months after clearing are shown in Figure 1D. The bedded treatment had the greatest total porosity and greatest

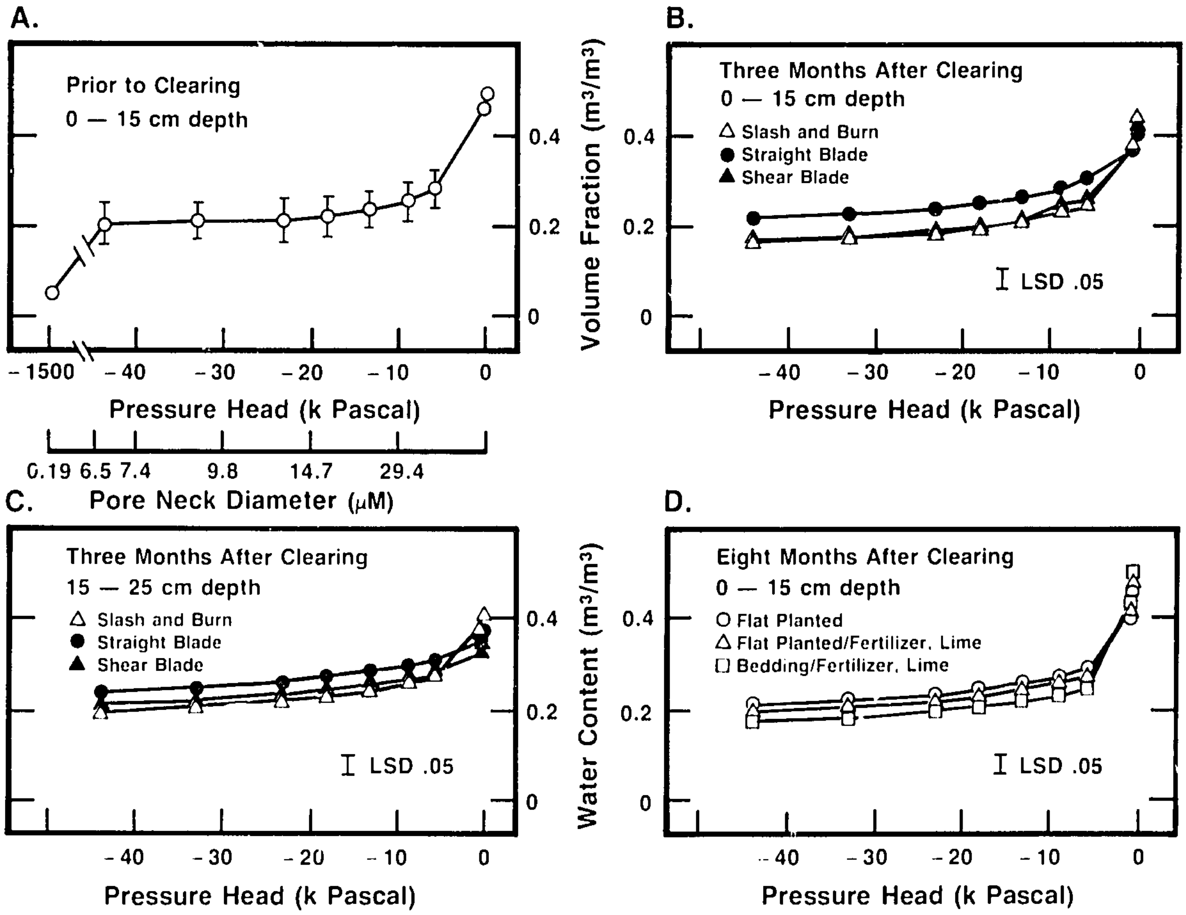


Figure 1. Soil water characteristics of Yurimaguas soil before and several times after clearing.

volume of large pores because less soil disturbance occurred due to land preparation by hand.

The mean infiltration rate before clearing was 420 mm/hr over a two-hour period (Figure 2A). Mechanical clearing with both the straight blade and the shear blade significantly reduced infiltration rate. Mean infiltration rates during the first two hours of infiltration were 304, 14, and 32 mm/hr three months after clearing for the slash-and-burn, straight-blade and shear-blade methods, respectively. Because infiltration measurements were so time-consuming, it was not possible to measure cumulative infiltration for all treatment-subtreatment combinations. However, measurements were replicated six times for those combinations measured. Cumulative infiltration during a two-hour period for selected land-clearing subtreatments 23 months after clearing is shown in Figure 2B. Continuously cropping the Yurimaguas soil for

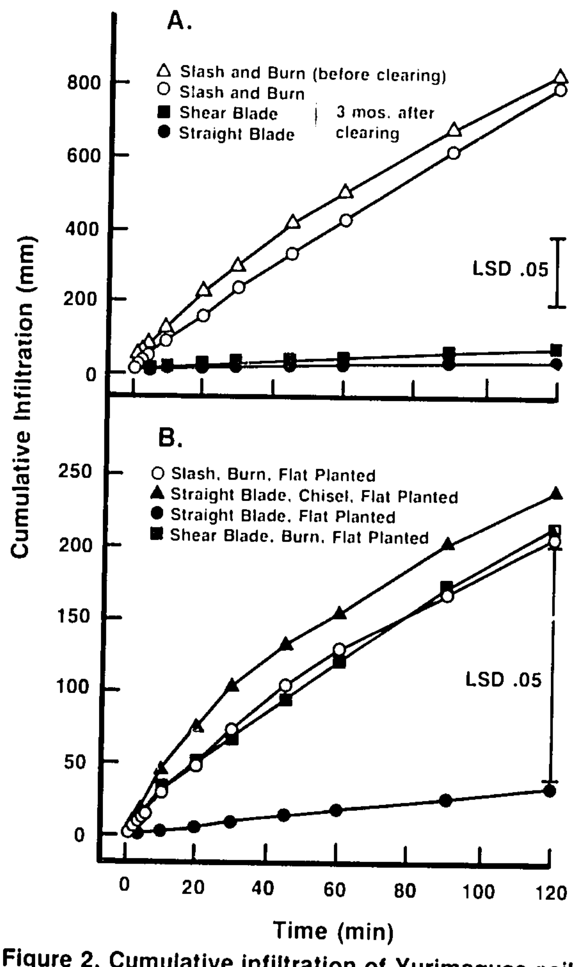


Figure 2. Cumulative infiltration of Yurimaguas soil before and after clearing for three land-clearing methods (A), and cumulative infiltration for selected land-clearing methods 23 months after clearing (B).

23 months after straight-blade clearing resulted in a low infiltration rate when no other soil-management treatment was used before planting. However, when straight-blade clearing was coupled with chisel plowing before planting the first crop, cumulative infiltration values were similar to those for the slash-and-burn treatment.

During the 23-month-long period of continuous cropping, cumulative infiltration over a two-hour period decreased from 800 to 200 mm for the slash-and-burn treatment (compare Figures 2A and 2B). On the other hand, cumulative infiltration increased for the straight blade/chisel and the shear blade/disk treatment.

Crop Response

Grain yield of rice, the first crop seeded after the treatments were imposed, was highest for the slash-and-burn treatment (Table 3). This was expected because slash and burn supplies nutrients in ash and leaves the topsoil in place. The shear blade/burn/disk treatment also incorporated nutrients from ash into the soil and produced the second highest yield. Very little removal of topsoil or mixing of subsoil with topsoil occurred for the shear-blade treatment. The bed/fertilization subtreatment had the highest grain yields followed by the flat/fertilization. Soil in the beds maintained good structure, partly because field laborers never walked on the elevated beds. The highest grain yield for the second rice crop (the fourth consecutive crop in the rotation) was for the shear/burn/disk treatment followed by the slash-and-burn and the straight-blade/chisel treatments (Table 3).

In general, rice grain yield was 0.5 to 0.7 Mg/ha less for the fourth crop compared to the first crop. This was especially true for those plots where no fertilizer was added because most of the nutrients had been removed by the previous crops.

A very poor soybean crop resulted from poor germination due to dry conditions and low-quality seed. Yields (Table 4) were low compared to the 2.5 Mg/ha yield obtained from other studies nearby. The highest grain yields occurred for the slash-and-burn, straight-blade/chisel, and shear-blade/burn/disk treatments. The response to chiseling land cleared by straight blade was 0.38 Mg/ha. Based on the general response to chiseling and disking, it appears that soil compaction constrained soybean growth and yield.

Corn height for the third crop was significantly greater for the slash-and-burn and shear-blade/burn/disk treatments (Table 5). For both treatments involving burning, some available nutrients still remained and plant height was 0.85 m. Grain yields for the fifth crop were greatest for the slash-and-burn and shear-blade/burn/disk treatments (Table 5). There was good response to all treatments receiving disk or chisel tillage. Without fertilizer and lime plants did not survive. Although application of fertilizer and lime appeared to compensate for some of the effect of compaction, corn growth and yield were better on chiseled land. Soil structure in the bedding system was favorable to germination and root distribution, and bedding produced higher grain yields.

For the slash-and-burn treatment, the bed/fertilization management resulted in the best soil physical conditions, less lodging and higher yields. Physical properties of the subsoil for this treatment were never altered by clearing or management from their initial condition, and therefore provided a good environment for roots.

Conclusions

1. Most of the changes in soil physical properties occur during the land-clearing process rather than after clearing.
2. Degradation of physical properties due to mechanical land-clearing is sufficient to decrease crop yields if no effort is made to improve soil physical conditions.
3. The least deterioration in soil physical properties occurred in the slash-and-burn treatment.
4. Chiseling and disking after mechanical land-clearing tended to offset some of the undesirable ef-

Table 3. Rice grain for the first and fourth consecutive crops as affected by land clearing, tillage and soil management.

Treatment	Grain			
	Flat/No Fert.	Flat/Fert.	Bed/Fert.	Mean
	Mg/ha			
First crop				
Slash/burn	3.11	3.56	3.98	3.55a **
Straight blade	0.91	2.75	3.38	2.35 cd
Straight blade/Chisel	1.14	2.84	2.85	2.28 cd
Shear blade/burn/disk	2.39	3.06	3.68	3.04 b
Shear blade	1.27	3.02	3.20	2.49 c
shear blade/disk	0.91	2.58	2.74	2.07 d
Fourth Crop				
Slash/burn	0.75	3.48	2.82	2.35 b
Straight blade	0.26	1.56	2.00	1.27 d
Straight blade/chisel	0.70	3.04	2.91	2.22 b
Shear blade/burn/disk	1.58	3.44	2.96	2.66a
Shear blade	0.97	2.13	2.28	1.80 c
Shear blade/disk	0.63	1.83	1.96	1.47 d

Table 4. Soybean grain yields for the second crop as affected by land clearing-tillage and soil management.

Treatments	Grain (Mg/ha)			
	Flat/No Fert.	Flat/Fert.	Bed/Fert.	Mean
Slash/burn	0.42	2.32	1.86	1.53ab **
Straight blade	0.10	1.03	1.50	0.88 d
Straight blade/chisel	0.32	1.44	2.03	1.26abc
Straight blade/burn/disk	0.48	2.17	2.05	1.57a
Shear blade	0.18	1.37	1.87	1.14 cd
Shear blade/disk	0.12	2.01	1.56	1.23 bc

** Means in a given column followed by the same small letter and means in rows followed by the same capital letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

Table 5. Corn height for the third crop and corn grain yield for the fifth crop harvest as affected by land clearing tillage and soil management.

Treatment	Flat/no Fert.	Flat/Fert.	Bed/Fert.	Mean
	Plant height,m			
Third crop				
Slash/burn	0.85	2.58	2.34	1.92a ***
Straight blade	0.00	1.48	2.20	1.23 d
Straight blade/chisel	0.28	2.29	2.35	1.64 bc
Shear blade/burn/disk	1.03	2.63	2.23	1.96a
Shear blade	0.45	2.51	2.25	1.74 b
Shear blade/disk	0.31	2.43	2.03	1.59 c
	Grain yield, Mg/ha			
Fifth crop				
Slash/burn	0.39	2.86	3.30	2.18a
Straight blade	0.00	1.47	1.18	0.88 c
Straight blade/chisel	0.00	1.85	2.87	1.58ab
Straight blade/burn/disk	0.04	2.45	2.82	1.77ab
Shear blade	0.00	1.36	1.76	1.04 c
Shear blade/disk	0.00	0.94	1.95	0.96 c

*** Means in columns for a given harvest followed by the same small letter and means in rows followed by the same capital letter are not significantly different at the 5% level by the Waller-Duncan multiple comparison test.

fects of land-clearing on soil physical properties. For example, the infiltration rates for soil cleared by the mechanized methods were increased by disking and chisel plowing prior to planting the first crop.

5. Declines in soil physical properties under continuous cropping were minimized when soil was bedded using a hand hoe.

6. Slash-and-burn clearing resulted in higher yields for rice, soybean and corn compared to mechanized clearing. Of the mechanical land-clearing and tillage methods examined, shear blade/burn/disk produced the highest rice, soybean and corn yields. All crops showed a positive yield response to treatments in which soils were chiseled or disked after clearing.

Implications

While all of the land-clearing methods examined adversely affect these soils to some extent, traditional slash and burn does the least amount of damage. Machinery can apparently be used to clear secondary forests for crop production if its use is coupled with effective soil-management techniques after clearing. Of the mechanical methods examined, the best alternative to slash-and-burn clearing was a combination of felling with a shear blade, then burning the vegetation on-site as traditionally practiced. However, unless followed by disking or chisel-plowing, this method will tend to produce lower crop yields and less favorable soil properties than traditional slash-and-burn clearing.

Tillage With Tractors In Continuously Cropped Ultisols

Robert E. McCollum, N. C. State University

Before January, 1984, the long-term continuous-cropping experiment at Yurimaguas had been tilled with a small hand rototiller to a depth of 7 to 10 cm since it was first cleared in 1972. While rototilling had been considered a possible intermediate step between hand tillage and tractor-drawn implements, it has several disadvantages: Tillage with rototillers has resulted in a shallow root system limited to the zone of fertilizer incorporation; small rototillers do not properly incorporate crop residues; and rototilling is slow. The objectives of this project are 1) to determine whether tillage with tractor-mounted farm equipment is possible on humid tropical Ultisols; and 2) to determine whether tillage with tractors is agriculturally and ecologically sound in humid tropical environments.

Tillage Practices

An abandoned portion of Chacra I, which is the site of the continuous-cropping experiment at Yurimaguas, was prepared during July-August, 1983 via the following steps: 1) Chop crop residues with rotary mower; allow to dry; burn; repeat as necessary; 2) disk as necessary to reduce remaining residues to a manageable

Table 1. Crop yields on Chacra I after initiating tractor-mounted tillage. Months refer to harvest date.

Comparisons	Rice Jan 84	Corn Jan 84	Corn July 84	Corn Jan 85	Corn[1] July 85
	Grain yields, th/a, and (number of observations)				
General Mean	2.47 (101)	2.96 (42)	3.15 (216)	3.48 (125)	2.90 (36)
Clearing Method					
Burned, 1972:	2.56 (41)	3.00 (8)	3.27 (99)	3.50 (64)	2.70 (15)
Bulldozed, 1972:	2.54 (43)	2.93 (33)	2.93 (90)	3.70 (32)	2.87 (12)
Peripheral Areas[2]	2.10 (17)	3.49 (1)	3.42 (27)	3.19 (29)	3.28 (9)
Lime + P					
None	2.74 (16)	2.35 (17)	2.71 (56)	—	—
Lime + P[3]	2.42 (85)	3.38 (25)	3.30 (160)	—	—
Banded P					
None	—	2.54 (15)	—	—	—
Banded P	—	3.19 (27)	—	—	—

[1] Low Corn population (29,000 plants/ha)
[2] Clearing method unknown
[3] 2.5 t lime/ha + 100 kg/P/ha

bulk; 3) plow to 20-25 cm with a moldboard plow to incorporate plant residues and soil amendments; 4) disk again; 5) make tractor tracks as row markers; 6) construct 75 cm beds; 7) prepare seedbed with rototiller, and 8) plant crop, either by hand or with tractor-mounted Cole planters. Lime and fertilizer applications were consistent with practices developed for Chacra I. Weeds were controlled chemically with metolachlor.

Corn and upland rice were planted in August, 1983 and harvested in January, 1984. The same tillage operations were repeated prior to planting three consecutive corn crops, which were harvested in July, 1984, January, 1985 and July, 1985.

Yields

Product yields during four biological cycles following initiation of tractor-mounted tillage are shown in Table 1. While there were no treatments in an experimental sense, some comparisons based on previous treatment and current management can be made regarding clearing method, and the effects of lime and P.

Clearing Method

The site was cleared in 1972 by bulldozing or by traditional cutting and burning. The data show that any differences between initial clearing methods were virtually eliminated by tilling to 20 cm.

Effects of Lime + Phosphorus

Lime and phosphorus, broadcast before the first crop, increased corn yields but had not effect on rice. In-row banded P resulted in a 26% increase in corn yields during the first cycle.

Observations

Initial observations have been that mechanized tillage is possible on Ultisols in the Yurimaguas environment. Tillage can be accomplished once a year, during the "dry" season, July-September. Mechanized tillage at other times should only be undertaken with strict attention to soil moisture. Continuing work in this area will seek to determine if mechanized tillage is agriculturally and ecologically sound in humid tropical environments.

Continuous Cropping: Central Experiment

Robert E. McCollum, N. C. State University
Pedro A. Sanchez, N. C. State University
Dale E. Bandy, N. C. State University

This experiment is a long-term demonstration of a continuous-cropping system for acid soils of the humid tropics. The system is based on the judicious use of fertilizers and the best available soil-management practices. It occupies eight 10 m by 28 m main plots in each of two fields known as Chacra I (site one) and Chacra III. There were seven fertility-management treatments under each of two rotations, rice-corn-soybeans and rice-peanut-soybeans, and four replications each in 4 x 10 m plots. These plots have been cropped continuously since September of 1972, producing 31 crops to date in Chacra I.

From May, 1982 until January, 1984, the seven fertility-management treatments were:

1. A check, with no tillage and no fertilizer or lime added.
2. Complete fertilization plus 1 kg Mn/ha, applied one month after planting, to the foliage of either corn or peanut.
3. Complete fertilization as follows (in kg/ha/crop): rice, 100 N; corn, 80 N, 30 P, 100 K; and 30 Mg to all crops.
4. Complete fertilization plus 2 kg Mn/ha, applied as in treatment 2.
5. Previous crop residues left on soil and incorporated.
6. Previous crop residues left on soil but not incorporated.
7. 1.5 times the complete fertilization.

This report describes results from July, 1981 to July, 1985, including the harvests of crops 25 through 31 (Table 1). Prior to January, 1984, all of the plots except the check (treatment 1) were rototilled with a hand tractor to a depth of about 7.5 cm. Tillage with tractor-drawn implements to a depth of 20-25 cm was introduced with crop 29, and was used thereafter in the corn crops discussed in this report.

Continous cropping on Chacra III was discontinued in September, 1983. No significant yield differences were noted between Chacras I and III during the last four harvests. Twenty-one crops were harvested from Chacra III within a span of 112 months.

Table 1. Crop yields of continuously cultivated plots from January, 1982 to July, 1985.

Treatments[2]	Crop No., Species and Harvest Date[1]									
	25 Corn 1/82	25 Peanut 8/82	26 Rice 1/83	27 Corn 6/83	27 Peanut 6/83	28 Corn 1/84	28 Rice 1/84	29 Corn 7/84	30 Corn 1/85	31 Corn 7/85
	Yields, t/ha									
1. Check[3]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2. Complete + Mn	2.97a	4.63a	3.04 c	1.93b	2.71a	1.21c	1.51b	1.82ab	2.56c	1.85ab
3. Complete	3.28a	4.39a	3.45b	1.62b	2.74a	1.91bc	1.55b	2.76b	3.02bc	1.56b
4. Complete + 2 Mn	2.87a	4.75a	3.68b	1.88b	2-.76a	2.48ab	1.99a	3.05ab	2.94bc	2.06ab
5. Complete + residue incorporated	3.21a	4.54a	4.48a	1.68b	2.42a	2.76a	2.00a	3.58ab	3.73a	2.80a
6. Complete + residue mulch	3.20a	3.28b	3.71b	2.04b	2.51a	2.61ab	1.44b	3.91a	3.21ab	2.48ab
7. 1.5 x complete	3.49a	4.54	3.54b	2.66a	2.50a	2.31ab	1.80ab	3.06ab	3.15	1.98ab
Mean	3.17	4.35	3.65	1.97	2.61	2.21	1.72	3.20	3.10	2.12
(No. of obs)	8	8	16	8	8	4	4	8	8	8
C.V. (%)	19	14	12	28	15	23	14	27	17	39

[1] Crop yields from 1/82 through 6/83 are pooled data from Chacras I and III; subsequent harvests are from Chacra I only.

[2] Treatments up to crop #28: uniform fertility and conventional tillage to 20-25 cm to all but treatment 1 for crops 29, 30, 31.

[3] Treatment 1 dropped from data array for statistical analysis.

Table 2. Effects of selected treatments on relative yields January, 1982 — January, 1984. Crops 25 — 28 in Chacra I.

Treatment	Corn (3 crops)	Rice (2 crops)	Peanut (2 crops)
		Relative Yield[1]	
3. Complete + residue removed	91 b	94 b	103 a
5. Complete + residue incorporated	104 a	121 a	99 a
6. Compete + residue as mulch	107 a	98 b	86 b
7. 1.5 x complete + residue removed	116 c	99 b	100 a

[1] Mean yield over all treatments within a cycle = 100.

Crop Performance

Yields of crops 25 to 31 from Chacra I: Check-plot yields have been zero for the last ten years. The first five harvests include pooled data from the two chacras because there were no chacra effects. Crop 28 (rice) was affected by pathogen attacks on the grain. Corn crops 29 and 30 showed nitrogen-deficiency symptoms from tasseling to maturity. Crop 31's stand was decreased to 26,700 plants/ha by an intense rainfall (225 mm in six hours) immediately after planting. The following observations can be gleaned from crop performance, expressed as relative yields in Table 2.

Incorporating residues produced significantly higher yields than residue removal in corn and rice, but not on peanut (Table 2). Leaving residues as mulch had a positive effect on corn, neutral on rice, and negative on peanut. Peanuts are more susceptible to attack from soil disease organisms such as *Sclerotium rolfsii*, which causes southern stem rot, when residues remain in the field.

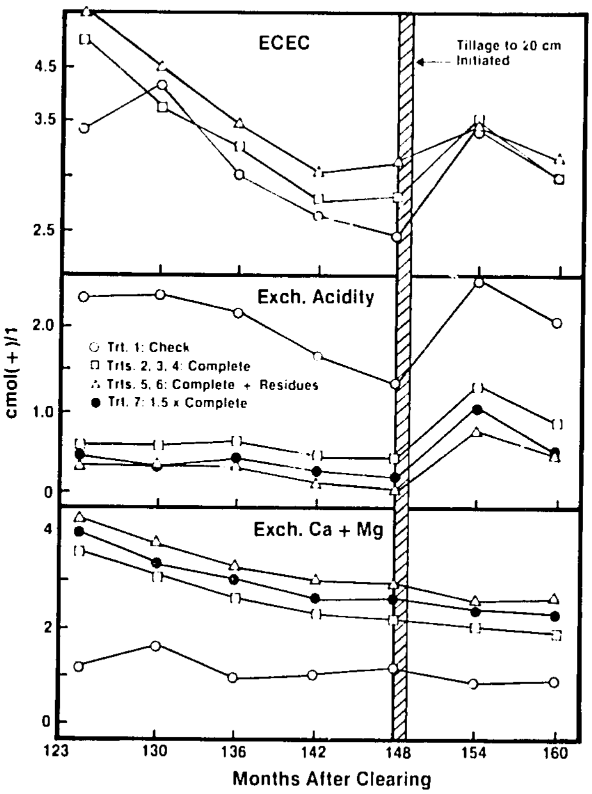


Figure 1. Trends in effective cation exchange capacity (ECEC), exchangeable acidity and extractable Ca-plus-Mg of soil on continuously cultivated plots in Chacra I.

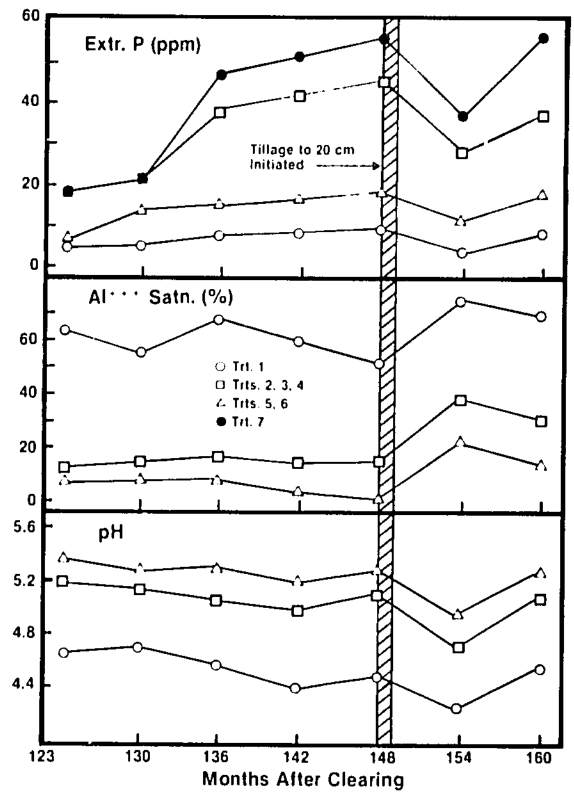


Figure 2. Trends in soil pH, % Al saturation and extractable soil P in soil on continuously cultivated plots in Chacra I. The shaded bar at month 148 represents the first tillage with tractor-mounted tools.

The "1.5 x complete" fertilization treatment produced significantly higher corn yields than others, suggesting the need for N rates greater than 80 kg/ha for this crop. In view of the deficiency symptoms observed, nitrogen may have been the limiting nutrient. Rice and peanut did not display this effect (Table 2).

Topsoil Properties

Figures 1 and 2 show relevant topsoil fertility indices from January, 1982 to January, 1985, during the growth of crops 25 to 30. Treatments 2, 3 and 4 were pooled as the "complete" because they were similar with respect to measured soil properties. Treatments 5 and 7 were likewise pooled to summarize the effect of residue cycling.

The check treatment had the least desirable soil properties in all fertility categories. Returning crop residue showed consistent and statistically higher fertility indices except for P. Obviously, treatments 5 and 6 have received less fertilizer P than treatments 2, 3 and 4. The positive effects of residue return on physical properties were apparent each time the land was tilled.

Lime was applied to these plots at the rate of 2 t/ha four years before the results shown in Figures 1 and 2. Soil-acidity indices were stable with less than 20% Al saturation in treatments other than the check plot. This observation indicates a considerable residual effect of lime.

Effects of Tillage to 20-25 cm

There was an abrupt change in most fertility indices when the soil was tilled to 20 cm. Soil pH and available P dropped while exchangeable acidity, percent Al saturation and effective cation exchange capacity increased. Exchangeable Ca + Mg remained stable, however. These changes are a consequence of mixing a less fertile and heavier-textured, 7-20 cm soil layer with the 0-7 cm topsoil. The situation was beginning to stabilize by the third crop under the 20 cm tillage regime, because the lime and incorporated fertilizers were then well mixed with a 20 cm plowed layer.

Conclusions

1) Returning crop residues, either by incorporation or as mulch, had a slight positive effect on corn and rice, but not on peanut.

2) An apparent response of corn yields to fertilizer in the "1.5 x complete" treatment, together with observed symptoms of N deficiency, suggest that N fertilization should be increased for this crop, though not for rice.

3) Most indices showed abrupt declines in soil fertility immediately after the introduction of tillage to 20 cm and the mixing of subsoil with topsoil. Testable fertility improved by the third crop, however, as lime and fertilizers were more thoroughly mixed in the soil.

Implications

After 31 harvests in 12 years, yields of corn, rice and peanut remain high by local standards. With judicious use of lime and fertilizers, it is apparent that acid soils in the humid tropics will produce acceptable yields of short-cycle food crops under continuous cultivation. It is also apparent that soil chemical properties can be improved while producing high yields.

Production Potential of Corn-Peanut Intercrops in the Humid Tropics

José R. Benites, N.C. State University
Robert E. McCollum, N.C. State University
Andres Aznaran, INIPA

This experiment was conducted to compare the productive efficiency of a corn-peanut intercrop with monocultures (sole crops) of the intercrop components grown in rotation and with continuous corn. A second objective was to determine the effect of nitrogen fertilization on cropping-system efficiency. Corn (*Zea mays* L.) and peanut (*Arachis hypogea* L.) were grown in a "strip-intercrop" arrangement for three biological cycles (trimesters). The strip-intercrop consisted of two 75 cm rows of corn in an alternating pattern with three 38 cm rows of peanut. This row arrangement permitted the intercrop to be grown as a corn-peanut rotation. Monocultures of the interplanted species, with corn in 75 cm rows and peanut in 38 cm rows, served as the reference standard (monocultre check) during each cycle. These monoculture checks were also grown as a corn-peanut rotation. The third cropping system was continuous corn.

Corn in both monoculture and intercrop received three levels of N fertilization (0, 100, or 200 kg N/ha), and the experiment was arranged in a split-plot design with four replications. Main plots were cropping system, and subplots were N fertilization. The experiment site was an Ultisol that had been limed and phosphated before initiating the experiment.

All three cropping systems were planted with tractor-mounted planters on the same date. Within-row seeding rates were the same for each species in each

Table 1. Yields of corn grain and peanuts as influenced by applied nitrogen and cropping systems.

Cropping Systems	Species & Trimester	Crop duration	N Rates (kg/ha) 0	100	200
		days	yield, kg/ha		
Strip Intercrop:					
Corn/Peanuts:	Corn (1)	108	779	1751	1602
	Peanuts (1)	110	1034	782	795
	Corn (2)	109	1806	1980	2297
	Peanuts (2)	111	243	175	210
	Corn (3)	119	1652	2295	2365
	Peanuts (3)	122	357	299	322
Suequential monocultures:					
Corn → Peanuts → Corn:					
	Corn (1)	108	917	2625	3218
	Peanuts (2)	111	1086	1086	1086
	Corn (3)	119	2595	3450	3185
Peanuts → Corn → Peanuts:					
	Peanuts (1)	110	2275	2275	2275
	Corn (2)	109	3191	3800	3758
	Peanuts (3)	122	859	1092	855
Corn → Corn → Corn:					
	Corn (1)	108	861	2757	3227
	Corn (2)	109	2441	3590	3561
	Corn (3)	119	2334	3106	3692
			Trimester 1	**Trimester 2**	**Trimester 3**
Corn	LSD 0.05 Cropping system		452	303	330
	LSD 0.05 Nitrogen level		232	257	389
	LSD 0.05 Int. CS x N		557	472	640
Peanuts	LSD 0.05 Cropping system		544	184	226
	LSD 0.05 Nitrogen level		56	36	119
	LSD 0.05 Int. CS x N		547	188	260

system. While this methodology provided near-equivalent total plant densities for each cropping system, it should be noted that the corn-peanut intercrop had only one-half as many corn plants and one-half as many peanut plants as its companion monocultures.

Product Yields

Corn was virtually unaffected by its association with peanuts (Table 1); the intercrop produced more than 60% of its reference monoculture during each cycle (average relative yield of intercropped corn during three cycles = 0.64). The N response was positive for all cropping systems, and yields were near-maximal at 100 kg N/ha. There is some evidence that corn following peanuts was less responsive to N than corn following corn (Figure 1).

In contrast to corn, the yield of interplanted peanuts was severely reduced by overstory corn. When averaged over three cycles, the intercrop produced 31% of its monoculture check. Peanut plants were severely affected by *Cercospora* leaf spot during the second cycle, and the detrimental effect of this pathogen seemed more pronounced in the intercrop.

Intercrop Efficiency

Table 2 shows the effect of N fertilization on area-time equivalency ratios (ATER) during each cycle (ATER = LER because intercrop duration equals production-cycle duration for each species). When corn was grown without N fertilization, the corn-peanut intercrop used area and time more efficiently than monocultures (ATER > 1.0) during two of the three cycles. When corn was fertilized with 100-plus kg

Table 2. Effects of N fertilization to corn in a corn-peanut intercrop on Area-Time Equivalency Ratio during three biological cycles.

kg N/ha to corn	Cycle 1	Cycle 2	Cycle 3	N Mean
		ATER[1]		
0	1.34	0.78	1.05	1.06
100	0.97	0.67	0.94	0.86
200	0.84	0.81	1.00	0.88
Cycle Mean	1.05	0.75	1.00	0.93

[1]ATER relative to sole-crop corn and sole-crop peanuts in the corn-peanut rotation.

Table 3. Effects of N fertilization and cropping systems on rate of caloric yield and relative croppping-system efficiency.

Cropping System	N Fertilization (kg N/ha) 0	100	200	CS Mean
		Caloric Yield M cal/ha/year		
Cont. Corn	16.36	27.44	30.42	24.74
Corn-Peanut Rotation	20.06	25.29	25.12	23.49
Corn-Peanut Intercrop	20.34	23.68	24.71	22.91
N Mean	18.92	25.47	26.75	
		Relative Efficiency (Continuous Corn = 100)		
Corn-Peanut Rotation	123	92	83	99
Corn-Peanut Intercrop	124	86	81	97
N Mean	124	89	82	

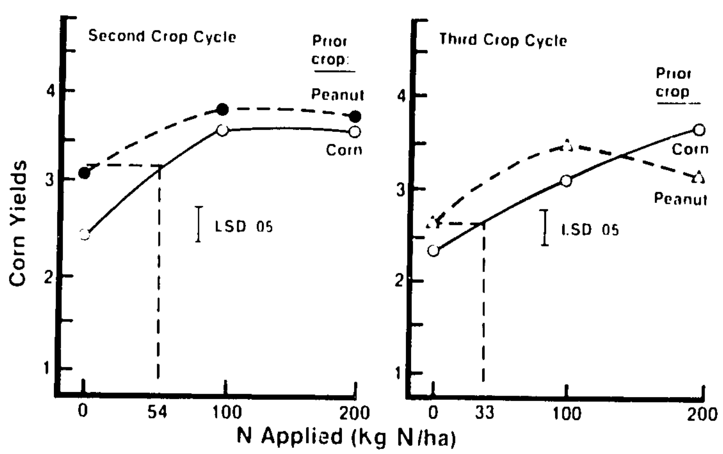


Figure 1. Apparent N carryover from preceeding peanut crops to subsequent corn crop.

N/ha, however, there was no evidence of any intercrop advantage (ATER = < 1.0). Low ATER's during the second biological cycle were due exclusively to extremely low relative yields of interplanted peanuts (relative peanut yields = 0.19 for cycle two versus 0.40 for cycles one and three). This observation lends support to the earlier supposition that *Cercospora* leaf spot was more severe in the intercrop.

Cropping-System Efficiency

Continuous corn was compared with the two corn-peanut rotations by converting absolute yields to caloric equivalents and summing over three cycles. Effects of cropping system and N fertilization on the rate of caloric yield (Mcal/ha/yr) are shown in Table 3. (All entries in Table 3 are comparable because each entry sums over three harvests of the relevant species). Implications from the Table 2 data are quite clear: 1) Without fertilizer nitrogen, the two systems that include peanuts are significantly superior to continuous corn in storing energy; but 2) continuous corn with adequate N (100-plus kg/ha) gives a higher rate of caloric yield than the corn-peanut intercrop or monocultures of its components grown in rotation. If, in fact, caloric yield were the principal basis for decision making, the only near-equivalent system to well-fertilized continuous corn would be continuous peanuts (approximately 25 Mcals/ha/year, not shown).

Implications

A two-crop intercrop of corn and peanuts may have merit under low-N regimes in humid tropical environments. In most such environments, however, the inherent soil condition is high acidity (high exchangeable aluminum) and low phosphorus. These initial conditions must be corrected with massive doses of lime and phosphorus before either species can be expected to produce the yields reported here.

There are some other favorable aspects to the intercrop system described here:

1. Three cycles per year are possible because each species can be grown year-round and because all have nearly identical production-cycle durations.
2. Most field operations can be done with machines or by hand.
3. Since the strip-intercrop system can be managed as a corn-peanut rotation, there may be some nitrogen carryover from the peanuts to the following crop of corn.

Phosphorus, Zinc and Copper Fertilization

Robert E. McCollum, N. C. State University
Luis Arevalo, INIPA
Andres Aznaran, INIPA

This project evolved after observations on several Yurimaguas sites suggested that band-applied phosphorus induces a micronutrient deficiency in corn. The phenomenon was first observed in an experimental field that had been limed and fertilized with N, P, K, Mg, Cu and Zn at recommended rates. The first corn crop had been machine-planted in January, 1984 with TSP in the fertilizer hoppers. Within ten days after corn emergence, virtually the entire planting had developed a chlorosis symptomatic of Zn deficiency. The possibility of a micronutrient toxicity was ruled out because the rate of Zn or Cu applied was only 1 kg/ha.

In response to these observations, a project was designed to meet the following objectives: 1) to determine the effect of banded phosphorus fertilizer on growth and yield of corn on continuously cropped Ultisols; 2) to explore the hypothesis that band-applied phosphorus exacerbates zinc deficiency on low-Zn soil, and 3) to determine if the nutritional abnormalities induced by band-applied phosphorus can be ameliorated by applying zinc or copper to the soil.

In July-August of 1984, eight plots (two contiguous sets of four plots each) that had not received lime or phosphate recently were selected for a "banded-P (BP) by soil zinc" experiment. All plots received applications of lime (2.5 t/ha), phosphate (100 kg P/ha) and copper (4 kg Cu/ha). Zinc variables were to have been 0, 2, 4, and 8 kg Zn/ha in 7.5 m by 12 m plots with eight replications, but an error resulted in a double application of P, Cu and Zn on one four-plot group and a double application of lime on two of them. Instead of one experiment with eight replications, this dosage error made it necessary to consider the "zinc by banded-P" endeavor as two separate experiments: 1) a three-factor experiment (2 lime x 4 zinc x 2 BP) with two replications, and 2) a two-factor experiment (4 zinc x 2 BP) with four replications.

At the same time (July-August, 1984), a second contiguous, eight-plot area that had received lime and phosphate a year earlier was selected for a "zinc by copper by banded-P" experiment. Copper was applied at 0 and 4 kg/ha in factorial combination with 0, 2, 4 and 8 kg Zn/ha. All plots were plowed, disked, bedded, and rototilled. For the first corn crop (September, 1984 to January, 1985), the banded-P treatment was achieved by planting four rows without banded P and six rows with banded P. This P-banding procedure was reversed for the following crop.

Crop Yields

Corn showed statistically significant, positive responses to applications of banded P, broadcast Zn and broadcast Cu in terms of grain yields and plant populations (Tables 1 and 2), but there was no "Zn x banded P" or "Cu x banded P" interaction. Plant population was much lower in the second crop because of intense rainfall (226 mm in six hours) immediately after planting (Tables 1 and 2), and poor product yields for this cycle are primarily the result of low plant density.

Table 1. Corn grain yields and plant population as affected by boradcast ZN and banded P application in two consecutive crops

Corn Crop (Harvest Date)	Zn Applied	Banded P Applied		Mean (Zn)	Banded P Applied		Mean (Zn)
		No	Yes		No	Yes	
		Yield, t/ha			1000 Plants/ha		
Jan 85	None	2.42	3.08	2.75	36.0	38.2	36.8
	Yes*	3.32	3.43	3.38	36.3	37.3	37.1
Mean (BP)**		3.09	3.34		36.2	37.6	
July 85	None	1.79	2.01	1.90	20.5	25.5	23.0
	Yes	2.28	2.59	2.44	24.3	27.1	25.7
Mean (BP)		2.16	2.45		23.4	26.7	

* Means of 2, 4 and 8 kg Zn/ha (36 plots) vs. 12 plots for 0 Zn.
** Weighted means.

Table 2. Corn grain yields and plant population as affected by broadcast Cu and banded P application in two consecutive crops.

Corn Crop (Harvest Date)	Cu Applied[1]	Banded P Applied No	Banded P Applied Yes	Mean (Cu)	Banded P Applied No	Banded P Applied Yes	Mean (Cu)
	kg/ha	Yield, t/ha			1000 Plants/ha		
Jan 85	0	3.06	3.27	3.17	33.6	35.0	34.3
	4	3.72	3.71	3.72	34.8	37.7	36.2
Mean (BP)		3.39	3.49		34.2	36.3	
July 85	0	1.80	2.51	2.15	20.1	25.0	22.6
	4	2.39	2.52	2.46	23.3	24.6	24.0
Mean (BP)		2.09	2.52		21.5	24.8	

[1] Extractable Cu levels in the soil were 0.94 and 2.05 ppm Cu for levels 0 and 4 kg Cu/ha.

Banded P

Banding P increased corn yields by 8 and 13% in the P-Zn plots (Table 1), and by 3 and 21% in the P-Cu plots (Table 2), with an average overall effect of 11%. While some of these apparent treatment effects were related to increased plant population, there was a marked growth response to banded P, which, unlike similar experiences in North Carolina, was reflected in grain yields.

Zinc Response

Corn responded significantly to the first increment of Zn (2 kg/ha). Since there was no significant response to the second or third increment in applied Zn, all plus-zinc treatments (2, 4, 8, or 16 Zn/ha) were pooled, and the data analyzed as a minus-Zn versus plus-Zn experiment. Data from all relevant plots in the "zinc by copper by banded-P" experiment were analyzed with the Zn-banded P data, and are included in Table 1.

Zinc plus banded P applications caused a 42% yield increase in the first crop with no effect on plant population (Table 1). Zinc alone caused a 23% yield increase. Zinc plus banded P and Zn alone caused a similar yield increase in the second crop, and a 12% increase in plant population.

Copper Response

Response trends for the "copper by banded-P" data are highly positive. Incorporating 4 kg of Cu/ha in the top 20 cm of soil caused a 6% population increase during each cropping cycle but a 14-17% increase in yield (Table 2).

Plant Population

This study underscores the difficulty of assessing treatment effects in crops whose populations are variable or inadequate because of such factors as heavy rainfall, poor seed quality or inconsistencies in sowing and thinning. A clear-cut estimate of treatment effects is confounded by the fact that additions of banded P and micronutrients affect not only the growth and yield of individual plants but also the number of plants that emerge.

The positive relationship between band-applied P and plant population has been apparent in virtually every banding vs. no-banding comparison to date. Figure 1 shows the relationship between plant population and yield when the comparison was first made (January, 1983 corn harvested from Chacra I, one of the original experimental fields at Yurimaguas). Banded

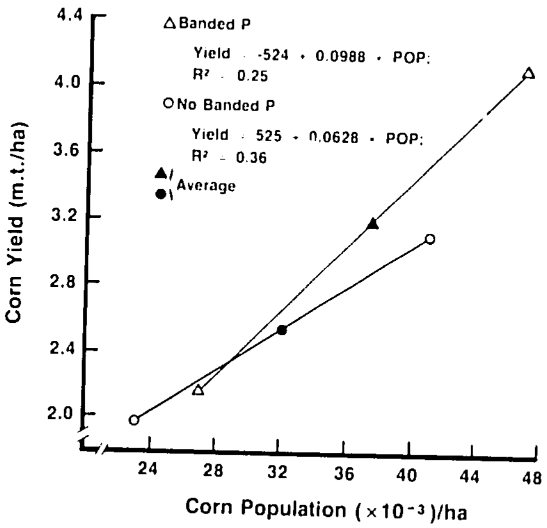


Figure 1. Relationship between corn population and grain yield with and without banded-in-row P.

P not only resulted in a higher plant population at harvest, but the slope of the yield vs. population curve was also steeper. Yield versus population curves have also been generated for other examples, and they show the same trends for more surviving plants with band-applied P. The slopes of the curves show that each additional 1000 plants up to 50,000 plants/ha produces an additional 60 to 120 kg of grain. These calculations also show that the corn population is usually inadequate. In no instance has there been a significant quadratic response to population, and only rarely have there been 50,000 plants/ha.

Observations

While it is too early to draw firm conclusions from this study, preliminary observations suggest the following:

1) Corn yield and plant populations significantly responded to banded P and broadcast Zn or Cu.

2) Although there has been no apparent effect of banding P on the response of corn to Zn or Cu in the first two crops (no measureable banded P x micronutrient interaction), yields were low because of reduced population density. Since plant population was also treatment-related, the effects of treatment on product yield are confounded with population effects.

3) While the observed chlorosis was corrected by micronutrients, the initial hypothesis is still unproven.

Potassium, Lime and Magnesium Interactions and Corn Yields

Rob Schnaar, Wageningen University
Robert E. McCollum, N.C. State University

A lime-by-potassium study was initiated at Yurimaguas during July and August, 1984. The objectives of this study were 1) to construct a potassium response curve for continuously cropped Ultisols in humid tropical environments; 2) to estimate a critical soil K level for corn in the soils; 3) to quantify the recycling of K via crop residues in the soils; and 4) to determine the effect of lime on K responses by food crops, K utilization by crops, and K retention in the soils. A between-site magnesium variable was introduced because two liming materials were used. While this was not part of the original plan, site-related yield differences provided some useful insights about cation balance and Mg nutrition.

Two experimental sites were selected because the soil represents the textural extremes for upland positions in the Yurimaguas environment (Table 1). At site #1, the top 45 cm of soil is a clay loam and its texture grades to clay between 45 and 60 cm. Site #2 has a transitional sandy loam—sandy clay loam surface (0-20 cm) with little or no textural change to 60 cm.

Procedures

Each site was cleared of secondary forest with a bulldozer in 1980 and left to regrow without chemical amendments. The sandy site was recleared and made

Table 1. Textural characteristics and effective cation exchange capacity (ECEC) of two Ultisols used for lime-by-potassium studies at Yurimaguas.

Depth Range cm	Site No.	Sand	Clay	Textural Class	ECEC
		%	%		meq/100cm³
0-20[1]	1	40	31	Clay Loam (C1)	4.66
	2	62	21	Trans. S1-SC1	2.69
20-30	1	35	37	C1	5.20
	2	58	25	SC1	3.28
30-45	1	38	36	C1	5.80
	2	52	29	SC1	3.63
45-60	1	36	42	C	6.86
	2	52	32	SC1	3.89

[1] Texture of surface layer determined after mixing to 20cm

tillable in mid-1983. It was then used for about one year to screen germplasm (rice, cowpeas, corn) for aluminum tolerance with a lime differential of 0 and 2.0 t/ha [lime source = $Ca(OH)_2$] as main plots. The lime was incorporated to 20 cm by routine tillage when the site was acquired.

The clayey site was renovated by mowing and plowing to 20 cm. The soil was sampled in detail. Initial soil properties were: pH = 4.6; Ac = 3.78; Ca + Mg = 0.89; Al satn. = 81%; K = 0.07., P = 3ppm. A factorial experiment consisting of three rates of lime and five rates of K was established. Lime levels (whole plots) were chosen to neutralize 0, 50% and 100% of the exchangeable acidity in the top 20 cm (0, 2, and 4 t/ha). One-half of the intended lime dose (dolomitic limestone) and one-half of the intended blanket doses of P, Zn, and Cu (100, 8, and 4 kg/ha,

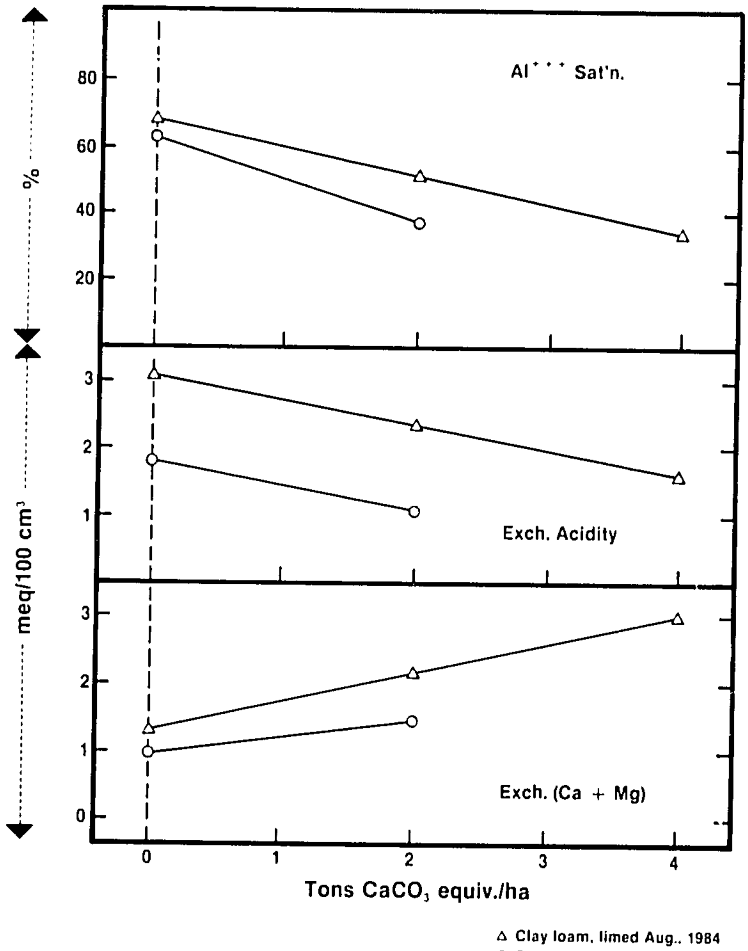


Figure 1. Effect of liming on two Yurimaguas Ultisols on pH-related properties. Both sites sampled in January, 1985.

respectively) were applied to the once-plowed soil and incorporated by plowing again with a two-bottom moldboard plow. After the second plowing, the remaining half of the various soil amendments [lime source = $Ca(OH)_2$] was applied and incorporated by routine disking, bedding and rototilling.

Potassium treatments (sub-plots) were selected to increase the K level in the top 20 cm of soil by 0, 0.05, 0.10, 0.15, or 0.20 meq $100/cm^3$ (0, 39, 78, 117, and 156 kg K/ha). The potassium (as KCl) was hand-drilled on the bedded rows and incorporated by routine pre-plant rototilling.

Corn was machine-planted on each site in late September of 1984 (harvested January, 1985). Nitrogen fertilization (as urea) was 150 kg N/ha with one-third of the total applied pre-plant and the remaining two-thirds at about 40 days after corn emergence. Total dry matter accumulation at early ear formation (maximum K accumulation) was estimated by harvesting and processing for analysis six whole plants per subplot. The soil was sampled to 60 cm (0-20, 20-30, 30-45, and 45-60) at corn maturity and analyzed for relevant properties.

A second corn crop was planted in late March of 1985 with the same K additions as indicated for cycle one, but excessive rainfall of high intensity resulted in a low plant population as well as poor weed control, and no meaningful treatment-related yield data were obtained. The following summary of treatment effects on soil properties as well as product yield is for the first biological cycle only.

Soil Properties

Two tons of lime applied to the sandy loam soil in 1983 had reduced aluminum saturation from 62% (pH = 4.4) to 38% (pH = 4.7) when the soil was sampled about 18 months later (Figure 1). On the clay loam soil, aluminum saturation at about six months after applying 0, 2, or 4 tons of lime was 68% (pH = 4.3), 52% (pH = 4.5) and 34% (pH = 4.8), respectively. Other pH-related properties followed predictable trends (Figure 1), but there was no measurable increase in effective cation exchange capacity (ECEC) due to liming.

Extractable soil potassium in the top 20 cm of soil was a linear function of K applied on each site (Figure 2), but the steeper response slope for the sandy soil shows that a higher percentage of the K applied was recoverable by the extractant used. These results are typical for soils of differing texture.

Product Yields

Grain yields on the sandy soil were less than 50% of those measured on the clay loam soil (Table 2). While there was a positive response to lime on each site, the only measurable response to K was on the clay loam soil, and grain yields on this soil were near-maximal with 78 kg K/ha. Figure 3 shows the relationship between aluminum saturation and corn yield when data from the two sites were pooled. Since absolute yields from the two soils differed drastically, a "relative yield" was first calculated (Relative yield = 100 * absolute yield/mean maximum yield at each site), and relative yields were regressed on the percentage of aluminum saturation. The data show that corn yields are maximal when aluminum saturation is around 30% of the cation exchange capacity. They are therefore in close agreement with results from similar studies on Utisols in southeastern U.S. environments.

Since the clay loam soil was the only site with a measurable K response, yield data from this experiment were used to estimate the "critical" soil K level for corn in this environment. Figure 4 shows that yields were near maximal when extractable soil K was 0.12 meq/100 cm³. Given the fact that these were among the highest corn yields ever recorded for upland positions at Yurimaguas, the data should provide the most reliable estimate to date of the critical K level; but similar data from succeeding corn crops and other soils are needed to confirm this estimate.

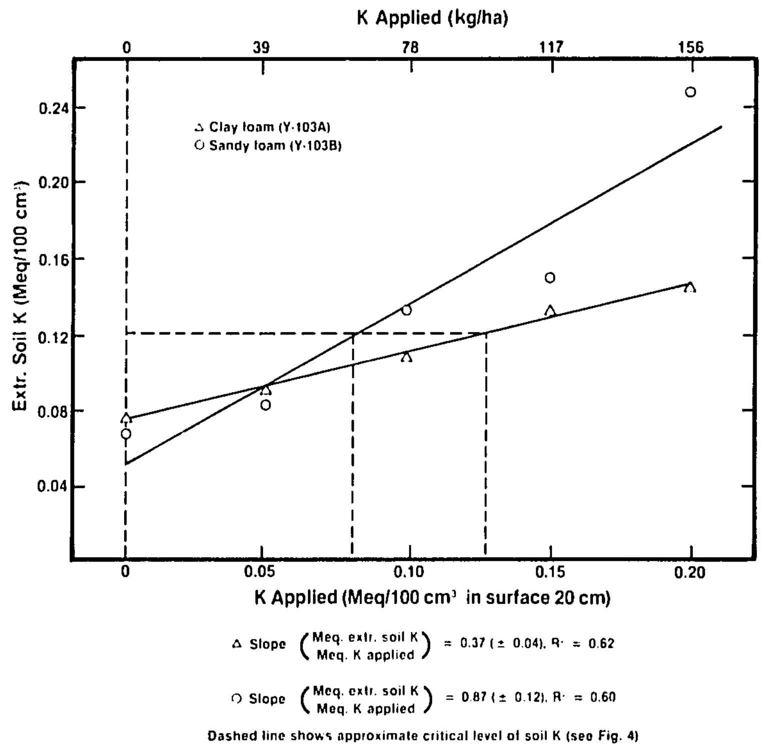


Figure 2. Effect of applied potassium on extractable soil K in two Yurimaguas Ultisols after one biological cycle (six months).

Table 2. Effects of lime and potassium applications to two Yurimaguas soils on corn yield. Jan. '85 harvest.

Soil	Kg K/ha	Tons of Lime/ha: 0	2	4	K Mean
		kg grain/ha			
Clay Loam	0	3724	4525	4968	4406
	39	3823	5409	5535	4922
	78	3750	5460	6074	5095
	117	4197	5587	5619	5134
	156	3653	5810	5598	5020
	Lime Mean	3830	5358	5559	4916
	LSD (0.05); K = 48; Lime = 503; Lime x K = NS.				
Sandy Loam	0	968	2653	—	1810
	39	1889	2517	—	2203
	78	1522	2443	—	1982
	117	1672	2761	—	2216
	156	1592	2794	—	2193
	Lime Mean	1529	2634	—	2081
	LSD (0.05); K = NS; Lime = 819; Lime x K = NS.				

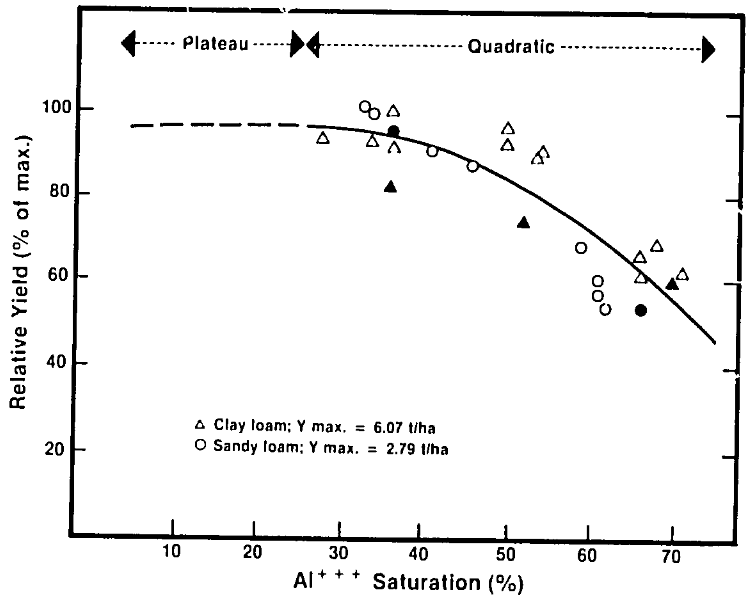


Figure 3. Effect of Al saturation in two Yurimaguas Ultisols on corn yield. Quadratic part: Relative yield = 82.64 = 1.045 (Al^{+++} sat'n)², R^2 = 0.48. Solid symbols: K = 0.

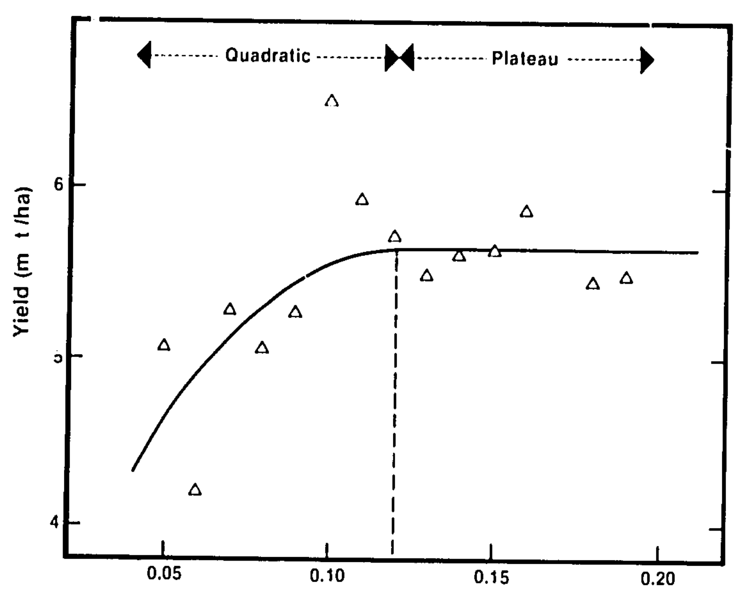


Figure 4. Effect of soil potassium in a heavy-textured (clay loam) Yurimaguas Ultisol on corn yield (each symbol is the mean yield of one to eight observations at indicated level of soil K). Quadratic part: Yield = 2.65 + 49.66K - 205.5K². "Critical" K level = 0.12 meq/100cm³.

Potassium Recycling

Whole-plant samples taken at early ear formation were used to estimate the amount of K returned to the soil in corn stover.

Since K accumulation by corn is maximal at ear formation, any K not removed in the grain is returned to the soil. Harvested corn grain was not analyzed for K, but its concentration in mature corn seed is virtually constant at about 0.30%; and this value was used to estimate K removal. "Recycled" K was then estimated as total plant K at ear formation minus K removed in the grain, and a relationship between product yield and recycled K was shown by least-squares multiple regression (Figure 5).

Several features of Figure 5 merit special comment: 1) Data from the two sites could not be pooled because the sandy loam produced as much vegetative dry matter as the clay loam but less than one-half as much grain; 2) recycled K was a linear function of product yield at each site, but the rate of K recycling was greater on the low-yielding sandy loam soil—(recycled K (sandy loam) = 0.022 kg K/kg grain versus 0.016 kg K/kg grain (clay loam))—because a smaller percentage of silking-stage potassium was stored in grain; 3) recycled K is highly correlated with silking-stage dry matter; and 4) all of the Figure 5 data serve to emphasize the point that nutrient cycling via crop residues is a critical component of fertility maintenance.

Site #1 versus Site #2

With one exception (the exception being soil texture and other properties associated with texture), these two experiments were supposed to be conceptually identical. Obviously, they were not identical in practice, and it seems worthwhile to speculate on a probable cause for the two-fold yield difference between the two sites. The clues point to a problem in cation balance (Table 3).

Limed plots on the clay loam soil received a sizeable dose of magnesium (120 or 240 kg Mg/ha) because dolomitic limestone (12% Mg) was used. The sandy loam soil, by contrast, was limed with $Ca(OH)_2$ and no magnesium was applied. By virtue of using two different liming materials, widely differing soil chemical environments were created on the two experimental sites (Table 3-A), and silking-stage cation concentrations, as well as concentration ratios in corn plants (Table 3-B), are a direct reflection of the suite of nutrient cations in the soil that produced them.

While the Table 3 data do not "prove" that the sandy loam soil was deficient in magnesium, they do show that limed plots on the clay loam site were well supplied with this element, and several pieces of evidence support the view that magnesium nutrition was at least a part of the problem on the sandy soil:

1) In the unaltered state, each soil was "nutritionally low" in Mg (0.18 and 0.12 meq/100 cm^3 soil) because Mg saturation of the exchange complex was less than 5% (5% Mg saturation is considered a "limiting value" for many crops).

2) After liming with dolomite, extractable Mg as well as percent Mg saturation in the clay loam soil increased in direct proportion to the amount of Mg applied; two tons of slaked lime on the sandy soil had no effect on extractable Mg nor Mg saturation.

3) Two tons of dolomite on the clay loam lowered the Ca:Mg ratio in the soil by 22%; two tons of slaked lime on the sandy loan raised this ratio by 48%.

4) On the clay loam soil, whole-plant Mg concentration in silking-stage corn increased in direct proportion to extractable soil Mg. Corn grown on the sandy loam had less tissue Mg than the unlimed check of the clay loam, and it was virtually unaffected by treatment.

5) Without lime, the ratio of Ca to Mg in corn tissue was the same on both sites. This ratio was decreased by liming the clay loam soil with dolomite; it was increased when soil acidity in the sandy soil was neutralized with $Ca(OH)_2$.

6) On the sandy soil, there was a significant positive effect of K fertilization on the K:Mg ratio in silking-stage corn plants (K/Mg = 2.15 when K = 0., K/Mg = 4.19 when K = 156 kg/ha); the effect of K treatment of the K:Mg ratio was not measurable on the clay loam.

7) There was a highly significant positive response to K on the clay loam soil (Table 2); there was no measurable response to K on the sandy soil.

None of these observations constitutes direct cause-and-effect support for the Mg-deficiency hypothesis. They do show, however, that the suite of cations in the two soils and in the plants differed appreciably because the practices followed were not comparable. It is also clear that a high-lime, high-Mg clay loam soil produced 5.5 tons of corn per hectare during the same period that a high-lime but low-Mg sandy soil was producing less than half as much. Furthermore, the yield-component data of Table 3 suggest that the sandy-soil problem was associated with pollenation and grain filling. Each site produced comparable amounts of silking-stage vegetative dry matter and would appear to have similar yield potentials. Yet the clay loam

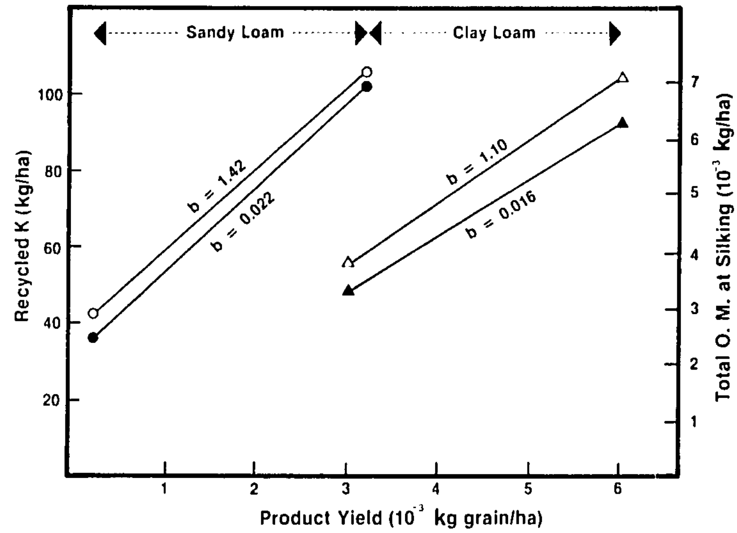


Figure 5. Relationship between 1) corn yield and silking-stage dry matter (open symbols), and 2) corn yield and potassium recycled in corn stover (closed symbols). Corn grown at the same time on differing soils in the Yurimaguas environment. Data plotted over range in product yield for each site.

soil produced nearly 50% more ears per plant (0.94 vs 0.64), and the harvested ears were more than twice as large (208 vs 98 g/ear). The relatively minor difference in soil texture is not considered to be the cause for the large differences in reproductive behavior. The Mg-deficiency hy; othesis is therefore the more plausible; it is supporte ', though indirectly, by the data at hand.

Summary

In summary, the explanation for the widely differing corn yields between the clayey site and the sandy site follows: Initially, the soil on each site was too high in exchangeable aluminum and too low in bases (K, Ca, and Mg) to produce corn. When the clay loam was limed with dolomite, the Mg problem was resolved simultaneously with the acidity and Ca problems, and corn responded to K fertilization as hypothesized. Liming the sandy soil with $Ca(OH)_2$ resolved two of the initial problems (acidity and Ca), but it intensified the inherent Mg deficiency.

This "imbalance" in nutrient cations was further exacerbated by each increment in K fertilization, and corn could not respond to K because inadequate Mg had become the principal growth-limiting factor.

Table 3. (A) Properties of the soil on two sites used for lime-by-K experiments at Yurimaguas; and (B) some characteristics of corn plants grown on each site under near-equal aerial environments.

A. Soil Property	Site No. 1	Site No. 2
1. Textural class (0-20cm)	Clay loam	Sandy loam
2. ECEC (meq/100cm³)	4.66	2.79
3. Mg applied (kg/ha)[1]		
Lime (t/ha) = 0	0	0
Lime (t/ha) = 2	120	0
Lime (t/ha) = 4	240	—
4. Extractable Mg (meq/100cm³)[2]		
Lime (t/ha) = 0	0.18	0.12
Lime (t/ha) = 2	0.36	0.13
Lime (t/ha) = 4	0.58	—
5. Mg saturation (%)		
Lime (t/ha) = 0	3.8	4.3
Lime (t/ha) = 2	7.7	4.7
Lime (t/ha) = 4	12.4	—
6. Cal mg		
Lime (t/ha) = 0	6.82	9.25
Lime (t/ha) = 2	5.31	13.73
Lime (t/ha) = 4	4.54	—

B. Plant Characteristic	Site No. 1	Site No. 2
1. Harvested population (plants/ha)	36350	39560
2. Total dry matter at silking (Kg/ha)	5884	5528
3. Product yield (Kg grain/ha)	4916	2081
4. Ears per plant	0.94	0.64
5. Weight per ear (gm)	208	98
6. [Mg] at silking (%, whole-plant)		
Lime (t/ha) = 0	0.18	0.14
Lime (t/ha) = 2	0.26	0.17
Lime (t/ha) = 4	0.34	—
7. [cation] at silking (meq/100gm0)[3]		
Lime (t/ha) = 0	67	62
Lime (t/ha) = 2	86	73
Lime (t/ha) = 4	89	—
8. Ratio: total cations/Mg, at silking[4]		
Lime (t/ha) = 0	4.75	5.52
Lime (t/ha) = 2	4.14	5.41
Lime (t/ha) = 4	3.36	—
9. Ratio: Ca/Mg, at silking[4]		
Lime (t/ha) = 0	1.10	1.13
Lime (t/ha) = 2	0.97	1.45
Lime (t/ha) = 4	0.83	—
10. Ratio: K/Mg, at silking[4]		
K (Kg/ha) = 0	2.06	2.15
K (Kg/ha) = 39	1.88	2.51
K (Kg/ha) = 78	2.06	3.47
K (Kg/ha) = 117	2.20	3.52
K (Kg/ha) = 156	2.40	4.19

[1] One-half of the limestone applied to site -1 was dolomitic (12% Mg); site -2 was limed with $Ca(OH)_2$.
[2] All soil chemical data are based on samples taken at crop maturity.
[3] [cation] = summation of Ca, Mg, and K (chem. equivalents).
[4] Ratios are as chemical equivalents.

Weed Population Shifts Under Continuous Cropping Systems

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, however, could be expected to require a comprehensive program of weed management, probably including the use of chemical herbicides. The objective of this project was to test the following hypotheses:

1) A given set of weed-control measures, if practiced over time, will cause a change in the spectrum of weed species. With intensive chemical control, a few species will become dominant, requiring new control measures.

2) Effective weed-management programs can be devised for high-input, continuous-cropping systems in the Amazon Basin.

A split-plot experimental design was used in a rice-corn-soybean-rice-corn rotation. Weed-control practices in rice were the main plot treatments; methods of weed control in corn and soybeans represented split-plot treatments. In rice, the herbicides used were propanil and oxadiazon; in corn, metolachlor, and in soybeans, 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.

Observations

Analysis of data from this experiment has not yet been completed. Therefore, only preliminary conclusions and observations will be given.

Grassy weeds are by far the most important weed problem in continuously cultivated, short-cycle food crops (Table 1). *Rottboelia exaltata*, an annual grass, is potentially the most noxious weed (Figure 1). *Rottboelia* cannot be controlled in corn except by hand weeding, and controlling it in rice and grain legumes requires a large herbicide input. In corn and soybeans, the continued use of metolachlor alone eliminates all weeds except *R. exaltata*, which establishes pure stands among the crops.

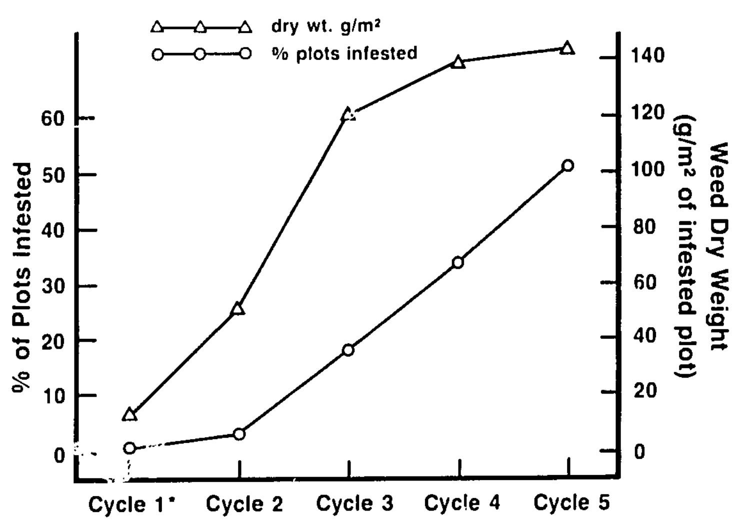


Figure 1. Trends in the level of infestation by *R. exaltata* during five production cycles. Yurimaguas, 1983-84.

Table 1. Weight and composition of weed population during five production cycles.

Cycle/Crop	Total dry wt* g/m²	BLW** (% of total)	Grasses (% of total)	Other Monocots (% of total)
1/Rice (11-83)***	188	20	52	15
2/Corn (3-84)	46	15	70	15
3/Soybean (9-84)	128	27	69	4
4/Rice (1-85)	266	14	63	23
5/Corn (6-85)	178	6	79	15

* Data are an average of four or five weed control treaments per crop, which included hand weeded, chemcial control and no weed control.

** BLW = Broad leaf weeds

*** Numbers in parentheses are date of weed sampling. In each case samples were taken near crop maturity.

Cyperaceae species are not competitive with either crops or grassy species. In addition, they are readily controlled with most of the herbicides in use at the station. The majority of the cyperaceae found in Yurimaguas are annuals, rather than nutlet-forming perennials. This probably accounts for their ease of control. With few exceptions, broad-leaf species are not important weeds.

Crop species have been observed to differ greatly in their ability to compete against weeds. Lack of weed control in upland rice often means crop failure. Corn, however, appears to be far more competitive. Yields may be reduced without weed control, but they are greater than zero.

Preliminary Conclusions, Implications

Even though data are still being analyzed, direct observations over the course of this experiment strongly suggest the following: Weeds can be controlled in intensively managed, short-cycle food crops in this environment, but the cost is likely to be high. With the products and rates used in this experiment, the average price of chemical control is approximately $100/ha. This is not economical control within the present price/profit structure in Yurimaguas.

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

This experiment will be continued for at least two more cropping cycles, with corn replacing rice in the rotation.

Chemical Weed Control in Corn

Jonathan Lopez, INIPA
Jane Mt. Pleasant, N. C. State University
Robert E. McCollum, N. C. State University

In the selva, chemical weed control in corn may be practical when hand labor is scarce or expensive. There are several herbicides available in Peru for controlling a broad spectrum of weeds in corn. In Yurimaguas, where the primary weed problem is grasses, metolachlor has generally given good control. Metolachlor is a preemergence herbicide effective against grasses. It also controls a large number of broad-leaf weeds. The objective of this project was to determine whether other herbicides such as atrazine, used alone or in combination with metolachlor, might improve weed control, or expand the spectrum of species controlled, and thereby improve corn yields.

Atrazine was selected for the experiment because it has been used extensively in temperate regions. Applied together, atrazine and metolachlor control a much broader spectrum of weeds than does either alone. In some treatments, metolachlor was also combined with other herbicides effective against broad-leaf weeds.

Corn was grown for two cycles using eight weed-control treatments in a randomized complete block design: Hand weeding; no control; atrazine pre (2.25 kg/ha); metolachlor pre (2.25 kg/ha); metolachlor pre + bifenox pre (2.25 + 1.25 kg/ha); metolachlor pre + atrazine pre (1.75 + 1.55 kg/ha); metolachlor pre followed by 2, 4-D post (2.25 + .30 kg/ha), and metolachlor pre followed by bentazon post (2.25 + 1.0 kg/ha).

Weeds were counted by species in each plot seven weeks after planting. Prior to corn harvest, aboveground dry-matter weights of weed species were recorded. Corn yields on all plots were very low, ranging from 1754 to 2349 kg/ha, due to poor germination and irregular stands. As a result, there were no significant differences in yield among treatments.

Weed Counts

Weed counts taken early in the season indicated large differences among treatments. Check plots (those with no weed control) had 874 weeds/m^2, while treatments with chemical control or hand weeding ranged from 16 to 109 weeds/m^2. Grass species were the dominant weeds in all plots, accounting for 47-87% of the total weed population (Table 1). Three grass species, *Axonopus compressus*, *Digitaria sanguinalis*, and

Table 1. Effect of weed control treatment on number of weeds and composition of weed population in corn seven weeks after planting.

Treatment	Total Weeds	All Grasses	All BLW+	All Cyperac.	Commelina
	No. Plants/m²	% of total weeds			
1. Hand weed	109	47	41	6	5
2. No control-check	874	53	34	10	2
3. Atrazine	88	84	1	11	3
4. Metolachlor	56	61	14	23	2
5. Metolachlor + bifenox	31	52	3	33	16
6. Metolachlor + bifenox	16	56	0	44	0
7. Metolachlor + 2, 4-D	42	67	0	31	2
8. Metolachlor + bentazon	46	87	7	4	2

+BLW = broad leaf weeds

Level of significant main effects	**	**	**	ns	ns
Species within grasses					
A.compressus		ns			
D.sanguinalis		**			
P.paniculatum		**			

Paspalum paniculatum, represented 75-96% of the grass weeds in all treatments.

Cyperaceae species and commelina species were not present in significant numbers in any treatments, while broad-leaf weeds were found in large numbers in only two treatments, hand-weeded and check. In both cases *Lindernia humilis* comprised more than 85% of the broad-leaf population. This low-growing weed is uncompetitive with cultivated plants and is of little importance.

Planned comparisons were used to determine which of the treatments were responsible for the significant differences identified by the F test. Single degree-of-freedom comparisons for relevant treatments are shown in Table 2. For all categories of weeds listed, plots with no weed control had significantly more weeds than other treatments. There was no difference between hand-weeded plots and those receiving chemical control. Metolachlor alone was equal to or better than all other treatments in controlling both the total number of weeds and also the different components of the weed population. No additional control of any weed group was obtained by the use of bifenox, atrazine, bentazon, or 2, 4-D with metolachlor. In addition, the data showed that atrazine alone did not control *D. sanguinalis*. When atrazine alone was compared with metolachlor alone or metolachlor plus atrazine, plots with atrazine alone had a significantly greater number of *D. sanguinalis*.

Table 2. Tests of significance for differences in weed counts for planned treatment comparisons.

Contrast	All Weeds	All Grasses	All BLW	P. Paniculatum	D. Sanguin.
	Level of Significance				
1. Handweed vs. all chemical trts.	ns	ns	ns	ns	ns
2. No control vs. all others	**	**	**	**	**
3. Metolachlor vs. atrazine	ns	ns	ns	ns	**
4. Metolachlor vs. (metol. + atrazine)	ns	ns	ns	ns	ns
5. Atrazine vs. (metol. + atrazine)	ns	ns	ns	ns	**
6. Metolachlor vs. (metol. + bifenox)	ns	ns	ns	ns	ns
7. Metolachlor vs. (metol. + 2,4-D)	ns	ns	ns	ns	ns
8. Metolachlor vs. (metol + bentazon)	ns	ns	ns	ns	ns

ns = Not significant; ** = Highly significant

Weed Weights Before Harvest

In all treatments, the poor stand of corn provided little or no competition to emerging weeds, which attained heavy growth by late season. Total dry weights ranged from 147 to 366 g/m². Grasses were the dominant species, comprising 83 to 98% of the total weed weight. Two species, *A. compressus* and *D. sanguinalis*, comprised 65-98% of the grass population. Broad-leaf weeds, cyperaceae species and commelina species were unimportant components of the weed population.

Since *A. compressus* was the only weed affected by treatment, single degree-of-freedom contrasts were made in order to determine which treatments were relevant to its control. Plots with metolachlor alone had much higher weights of this species than plots with atrazine alone or atrazine plus metolachlor. All chemical-control treatments also had a much higher weight of *A. compressus* than did hand-weeded plots. The data indicated that atrazine controls *A. compressus* while metolachlor does not.

Conclusions

Despite the lack of corn-yield response to weed-control treatments, two conclusions can be drawn from the first cycle of this experiment:

1. Use of metolachlor plus atrazine increased the spectrum of weeds controlled compared to either herbicide alone. Atrazine alone did not control *D. sanguinalis* early in season, while metolachlor alone failed to control *A. compressus* later in the season.

2. Broad-leaf weeds and non-grass monocots such as *cyperacea sp.* and *commelina sp.* are not important components of the weed population. It is unlikely that there would be any benefit in using additional herbicides in combination with metolachlor to control them.

Implications

D. sanguinalis is an important species in most fields at the station. Research in temperate regions has shown that atrazine has little effect on this grass. Confirming this information under Yurimaguas conditions enables the development of more effective weed-control measures for corn. *A. compressus*, a perennial grass, has not been an important weed species in short-season food crops in Yurimaguas. An additional cycle of this experiment is required to determine *A. compressus*' resistance to metolachlor and its importance as a weed in corn.

Weeds are a critical factor in continuous cropping systems. They are as important in limiting yields as soil fertility while their management is considerably more difficult. Two years of research has shown that the 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. 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 in many cases labor is simply not available. Continued research effort will be required to develop weed management practices that are agronomically effective as well as economically viable.

Paddy Rice in Alluvial Soils

Technology tested at Yurimaguas for sustained irrigated rice production in fertile alluvial soils of the Amazon has been validated and is now being transferred to producers through Peruvian extension programs. Peru recently became self-sufficient in rice, due in part to the expansion of flooded-rice agriculture into the Amazon. Several general principles of Amazon flooded-rice production have been established, including the following:

1) Land can be cleared by slash and burn or by bulldozing, as the usually detrimental effects of soil compaction by bulldozers do not seriously affect paddy rice. Care must be given not to displace topsoil during the land-leveling operation.

2) Supplemental irrigation every two weeks increases yields by about 50% as compared to yields from crops dependent entirely on rainfall. The source of water may be gravity canals or pumping from rivers.

3) Transplanting provides higher yields than broadcasting seeds for the first two crops due to insufficient leveling. Broadcasting pregerminated seeds is highly advantageous after the paddies are adequately leveled.

4) Fertilization will be minimal. No significant responses to N or P fertilization have been observed during eight consecutive crops grown in a four-year period. N deficiencies are expected to appear with continous use.

5) A combination of herbicides provides satisfactory weed control.

6) Two crops a year with recommended short-statured varieties can produce annual yields of 12 to 15 ton/ha or 5.2 to 6.6 t/ha/crop. Considering that one hectare of acid soils must be cleared every year to produce one ton of upland rice, every hectare under irrigated rice production might save from 12 to 15 hectares of tropical forests annually from deforestation.

Research and extension activities are now the responsibility of INIPA's National Rice Program. The work reported here is conducted to further test and refine this technology for long-term flooded-rice production.

Intensive Management of Alluvial Soils For Irrigated Rice Production

Luis Arevalo, N. C. State University
Robert E. McCollum, N. C. State University
José R. Benites, N. C. State University
Alfredo Rachumi, INIPA
Cesar Tepe, INIPA
Kristinaa Hormia, Institute of Development Studies, Finland

Research on this important management option has progressed to the point of widespread technology transfer, contributing to a 40% increase in rice production on fertile, alluvial soils of the Amazon Basin of Peru. The objectives of this project, which was conducted at the Yurimaguas Experiment Station, were 1) to determine the best methods of planting to achieve maximum yields in paddy rice; 2) to determine the best fertilizer sources, schedules and rates; 3) to determine optimal irrigation frequency, and 4) to determine the effect of water-level fluctuation on the survival of paddy-rice seedlings.

Transplanting vs. Direct Seeding

A project was initiated in August, 1981 with the objective of determining the best planting methods in paddies newly developed on an Eutric Haplaquept (clayey, mixed, isohyperthermic), on a high terrace near the Shanusi river at Yurimaguas. The results shown in Table 1 indicate that annual mean production was only slightly less with direct seeding than with transplanting. Two new experiments were initiated in 1985 to develop seeding methods and weed-control practices for direct-seeded rice. The first found that there was no significant difference in yields between crops broadcast-seeded by hand and those broadcast with a Cyclone-type seeder. One man can seed 1.5 to 2.0 ha per day by hand, but the same person can plant 5.0 ha in one day with the Cyclone seeder.

In the second experiment, three types of herbicides were tested with direct-seeded rice. Ten days after seeding, the thiobencarb and oxadiazon treatments produced harmful effects. The check plots gave 100% germination, but all the other herbicide treatments gave only 30 to 50%. The effects on yields are shown in Table 2. Using 2-4 D amine alone at a rate of 2.0 L/ha resulted in a 20% higher yield than the check plot and performed better than the other herbicides. The low yields obtained in this experiment are probably due to herbicide toxicity and an attact of molluscs *Arion*, the two together affecting initial plant growth severely.

Nitrogen and Phosphorus Fertilization

After eight consecutive rice crops, there have been no significant responses to either fertilizer N at rates up to 200 kg/ha or to P at rates up to 100 kg P_2O_5/ha. In the N experiment, mean grain yields were in the range of 6 to 7 t/ha for all treatments. In the P experiment, mean grain yields were also around 6 t/ha regardless of P rate or P source.

Supplementary Irrigation

The paddy-rice production system developed by the project includes supplemental irrigation. Table 3 shows that the best yields were obtained with supplemental irrigation once every two weeks, as compared with rainfall dependency. Table 4 shows the effect of different water depths on crop yields through three harvests. The data indicate that highest yields were obtained when water depth was maintained between 10 and 20 cm. At higher and lower levels, yields tend to decrease.

Table 1. Performance of floooded IR4-2 rice in different land preparation systems in an Eutric Haplaquept at a "restinga" in Yurimaguas, during the first 26 months after clearing.

Land preparation	Planting system	First crop	Second crop	Third crop	Fourth crop	Fifth crop	Mean per crop	Mean annual production[1]
		Grain Yields, ton/ha						
Puddled:	Transplanted	7.9	5.2	7.1	6.0	6.8	6.6	15.2
	Broadcast/direct-seeded[2]	3.2	4.9	6.4	4.8	6.7	5.2	12.0
Dry:	Transplanted	8.3	6.7	6.2	5.6	6.3	6.6	15.3
	Broadcast/direct-seeded[2]	6.3	5.6	4.9	4.6	6.0	5.5	12.6

[1] Assuming 2.3 crops per year
[2] Hand-weeded

Conclusions

1) Direct-seeded paddy rice produced mean annual yields only slightly lower than those from transplanted rice. Direct seeding eliminates pre-plant soil puddling and thereby reduces labor costs.

2) Broadcast-seeding rice with a cyclone-type seeder was as effective as broadcasting by hand, and required less than half the manpower.

3) Of the three herbicides tested for use in broadcast-seeded rice, 2-4 D amine used alone gave the best results.

4) Best rice yields were obtained with supplemental irrigation once every two weeks, which maintained the water level between 10 and 20 cm.

Table 2. Effects of week-control methods on direct-seeded IR4-2 paddy rice.

Herbicide	Rate, L/ha	Rice Grain Yield, t/ha
Thiobencarb 2-4 D amine	7.0 + 3.0	4.64
Thiobencarb 2-4 4 D amine	8.0 + 2.0	4.56
Oxadiazon 2-4 D amine	2.0 + 3.0	4.51
Oxadiazon 2-4 D amine	4.0 + 2.0	4.32
2-4 D amine	2.0	4.79
Check	———	3.90

Implications

Recommended varieties of paddy rice can produce yields in the range of 12 to 15 ton/ha/yr on alluvial Amazon soils without fertilization for the first three years. Direct seeding with a Cyclone-type broadcaster, coupled with judicious herbicide use, can save substantially on labor, an important factor because skilled laborers are scarce in this area. Despite the heavy rainfall in the Amazon, supplemental irrigation from rivers or ponds every two weeks improves rice production 50%. These results are being tested in farmers' fields in the Tupac Amaru settlement near Yurimaguas.

Table 3. Effect of the irrigation frequency on the rice yield for cultivar IR4-2.

Supplemental Irrigation Frequency	Number of Harvests			
	1st	2nd	3rd	Mean
	L/ha			
Once/2weeks	5.78	6.74	6.00	6.17
Rainfall only	4.08	5/13	3.99	4.40

Table 4. Grain yield as affected by different water levels. Rice variety IR4-2.

	Number of Harvests			
Water Levels	1st	2nd	3rd	Average
cm	L/ha			
0	5.48	3.80	5.13	4.80
10	6.77	5.03	5.44	5.75
20	6.45	5.18	6.18	5.94
30	5.66	4.92	4.48	5.02

Soil Characterization and Interpretation

Knowledge of the properties and distribution of soils in the humid tropics serves as the basis for soil management. Proper selection of sites for extrapolation work requires good soil characterization and classification by Soil Taxonomy, as well as interpretations practical in agronomic terms. The Fertility Capability Classification (FCC) system is being adopted in many areas of the world as a basis for research planning and technology transfer because it helps identify the soil characteristics that affect crop production. Coupled with Soil Taxonomy, the FCC system is an effective tool in the development of soil-management technologies adapted to specific sites and conditions.

An example of the widespread applicability of this approach is an FCC map of Africa, being developed by the Food and Agriculture Organization of the United Nations (FAO). By providing planners with an inventory of Africa's soils characterized by their productive potential, the FAO's map will assist in long-range agricultural research and development. N.C. State University collaborators on this project are developing software for personal computers that will allow soil maps to be digitized, so that users might have at their fingertips maps with any soil grouping desired. The work described here concentrates on two general areas. The first is the adaptation and refinement of the FCC system for various tropical ecosystems and crops. The second is the study of soils in several humid tropical regions on the agricultural frontier, where soil characterization lays the groundwork for future research and development.

FCC Adaptation to Wetland Soils

Pedro A. Sanchez, N. C. State University
Stanley W. Buol, N. C. State University

The Fertility Capability Classification system (FCC) has been tested on many sites around the world in order to adapt it to various soils and conditions. In each case, the primary aim has been to identify soil constraints to crop production and to guide decisions about how to relieve or offset these constraints. At the request of the International Rice Research Institute (IRRI) and Soil Management Support Services (SMSS), the FCC system was applied to soils with aquic soil-moisture regimes in order to relate soil classification with soil-productivity parameters that are important for flooded-rice production.

Interpretations for FCC soil types and substrata types for wetland soils are shown in Table 1, and for condition modifiers in Table 2. The FCC system identified specific soil characteristics directly related to most of the physiological disorders of rice, except for iodine and boron toxicity. Iron toxicity caused by Fe-rich interflow from adjacent uplands requires an FCC classification of such upland soils. One additional condition modifier was necessary to include in the FCC: a g' modifier for constantly flooded soils.

The FCC interpretations of aquic soils were tested by workshop participants from the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) and Soil Management Support Service (SMSS), during a five-day field trip in Central Luzon, Phillipines, where 16 profiles were examined. Information from these profiles was related to the condition of rice plants growing on adjacent plots established for INSFFER fertilizer trials. The FCC system was successful in predicting Zn deficiency by the presence of either the b (calcareous) or the g' (prolonged flooding) modifiers. Two other characteristics, ease of puddling and difficulties in regenerating the puddled structure for rotation with upland crops, were also readily identified by FCC classes. The possibility of low N fertilizer efficiency indicated by the v (vertic) and b (calcareous) modifiers was confirmed by the results of the INSFERR trails. Table 3 shows the Soil Taxonomy and FCC designation of the pits studied and the fertility problems encountered.

Conclusions

The workshop's soil-fertility group recommended the following in relation to FCC:

1. The FCC system should be tested and applied to wetland rice soils as a means for grouping together soils with similar constraints.

Table 1. Interpretations of FCC type and substrata types for rice cultivation in aquic soil moisture regimes.

S	High in infiltration, low water-holding capacity, more difficult to do thorough puddling; traffic pans infrequent; relatively easy to regenerate structure for rotation with other crops. Level of management (nutrients and water) required for high rice yields is higher than in L or C soils.
L	Medium infiltration, medium water-holding capacity, usually easy to puddle (except Lx), and medium difficulty in regenerating structure. Traffic pans important in these soils except for Lx. L soils are generally more productive for rice than S soils and less than C soils, provided condition modifiers are similar.
C	Low infiltration rates, high water-holding capacity (except Ci), easy to puddle and difficult to regenerate previous structure (except Ci); traffic pans not common. Generally higher productivity for rice than L or S soils provided condition modifiers are similar.
O	Deep organic or peat soils, with little to no potential for rice production.
OC, OL or OS	Shallow organic soils with a mineral layer of less than 50 cm depth. Potential for rice production
SL, SC	Somewhat better water-holding capacity and thus better suitability for rice production than S soils.

Table 2. Interpretations of FCC condition modifiers for rice cultivation in aquic soil moisture regimes.

When only one modifier is included in the FCC unit, the following limitations or management requirements apply to the soil. Interpretations may differ when two or more modifiers are present simultaneously or when textural types are different.

g

Defines wetland soils. Preferred moisture regime for rice cultivation.

g'

Prolonged submergence causes Zn and perhaps Cu deficiency.

d

Topsoil moisture limited during dry season unless irrigated. Generally only one rainfed rice crop can be grown a year. Irrigated rice during the dry season has higher yield potential and responds to higher N rates.

k

Low inherent fertility because of low reserves of weatherable minerals. Management levels higher than in soils without this modifier. Potential K deficiency depending on base contents of irrigation water.

e

Low ECEC reflects less gradual N release, more exacting N management. Identifies degraded paddy soils with **SLa** or **LCa** and low organic matter contents. If so, potential H_2S toxicity can occur if $(NH_4)_2SO_4$ is used as N source. Potential Fe toxicity if adjacent uplands have Fe-rich soils.

a

Aluminum toxicity will occur in aerobic layers. Soil test for identifying P deficiency recommended.

h

Potential P deficiency under continuous rice cropping. Otherwise optimum aerobic pH for flooded rice production. If combined with **SLe** or **LCe**, potential **Si** deficiency.

b

High pH may induce Fe deficiency when aerobic, and Zn deficiency when water-logged. High N volatilization loss potential from broadcast N applications. NH_4^+ fixation by 2:1 clays possible. Mollusk shells indicative of Zn deficiency.

i

High P fixation by Fe; P deficiency likely; Fe toxicity potential; soils difficult to puddle and will regenerate original structure rapidly. Inter-flow from **Ci** uplands may cause Fe toxicity to **e** soils with lower topographic position.

x

Volcanic materials indicate high inherent fertility with no potential Si deficiency; N and P deficiencies common and soil may fix large quantities of P; soils difficult to puddle and will regenerate original structure rapidly.

v

Soils will shrink and crack when dry, causing excessive percolation losses afterwards. Easy to puddle but difficult to regenerate structure. P deficiency suspect and should be determined by soil tests. Soil fixes applied NH_4^+ and releases it later to the rice crop - a positive attribute. Cracks may not close after reflooding due to ripening-water percolation and additional N losses.

s

Defines saline soils. Drainage needed but must consider conductivity of irrigation water.

n

Defines alkali soils. Reclaiming with drainage and gypsum applications may be needed.

c
Acid sulfate soils causing Fe and S toxicity when anaerobic and Al toxicity when aerobic. Depth at which **c** modifier occurs determines feasibility of rice production. Strong P deficiency likely and Al toxicity when aerobic.

':
Presence of gravel limits land preparation and water holding capacity.

'':
Skeletal soils with limited potential for rice production.

%:
The higher the % slope, the narrower the paddies will be and the higher the rise between terraces will be.

2. The FCC modifier for acid-sulfate soils (c) needs further refinement to establish a better limit. An additional modifier for cation imbalance ratios (r) should be developed; additional modifiers for high organic nitrogen in the topsoil (q), and for high available native topsoil phosphorus (p), should be investigated and incorporated into the system if reliable quantitative limits can be identified.

3. Field trials in rice fertility and soil management should have the soil classified according to Soil Taxonomy at the family level. Emphasis should be given to mineralogy characterization, in relation to fixation and release mechanisms. FCC should not be considered an altenative to Soil Taxonomy, but as a technical system that facilitates its interpretation for agronomic purposes.

4. A Hydrological Capability Classification (HCC) system should be developed along similar lines as FCC to characterize in a systematic and quantitative basis extremely important factors such as: 1) water-table depth during dry and wet seasons, 2) frequency, depth, speed, and duration of natural flooding, 3) quality of irrigation, flood or ground water and other relevant hydrological parameters. A working group should be established to develop the HCC. Hydrological constraints often override soil constraints in rice production. The development of this technical system is, therefore, considered an urgent matter.

In addition, the INSFFER network meeting concluded that Soil Taxonomy is to be used to characterize network sites and that the FCC system is to be tested by all countries participating in the network, which are: Burma, Bangladesh, China, India, Indonesia, Malaysia, Nigeria, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam. Tests are under way in many of these countries.

Table 3. Field testing of FCC system in 14 pedons of Luzon, Philippines, and nutritional deficiencies observed in adjacent INSFERR trials.

Taxonomy	FCC	Zn deff	P response	N inefficiency	Mg/K imbalance
Andaqueptic Fluvaquent	CLg'	X			
Vertic Haplaquoll	Cg'v	X			
Vertic Tropaqualf	Cgh		X		
Udorthentic Pellustert	Cgdv		X	X	
Aeric Tropaquept	Cg				
Entic Pellustert	Cgdhv		X	X	
Aeric Tropaquert	LCgd				
Fluvaquentic Haplustoll	CLdbg	X			
Entic Chromustert	Cdvbg	X			
Andic Palehumult	Lkax			no trial	
Typic Haplaquoll	Lgdbk	X			X
Cummulic Haplaquoll	LCgdbk	X			X
Typic Tropaquept	Lgd				
Aquic Ustifluvent	LSdeh				

New-Project Update

Several projects in this series have not been under way long enough to yield substantive reports, but should be mentioned because of their importance to the program as a whole.

Volcanic Ash Influence on Transmigration Areas of Sumatra

Hardjosubroto Subagjo, Center for Soil Research
Stanley W. Buol, N.C. State University
John R. Thompson, University of Hawaii
Michael K. Wade, N.C. State University
Mohammed Sudjadi, Center for Soil Research
I. Putu Gedjer, Center for Soil Research
Agus B. Siswanto, Center for Soil Research

The objective of this project is to determine the amount, thickness and effect on phosphate chemistry of amorphous material in the major soil and geographic areas around the Sitiung-Bangko transmigration settlements, on the island of Sumatra. The western part of Sumatra belongs to the Bukit Barisan mountain range, where faulting and folding have been accompanied by volcanism. Along the foot of these mountains lies a vast, undulating and rolling plain.

Two transects extending from the lowland to volcanoes were studied, along with sites intermediate to them in the transmigration areas. Profiles were described and soils were sampled to a depth of 2 m at each site. The tentative classification of these soils is generally Paleudults or Haplorthox at the lower altitudes (40-160 m), Topudults at the middle altitudes (300-350 m), and Dystrandepts or Hydrandepts on the lower slopes of the volcanoes (1200-1350 m). As this project continues, soils will be further characterized and analyzed at the Center for Soil Research and at N.C. State University.

FCC and Site Characterization In Relation to Caribbean Pine

Leon H. Liegel, USDA Southern Forestry Station, Puerto Rico
Stanley W. Buol, N.C. State University
Robert E. Hoag, N.C. State University
Pedro A. Sanchez, N.C. State University

The purpose of this project was to evaluate the Fertility Capability Classification system (FCC) in relation to an important commercial tree crop, Caribbean pine, and to determine if the system needs modification for use with perennial tree crops. To date samples have been taken at 46 sites in Venezuela, 44 in Jamaica, and 29 under Caribbean pine (*Pinus caribaea*, var. honurensis). These samples were analyzed for particle-size distribution, pH value, extractable Al, Ca, Mg, K, and P. Brief profile notes were made at each site. Using these data, each site was classified by FCC criteria.

A preliminary summary of the data reveals that the majority of the Venezuela sites were coarse to medium in texture, types S, L, or SL, and had high Al concentrations (a), low CEC (e), an ustic soil moisture regime (d), and low potential to supply potassium (k). The Jamaican sites were medium to fine in texture, types L or C, with many having no obvious chemical constraints. Some did have acidity constraints (h), and a few had Al constraints (a). A low potential to supply K was also present at several sites. Soils studied in Puerto Rico were also medium and fine in texture, types L and C, with no subtype texture modifier. These generally contained more Al, and were universally low in their potential to supply K. Further work on this project will compile soils data, comparing tree growth and FCC grouping for each site.

Alluvial Soils of the Amazon Basin

Robert E. Hoag, N.C. State University
Stanley W. Buol, N.C. State University
Jorge Perez, INIPA

Alluvial soils are usually considered to be of high native fertility. The purpose of this work was to test such a hypothesis, which would be useful in extrapolating soil-management options for alluvial soils in the humid tropics. To do so, the investigators sampled soils from three different types of deposits in the Amazon Basin of Peru, determined their physical, chemical and mineralogical properties, and developed a means of predicting the occurrence of the contrasting soil properties on flood-plain landscapes in the region.

The 20 sampling sites, placed into three groups, were selected on the basis of the geologic formation from which the tributaries originate. Representative data are given in Table 1. Sampling sites in Group One were along rivers that originate within the Eastern Peruvian Cordillera. As predicted, these soils have relatively high pH values throughout their profiles, ranging from 6.5 to 8.5. (Complete data for each of the profiles sampled are in Mr. Hoag's thesis).

Sampling sites in Group Two were along rivers that originate in the foothills of the Peruvian Andes, where carbonaceous and non-carbonaceous sandstones predominate in the headwaters. These soils have chemical properties similar to those sampled along certain rivers that originate in the Ecuadorian Cordillera. Although upper elevations of the Ecuadorian Andes are composed predominantly of acid igneous and volcanic rock strata, the tributaries dissect limestone-bearing marine deposits along the eastern flank of the mountains. This group of nine sampling sites has pH values throughout their profiles of 5.0 to 6.5, and tend to be near a value of 6.0 in the upper horizons. Min[illegible]gy of the sand fraction is mixed, and montmorillonite dominates the clay fraction. Characterization data for the sampling site along the Cashiboya are representative of this group, although textures may be loamy rather than clayey.

The third group of soils includes those sampled along rivers that originate among pre-weathered, within-basin sediments of Peru. Chemical properties of soils sampled along two rivers that originate from within-basin sediments and northern portions of the Andes in Ecuador are also included with this group. These soils are strongly acid, with pH values ranging from 4.0 to 5.0. The clay fractions of these soils are dominated by either montmorillonite or kaolinite, with both minerals being present in abundance. Aluminum saturation is high and may exceed 85% of the exchange complex.

The soil profiles were classified according to soil taxonomy and results are presented in Table 2. Classification according to the Fertility Capability Classification system (FCC) was based upon data obtained from samples submitted to the N.C. State University Soil Testing Laboratory.

Table 1. Summary of topsoil fertility and FCC classification representative of sampling sites in three groups of soils in the Amazon Basin of Peru. (Chemical values are for top 20 cm)

	Location		
Soil Property	Group 1 Rio Mayo	Group 2 Rio Cashiboya	Group 3 Rio Yavari
FCC Classification	Cgvb	Cg	Cga
Ph	7.5	5.6	4.0
Al Saturation	0	0	78
Ca, meq/100 g	39.7	29.7	1.8
Mg, meq/100 g	9.7	7.0	0.5
K, meq/100 g	2.02	0.69	0.36
Mn, ppm	90	130	35
Cu, ppm	6.2	4.9	2.3
Zn, ppm	4.5	3.2	3.3
P, ppm	145	29	6

Conclusions

Physical, chemical and mineralogical data support the premise that information describing the geologic formations from which tributaries in the Amazon Basin of Peru originate may be useful in predicting soil properties on floodplains. Soils along rivers with headwaters in the Eastern Peruvian Cordillera are generally of high base status and pH values. Montmorillonite dominates the clay fraction of these soils. There may be some question as to the availability of P and micronutrients due to complexing at the high pH levels. Soils developing in sediments eroded from the calcareous sedimentary deposits of the Andean foothills in both Peru and Ecuador tend to be slightly acid with no serious chemical or mineralogical problems. In the Eastern portion of the Peruvian Basin, the floodplain soils tend to be strongly acid with very high levels of aluminum saturation. Repeated sequences of weathering, erosion and deposition over a long period of time have apparently contributed to the leaching of soluble bases and dominance of Al on the exchange complex.

Table 2. Taxonomic classification of representative profiles of alluvial soils of the Upper Amazon.

Location	Classification
Rio Aguaytia	-Typic Tropofluvent, clayey over loamy, mixed (nonacid) isohyperthermic.
Rio Blanco	-Aeric Tropaquept, fine, montomorillonitic (acid), isohyperthermic.
Rio Cashiboya	-Aeric Tropic Fluvaquent, very-fine, montmorillonitic (acid), isohyperthermic.
Rio Cumbaza	-Typic Tropofluvent, coarse-loamy, siliceous (nonacid), isohyperthermic.
Rio Cushabatay	-Aeric Tropic Fluvaquent, coarse-loamy, mixed (nonacid), isohyperthermic.
Rio Mayo	-Aquic Hapludoll, very-fine, montomorillonitic (calcareous), isohyperthermic.
Rio Mazan	-Aeric Tropic Fluvaquent, fine, kaolinitic (acid), isohyperthermic.
Rio Nanay	-Aeric Tropic Fluvaquent, fine-loamy, siliceous (acid), isohyperthermic.
Rio Napo	-Typic Tropofluvent, coarse-silty over clayey, mixed (nonacid), isohyperthermic.
Rio Nucuray	-Typic Eutropept, fine-silty, mixed, isohyperthermic.
Rio Paranapura	-Typic Tropofluvent, coarse-loamy mixed (nonacid), isohyperthermic.
Rio Pastaza	-Typic Fluvaquent, coarse-loamy, mixed (nonacid)
Rio Putumayo	-Aeric Tropaquept, very-fine, kaolinitic (acid), isohyperthermic.
Rio Samiria	-Typic Tropofluvent, fine-silty, mixed (nonacid), isohyperthermic.
Rio Tamshiyacu	-Typic Fluvaquent, fine, montmorillonitic (acid), isohyperthermic.
Rio Tapiche (upper)	-Aquic Fluvaquent, fine montmorillonitic (acid), isohyperthermic.
Rio Tapiche (lower)	-Aquic Eutropept, fine-silty, mixed, isohyperthermic.
Rio Tigre	-Aeric Tropic Fluvaquent, fine-loamy, mixed (acid), isohyperthermic.
Rio Utoquinea	-Aeric Tropic Fluvaquent, fine-silty, mixed (acid), isohyperthermic.
Rio Yavari	-Typic Tropaquept, very-fine, montmorillonitic, (acid), isohyperthermic.

Implications

Soils of the humid tropics are diverse not only on uplands and mountains, but also on floodplains. The notion that all alluvial soils within the Amazon Basin of Peru are homogeneous is clearly mistaken. As chemical and physical properties diverge from one location to another, so must management recommendations. Results of this study may help to identify the geographical boundaries within which research data may be extrapolated. The study may serve to identify regions that may require additional research if agriculture is to expand in them. As an example, it may be necessary to use lime or Al-tolerant genotypes in the very acid alluvial soils in Eastern Peru. Data from this study may also prove to be useful in selecting drainage systems for more intensive soil-genesis or fertility investigations.

Ultisol Dominated Landscapes In Southeastern Peru

Laurie J. Newman, N.C. State University
Stanley W. Buol, N.C. State University
Rafael Chumbimune, INIPA-CIPA XVII, Madre de Dios

An area of southeastern Peru was selected for a study whose objectives where 1) to characterize the physical, chemical and mineralogical properties of the soils of the region, and 2) to determine the relationship of soil properties to landscape position. The research site, 450 ha near Puerto Maldonado, Madre de Dios, is considered representative of the soils, climatic conditions, landscapes and vegetation in the region. Results from this project may assist in the extrapolation of research to areas within the region where knowledge of the soil resource is scarce.

The topography of the region is characterized by level uplands, dissected side slopes and recent flood plains. Lower base levels caused drainage entrenchment and formation of the associated convex and planar side slopes. The flood-plain soils are forming in Holocene, local alluvium and organic parent materials.

Ultisols with ustic soil moisture regimes are the predominant soils of the uplands. These Ultisols can be characterized as having pH values ranging from 3.9 to 4.9, aluminum saturation values greater than 70% of the effective CEC in the argillic horizons, and surface horizon cation exchange capacities of 1 to 6 cmol (+)/kg. Textures of the Ustults vary from clayey to course-loamy, as a function of the texture of the initial materials and position on the landscape. There are few weatherable minerals in the sand size fractions of these soils. The dominant clay mineral is kaolinite. Some muscovite mica, vermiculite and hydroxy-Al-interlayered vermiculite are present. Paleusults, located in positions where water tables fluctuate within the profile, have features associated with oxidizing and reducing conditions such as mottling, plinthite and indurated iron.

The poorly drained soils formed in recent alluvium are Placaquods and Troposaprists. The texture of these soils is dependent on the depositional environment of the alluvial materials. The sand fraction is primarily quartz. Magnetite, pyrite and kyanite are present in trace quantities. The soils are strongly acid to medium acid and vary in base status.

Three geomorphic surfaces have been defined within the area. Two of these are located on the upland, and the other occupies the lower areas associated with stream drains.

Surface 1 covers the level and nearly level uplands. It is the oldest and most stable surface of the three. Surface 2 consists of the side slopes and dissected portions of the uplands. Within this group are landscape positions with greater than 3% slope. Surface 3, on the recent flood plains, occupies the smallest portion of the study area. This surface is the youngest and may be subject to rapid changes in morphology with the movement of the nearby channel.

The soils have textures ranging from loamy fine sand to clay. All of the upland soils in the sandy area have an increase in clay content and a decrease in sand content with depth. In the flood plain of the third order stream, organic soils are dominant. On the uplands of the sandy area, clayey soil families are located beside soils with coarse loamy control sections. These abrupt changes in texture laterally across the landscape are characteristic of areas where soils have developed in alluvial parent materials.

Soil pH values for the upland soils are generally higher at depth in the profile than at the soil surface. Values determined in water range from 3.4 to 4.9 (Table 1). The soils in the recent flood plain of the second-order streams have pH values ranging from 1.9 to 5.6. The pH values of the upland soils of the region may be a result of soil formation in acid parent materials, or of formation in higher pH materials where bases have been leached out over time.

Soil reaction data from the flood plains of the Madre de Dios and Tambopata Rivers indicate that recent alluvium is neutral to slightly acid reaction, having pH values ranging from 5.2 to 6.9. Because the present-day rivers have a similar source as the sediments in which the upland soils are formed, it is assumed that the soils of the upland have developed in sediments with neutral reaction and that post depositional removal of bases is responsible for the increase in soil acidity.

Extremely low pH values of 1.9 to 2.1 have been measured in the epipedon and subsurface horizon of a buried soil in the second-order stream drain (Table 1). pH values of less than three are rare in saturated soils, but have been recorded in sulphitic soils, a result of oxidation after soil drainage. Pyrite (Fe_2S) may be present in these horizons and may be assumed to be controlling the very acid soil reaction. The organic soils associated with the Rio Chonta have pH values similar in range to those on the upland.

The amount of exchangeable aluminum of the

Table 1. Physical and chemical properties of selected profiles in Puerto Maldonado, Peru.

Depth	Clay	Sand	Org.C	pH	Extractable Al	Ca	Mg	K	ECEC	ECEC	Al sat.
(cm)	---	%	---	H_2O	---	---	c mol(+)kg	---	---	cmol(+)kg clay	%
Soils of the Level Upland (Surface 1):											
Carretera; Typic Paleustult; clayey, kaolinitic, isohyperthermic											
0-9	27	26	1.6	3.9	4.1	0.1	0.2	0.2	5	19	81
9-25	30	22	0.7	3.9	4.2	0.1	0.1	0.1	5	17	82
25-52	39	19	0.6	4.2	5.3	0.1	0.1	0.2	7	17	79
52-70	44	18	0.5	4.4	6.4	0.1	0.1	0.1	7	16	90
70-118	48	17	0.5	4.5	6.8	0.0	0.1	0.1	8	16	89
118-155	47	16	0.7	4.6	6.7	0.0	0.2	0.1	8	17	86
155-200	46	21	0.3	4.6	6.3	0.0	0.2	0.1	8	16	86
Estacion; Typic Paleustult; coarse-loamy, siliceous, isohyperthermic											
0-9	3	81	0.4	4.3	0.3	0.4	0.4	0.1	2	53	18
9-24	2	70	—	3.9	1.0	0.1	0.2	0.1	2	73	60
24-53	5	69	—	3.9	1.7	0.1	0.1	0.1	2	43	73
53-82	15	62	—	4.1	1.4	0.2	0.2	0.1	2	14	68
82-110	16	68	0.3	4.1	1.4	0.0	0.0	0.1	2	12	74
110-153	18	66	—	4.1	1.4	0.0	0.0	0.1	2	10	79
153-200	19	64	—	4.1	1.7	0.0	0.0	0.1	2	10	84

upland soils in the study area range from 0.1 to 7.5 cmol(+)/kg. The maximum occurs in the lower B horizon of the Palma Real profile, a somewhat poorly drained soil with clayey textures throughout the solum. The minimum occurs in the surface horizon of the Amable profile, a sandy textured epipedon on a 12% slope. In the upland soils, exchangeable hydrogen is a significant portion of the acidity, comprising up to 25 percent in B horizons. In all well drained soils, the total exchangeable acidity is higher in B horizons than in the surface horizons.

All upland soils in undisturbed forests have low contents of exchangeable bases throughout. Soils that have recently been cut and burned for agricultural use have concentrations of calcium and magnesium in the surface horizons of 0.30 to 0.41 cmol(+)/kg. Basic cation content ranges in most B horizons are 0.01 to 0.05 cmol(+)/kg for calcium, 0.0 to 0.22 for magnesium, and 0.2 to 0.15 for potassium. The highest values are found in soils with clayey family particle size classes. The location of Estacion profile has been used in the past for lime rate experiments. This may account for the calcium concentrations of 0.10 cmol(+)/kg to 82 cm in the profile.

Soils of the recent flood plain have cation saturation values for calcium, magnesium, and potassium in mineral soils ranging from 0.06 to 0.89, 0.26 to 4.49, and 0.02 to 0.06, respectively and values for calcium, magnesium, sodium and potassium in organic horizons ranging from 2.37 to 4.71, 8.95 to 18.10, 0.10 to 0.33 to 0.17 to 0.68 cmol(+)/kg, respectively. High concentrations of calcium and magnesium could be a result of the deposition of sediments from more basic waters of the Tambopata that flood the Chonta River during the wet season.

In the surface and some subsurface horizons of the coarser-textured soils, effective CEC values range from 23 to 82 cmol(+)/kg. The presence of muscovite mica, vermiculite and hydroxy-Al-interlayered vermiculite with cation exchange capacities of 20-40, 100-150, and 10-40 cmol(+)/kg account for the greater CEC. Soil horizons that have organic carbon contents greater than 2% have higher exchange capacities than clayey content CEC correlations could suggest as a result of the 100-300 cmol(+)/kg CEC associated with organic matter. In these samples, effective CEC values range from 44 to 275.

The pH-dependent charge ie., CEC, ECEC, increases

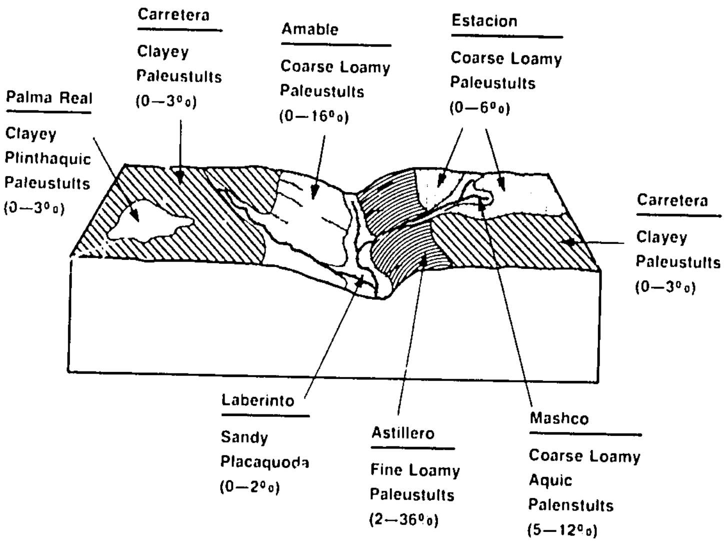


Figure 1. Relationship of soil map units to landscape positions.

with depth in all mineral soil profiles, reflecting an increase in kaolinite in the clay fraction. This property has been observed in Ultisols of the southeastern United States.

X-ray diffraction was used to identify and quantify the minerals present in the clay fraction of selected horizons. Diffraction patterns show the predominance of kaolinite in all of the horizons analyzed. Muscovite mica, low-charge vermiculite and hydroxy-aluminum interlayered vermiculite are present in varying quantities, as are minor amounts of goethite, gibbsite, and talc.

Soils with clayey family particle size classes have vermiculite as the second most abundant clay mineral. All other soils in loamy, sandy and organic particle size classses have muscovite mica as their second most abundant clay mineral. The sandy, poorly drained soils in the second-order stream drain have the lowest amount of vermiculite of any of the soils. Gibbsite is present in the B horizons of profiles that contain plinthite. The trace contents of talc, which is a stable product of metomorphism, have probably been transported from the sedimentary parent material source in the Andes.

In the clay fraction the sequence: mica ⟶ vermiculite (expanded hydrous mica) ⟶ hydroxy interlayered vermiculite ⟶ kaolinite represents the succession of the stages of weathering.

All sand fractions examined by petrographic analysis were greater than 95% quartz. Muscovite mica was present in small amounts as were the heavy minerals, anisotrapic kyanite and the isotropic magnetite.

All of the soils in the study area have developed from unconsolidated sediments. Most have formed in ancient alluvium, and some are formed from more recent alluvial deposits. Soil morphology and genesis differ in these soils as a result of differing textures of the original parent materials, their geomorphic position and their relationship with the present day water table. The idealized block diagram in Figure 1 presents seven major map units and their position on the landscape.

Soils of Pichis Valley Extrapolation Sites

Laurie J. Newman, N. C. State University
Dennis del Castillo, N. C. State University -PEPP

The purpose of this project was to characterize the soils where the Pichis Extrapolation Project is adapting soil-management technologies developed at Yurimaguas to a location in the High Selva of Peru. The extrapolation sites are two neighboring experiment stations situated on opposite sides of the Pichis River. Compared to Yurimaguas, this area has lower night temperatures, 50% more rainfall and steeper slopes. The important landscapes for agriculture are alluvial positions and gently rolling to steep uplands.

Four pedons were sampled in October 1984 and samples were analyzed at the Yurimaguas laboratory. Mineral family was inferred from the sum of cations and clay content. The results shown in Table 1 indicate that the alluvial terrace soils are Fluventic Eutropepts, slightly acid, but with otherwise high native fertility (Pedon A). Soils on the upland, rolling sites at La Esperanza Station are clayey, kaolinitic Typic Paleudults (Pedon B). Soils on the high, nearly level terraces at both stations are Typic Palehumults and Typic Tropohumults, with high topsoil organic matter contents (Pedons C and D).

On the basis of the four pedons described and analyzed, soils at the extrapolation sites differ only slightly from those at Yurimaguas. The Pichis soils contained proportionately more clay and organic matter, and there are probably more 2:1 clays. These characteristics, taken together, indicate that these soils will retain more exchangeable Al. Lime requirements are expected to be higher, and percolation of bases less than those on soils at Yurimaguas. The high base status soils on the low terraces at the extrapolation site appear comparable to soils on the low terrace at Yurimaguas.

Table 1. Characteristics of four soil profiles on the Pichis Valley, Peru.

Horizon		Texture	pH	Exchangeable A1	Ca	Mg	K	ECEC	Al sat.	Organic matter
cm			(H_2O)	cmol(+)/L					%	%
El Vivero, low terrace, Fluvaquentic Eutropept, clayey, mixed, isohyperthermic. FCC:LCh.										
Ap	0-9	silt loam	5.4	0.3	9.00	2.08	0.24	11.62	3	3.4
Bt1	9-24	silty clay	5.5	0.5	9.45	1.83	0.14	11.92	4	1.3
Bw	254	silty clay	5.1	5.4	4.53	1.50	0.10	10.53	51	0.7
Ab	54-89	loam	5.3	3.7	3.77	1.24	0.09	8.80	42	0.3
Bwgl	89-130		5.4	1.8	6.75	2.48	0.15	11.18	16	0.3
Bwgl	130-151	silty clay	5.7	1.0	7.44	3,41	0.16	12.01	8	0.2
Cg	151-180	clay	6.0	0.4	8.59	3.79	0.16	12.94	3	0.4
Esperanza Experiment Station, upland area secondary forest. 11% slopes. Typic Paleudult, clayey, mixed, isohyperthermic. FCC:LCak.										
A	0-6	loam	3.8	5.3	0.20	0.20	0.16	5.86	90	5.2
Bt1	6-33	clay loam	4.2	5.8	0.20	0.17	0.05	6.22	93	1.4
Bt2	33-65	clay loam	4.3	6.7	0.24	0.14	0.06	7.14	94	1.0
Bt3	65-114	clay	4.5	8.4	0.23	0,10	0.03	8.76	96	0.3
Bt4	114-150	fine sandy clay	4.7	9.3	0.20	0.09	0.05	9.44	99	0.3
BC	150-180	fine sandy clay	4.7	6.9	0.20	0.09	0.05	7.24	95	0.3
El Vivero, high terrace, 3% slope on gently undulating topograph. Typic Palehumult, claey, mixed, isohyperthermic. FCC:LCa.										
Ap	0-2	silt loam	4.2	5.9	1.74	1.02	0.22	8.88	66	6.2
Apb	2-13	clay loam	4.3	6.9	0.40	0.3[illegible]	0.16	7.82	88	1.7
A	13-36	clayloam	4.4	7.3	0.27	0.24	0.12	7.93	92	1.3
Bt	36-84	clay loam	4.4	8.8	0.27	0.23	0.08	9.38	94	1.2
Btg	84-123	clay	4.3	9.1	0.47	0.16	0.07	9.80	93	0.5
BC	123-165	clay	4.7	10.1	0.43	0.14	0.06	10.73	94	0.4
Cg	165-180	clay	4.8	15.3	0.20	0.14	0.06	15.7[illegible]	97	0.2
Esperanza Experiment Station, virgin forest. 0-2% slopes. Typic tropo humult, mixed, isohyperthermic. FCC: LCak.										
A	0-8	clay loam	3.7	7.9	0.23	0.18	0.12	8.4,3	94	4.2
AB	8-19	clay loam	4.1	5.6	0.27	0.18	0.10	6.15	91	2.3
Bt1	19-46	clay loam	4.6	4.4	0.53	0.17	0.08	5.18	85	1.13
BT2	46-79	clay	4.5	7.0	0.23	0.10	0.03	7.36	95	0.8
Bt3	79-96	clay	4.5	6.1	0.20	0.10.	0.03	6.43	95	0.9
Bt3	96-120	clay	4.6	5.6	0.20	0.10	0.03	5.93	94	0.7
Btg	120-142	si. clay loam	4.7	5.2	0.20	0.10	0.03	5.53	94	0.2
Bx1	142-162	loam	4.7	5.1	0.23	0.09	0.03	5.45	94	0.2
Bx2	162-180	loam	4.8	4.8	0.23	0.09	0.03	5.15	93	0.4
Bx2	180-200	loam	4.8	4.8	0.13	0.09	0.04	5.06	95	

Soil Survey of the Puerto Maldonado Experiment Station

Laurie J. Newman, N. C. State University
Stanley W. Buol, N. C. State University
Rafael Chumbimune, INIPA, CIPA XVII, Puerto Maldonado

The purpose of this study was to obtain an understanding of soils, including their genesis and morphology, at the Puerto Maldonado Experiment Station, so that local agriculturalists will be able to recommend management options for similar soils in the region. The station is in the Acre alluvial basin of southeastern Peru. The upland soils have ustic soil moisture regimes, and the natural vegetation is seasonal semi-evergreen forest.

Table 1 presents the soils classified by Soil Taxonomy and Fertility Capability Classification (FCC). The complete *Soil Survey of the Puerto Maldonado Experiment Station* (Newman, L. J. 1985) is available from the Tropical Soils Research Program, Box 7619, N. C. State University, Raleigh, NC 27695-7619, USA.

Table 1. Classification of the soils of the Puerto Maldonado Station, Peru

Name	Soil Taxonomy		FCC
	Sub Group	Family	
	Soils of the Level Upland		
Carretera	Typic[1] Paleustult	clayey, kaolinitic, isohyperthermic	LCadk
Estacion	Typic[1] Paleustult	coarse-loamy,siliceous, isohyperthermic	SLadek
Palma Real	Plinthaquic[1] Paleustult	clayey, kaolinitic, isohyperthermic	Cadgk
	Soil of the Upland Sideslopes		
Astillero	Typic[1] Paleustult	fine-loamy, siliceous, isohyperthermic	Ladek
Amable	Typic[1] Paleustult	coarse-loamy, siliceous, isohyperthermic	Ladek
Mashco	Aquic[1] Palestult	coarse-loamy, siliceous, isohyperthermic	SLadegk
	Soils of the Recent Floodplain		
Laberinto	Aeric[1] Placaquod	sandy, siliceous, isohyperthermic	Sdeghk
Chonta	Typic Troposaprist	dysic, isohyperthermic	Ok

[1] Sub group not presently defined in Soil Taxonomy (Soil Management Support Systems, 1985).

Soil Management Research Network

In the humid tropics, the limited resources and qualified professionals of national institutions often prevent programs from pursuing improved soil-management practices beyond the primary research sites. Linking programs and institutions into a network, however, can pool talent and resources, accelerating the flow of information among scientists and specialists, and the transfer of soil-management technology to producers.

Work led by TropSoils, REDINNA and IBSRAM scientists has launched the development of a soil-management research network for the humid tropics. The network's objectives are 1) to develop the capability of collaborating country personnel to conduct, interpret, and report user-oriented, soil-management research, and 2) to validate and extrapolate available soil-management technologies to other countries beyond the TropSoils primary research sites.

Approach

Work during 1985 was geared at promoting the establishment of such a network at three levels: nationally in Peru in cooperation with INIPA; regionally in Tropical America in cooperation with REDINNA and AID's Latin America and Caribbean Bureau; and tropics-wide in cooperation with IBSRAM. An underlying assumption has been the need to link with other insitutions, because of the limited time and resources available for research validation in TropSoils and the fact that actual technology transfer is the mandate of other projects or institutions. TropSoils' role in networking is viewed as catalytic, educational and as a major source of new management technology for the humid tropics. Agencies with a clear mandate for technology transfer such as national insitutions like INIPA, and network institutions like REDINNA and IBSRAM, are viewed as the means to conduct the networks. The U.S. Agency for International Development (USAID) participates in the network, and the project has engaged the cooperation of several USAID bureaus, as well as USAID missions in the humid tropics around the world.

Although countries with significant areas in the humid tropics differ widely in their stage of soil-management technology development, they all share one common limitation: lack of up-to-date know-how on management of humid tropical soils by scientists and extension agents stationed in the humid tropics. They may have excellent backing from top scientists, most of whom are in the nation's capital. Although they may exert considerable positive influence on program direction, it is the people in the field who determine the success of technology transfer. The vast majority of them are the B.S. level (*ingeniero agrónomo* or similar title) who received university training based on now oboslete concepts of tropical soil management (lime to pH 7, for example). This project intends to focus on such individuals as the real validators and transformers of technology.

Catalyzing Events

In order to promote network development, TropSoils personnel in 1985 helped conduct a series of workshops, courses and meetings, organized jointly with several agencies and institutions. Highlights included:

• **IBSRAM's Inaugural Workshop to Launch the Acid Tropical Soils Management Network,** in Yurimaguas, Manaus and Brasilia, April 24-May 3. There were 67 participants, representing 13 national institutions, seven donor agencies and a number of international centers and universities. The sponsoring institutions were INIPA, EMBRAPA, ACIAR-Australia, ORSTRM-France, Soil Management Support Services (SMSS), USAID and N.C. State University. Acting on expressed country interests, participants determined that the Acid Tropical Soils Management Network will concentrate its technology-validation activities on 1) pedology and fertility interactions, 2) soil acidity, 3) phosphorus fertilization, 4) management of the soil surface, 5) rehabilitation of degraded, acid tropical lands, and 6) soil dynamics. A TropSoils scientist participates in the follow-up acitivities as a member of the network's coordinating committee. Initial emphasis will be given to humid tropical Africa.

Also supported was IBSRAM's sister Inaugural Workshop on Land Clearing and Development, held in Jakarta in August, 1985, which was attended by a scientist who summarized TropSoils research experience on land clearing and reclamation in both Peru and Indonesia. The TropSoils scientist is a member of that network's coordinating committee.

• **Agroforestry Research Course for the Humid Tropics,** in Yurimaguas, June 3-22. This course was co-sponsored by INIPA and ICRAF with IDRC-Canada. There were 27 participants from Bolivia, Brazil, Colombia, Ecuador, Peru, and Venezuela. Follow-up acitivities include research validation in soil management for agroforestry systems throughout the Amazon.

• **National Selva Program Planning Workshop,** in Yurimaguas, October 24-31. Ninety Peruvian research and extension workers of INIPA's National Selva Program met and determined priorities for technology transfer throught the Selva. Other participants came from Peruvian universities, from IIAP and from the USAID-sponsored Selva Special Projects. A TropSoils senior scientist was assigned the task of coordinating technical aspects of the Selva Program. The 22 soil scientists present developed and recommended 11 specific activities for technology validation and transfer.

New Collaboration

Plans are to expand the network by capitalizing on collaborative research and training activities already planned or conducted by NCSU and TropSoils in some 33 countries around the world, and by maintaining contact with the several hundred students and professionals who have received training or degrees while participating in NCSU and TropSoils projects. Interest is especially strong in Asia, where the INSFERR Network has begun widespread testing of the Fertility Classification System (FCC). Countries with collaborative, network relationships with N.C. State University TropSoils are:

Latin America (13): Bolivia, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, Jamaica, Mexico, Panama, Peru, Puerto Rico, Trinidad, Venezuela.

Africa (8): Burundi, Cameroon, Congo, Ivory Coast, Madagascar, Nigeria, Zambia, Zimbabwe.

Asisa (11): Burma, China, India, Indonesia, Malaysia, Nepal, Pakistan, Phillipines, Sri Lanka, Taiwan, Thailand.

Extrapolation to Clayey Oxisols

Research conducted at Manaus, Brazil has offered the opportunity to select promising soil-management technologies from the primary research site at Yurimaguas, Peru, and test them in an ecosystem with different soils and climate. The ecosystem which includes Manaus occupies approximately 57 percent of the Amazon Basin. It is near-ustic, and the predominant vegetation is semi-evergreen, seasonal, primary forest, whereas vegetation at Yurimaguas is typically secondary forest. The soils at Manaus are Oxisols, found in 45 percent of the Amazon Basin, mostly in near-ustic and ustic soil-moisture regimes. They are clayey, very fine, kaolinitic Typic Acrorthox on flat plateaus, in contrast to the fine loamy, siliceous Typic Paleudults of Yurimaguas. Phosphorus sorption capacity for the clayey Oxisol at Manaus is intermediate between the high levels for the Cerrado Oxisols and the low levels found in Yurimaguas Ultisols.

Research has been conducted to discover how these differences in soils and climate affect the adaptation of soil-management technologies to the ecosystem found at Manaus. The first experiment examined the response of crops under continuous cultivation to a range of nutrients. It was designed to establish the times at which the application of each nutrient was required in order to sustain long-term production. As this central experiment indicated the need for more detailed information related to individual nutrients, satellite experiments were established. The work reported here is a cooperative project conducted at the UEPAE/Manaus Station (Unidade de Execucao de Pesquisa de Ambito Estadual de Manaus), conducted jointly with EMBRAPA (Empresa Brasileira de Pesquisa Agropecuaria).

This section also includes a report on work conducted in the Cerrado region, in collaboration with the Centro de Pesquisa Agropecuaria dos Cerrados (CPAC/EMBRAPA).

Soil Nutrient Dynamics and Fertility Management for Sustained Crop Production on Oxisols In the Brazilian Amazon

Thomas Jot Smyth, N. C. State University
Manoel Cravo, EMBRAPA
Joaquim B. Bastos, EMBRAPA

The objectives of this project were 1) to establish the patterns of soil-nutrient depletion as a function of time after clearing for a Central Brazilian Amazon Oxisol under continuous cultivation; 2) to determine the fertilizer inputs required for sustaining continous crop production on these Oxisols; and 3) to determine how a soil-fertility management system for the Manaus Oxisols would differ from one for the Yurimaguas Ultisols.

During the four years in which this study has been conducted, eight crops have been harvested in the sequence described in Table 1. Table 2 shows selected fertilizer treatments during continuous cultivation. Other treatments included a check (no fertilization), and a treatment with residue incorporation. A judicious monitoring of soil and plant nutrient levels for every crop determined when each treatment was established. Treatments for copper and lime were initiated in the second soybean crop, for sulfur in the second corn crop, for boron and zinc in the third corn crop, and for manganese in the third cowpea crop.

Topsoil nutrient-depletion patterns for this Oxisol are shown in Figure 1 and Table 3 for the absolute check treatment, which has not received any fertilizer or lime. Soil nutrient levels initially increased as a result of ash additions from burning the primary forest. The liming effect of the ash reduced Al saturation values from 73% to 18% during the first crop.

Table 1. Sequence of crops, varieties and time after burning for the cultivation of each crop.

Crop	Variety	Planting to Harvest Time
		Months After Burning
Rice	IAC 47	3.0 - 7.4
Soybeans	Tropical	8.9 - 12.6
Soybeans	Tropical	18.5 - 22.3
Cowpeas	Manaus	22.9 - 25.2
Corn	BR 5102	27.6 - 31.3
Cowpeas	VITA 3	32.7 - 34.9
Corn	BR 5102	37.2 - 41.8
Soybeans	Tropical	42.3 - 46.2

Phosphorus

Ash analysis indicated that approximately 10 kg/ha of P were added to the soil by the burn. Crop yields for the absolute check treatment (Figure 2) suggested that yields, in the absence of fertilizer inputs, would be negligible after the first crop. Despite the initial in-

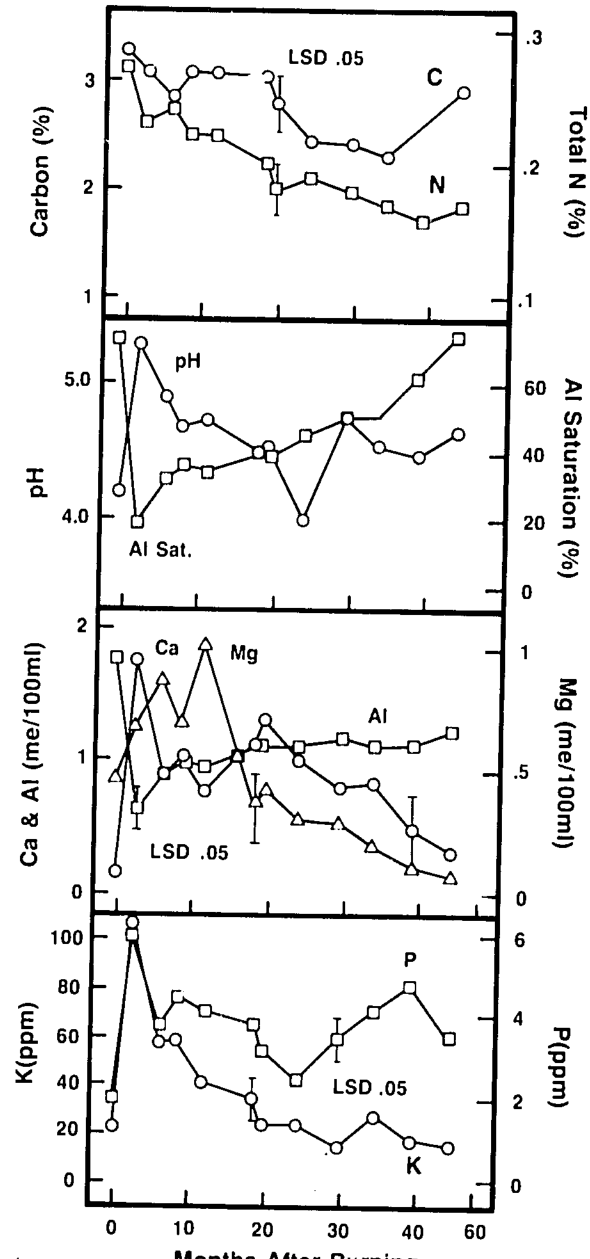


Figure 1. Soil dynamics for carbon, total N, acidity, exchangeable Al, Ca, Mg, K and Mehlich I P during the initial 44 months after clearing the primary forest on a Manaus Oxisol.

crease in Mehlich 1 extractable soil P (Figure 1), rice yields were doubled by the broadcast application of 22 kg P/ha (Figure 2). Although all succeeding crops showed a significant response to P fertilization, the optimum P rate was related to the timing of fresh P applications and crop P requirements. Relationships between crop yield and soil-test P suggested optimal Mehlich 1 P levels in the range of 5-10 ppm for corn, 8-10 ppm for cowpeas and 10-15 ppm for soybeans. Cumulative yields for the total applications of 88, 176, and 264 kg P/ha were 11.3, 13.5, and 16.7 t/ha, respectively.

Potassium

Topsoil K levels had declined from 107 to 56 ppm before planting the second crop (Figure 1). Treatments evaluating three rates of K were, therefore, initiated with this crop. Yield responses to K and the incorporation of residues from the previous crop are shown in Figure 3. The crop-residue treatment was included to evaluate the effects of returning residues when these are harvested for threshing the grain. Yield for this treatment was low on the initial soybean crop, since P was only applied prior to planting the third crop in the study (Table 2). Yields for the crop-residue treat-

Table 2. Fertilization history for selected treatments in the nutrient-dynamics study.

Crop	Fert. (kg/ha)	Treatment P_1	P_2	P_3	N_1	N_2	N_3	K_1	K_2	K_3
Rice										
	N	60	60	60	30	60	90			
	P	22	44	66	44	44	44			
Soybeans										
	N	20	20	20	0	0	0	20	20	20
	P	22	44	66	44	44	44	88	88	88
	K	50	50	50	50	50	50	25	50	100
	Mo	.02	.02	.02	.02	.02	.02	.02	.02	.02
Corn*										
	N	54	54	54	27	54	80	54	54	54
	P	0	0	0	0	0	0	22	22	22
	K	50	50	50	50	50	50	25	50	100
	Cu	1	1	1	1	1	1	1	1	1
Soybeans										
		(no fertilizer applications in these treatments)								
Cowpeas										
	K	0	0	0	0	0	0	25	50	100
Corn										
	N	80	80	80	40	80	120	80	80	80
	P	22	44	66	22	22	22	22	22	22
	K	50	50	50	50	50	50	0	0	0
	Lime (t/ha)	2	2	2	2	2	2	2	2	2
Cowpeas										
	K	0	0	0	0	0	0	25	50	100
Corn										
	N	80	80	80	40	80	120	80	80	80
	K	50	50	50	50	50	50	25	50	100
Soybeans										
	P	22	44	66	44	44	44	44	44	44
	K	50	50	50	50	50	50	25	50	100
Cowpeas										
	K	50	50	50	50	50	50	25	50	100

* Crop failed in 43-day drought. Corn was cut and the stover incorporated.

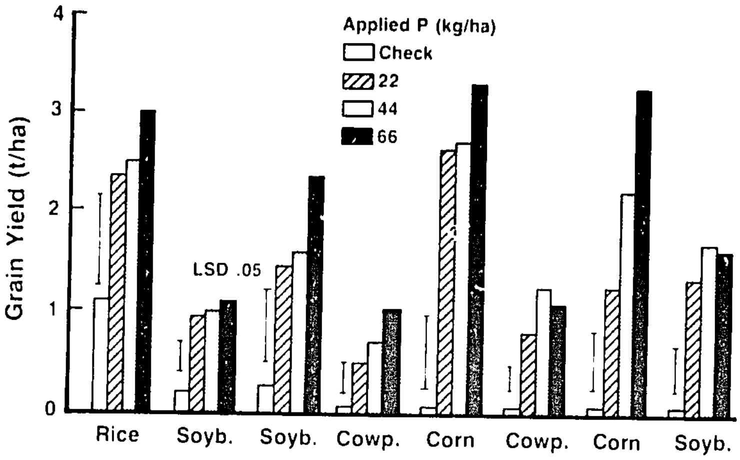


Figure 2. Grain yields for eight consecutive crops on tne absolute check and P treatments.

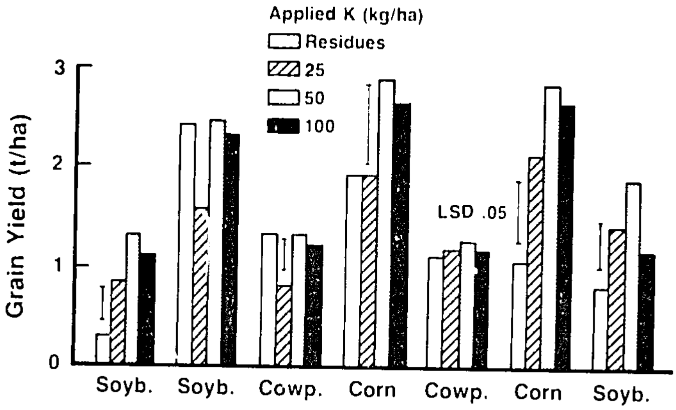


Figure 3. Effects of K fertilization and crop residue incorporation on yields of seven crops.

ment, relative to the K treatments, declined progressively following the first corn crop and were primarily related to a continual decline in soil K (Table 4) and increasing levels of soil acidity.

Yield response to fertilizer K has not exceeded 50 kg K/ha for any crop. Foliar K levels with this treatment approached the recommended values in most crops (Table 4). Topsoil K data suggested that residual effects from fertilizer K were low (Table 4). This was

Table 3. Mehlich 1 extractable soil micronutrient levels on the absolute check treatment as a function of time after burning.

Time After Burning	Melich 1 Extractable		
	Cu	Mn	Zn
months		ppm	
0	0.1	2	1.0
2.6	1.8	10	0.9
6.3	1.5	4	0.5
8.7	2.2	6	1.2
11.8	0.8	6	1.0
18.6	1.8	5	1.0
19.7	2.0	6	1.0
24.3	1.5	6	2.5
29.8	1.0	2	0.8
34.1	1.1	3	1.0
39.2		3	
44.0		2	
LSD .05	0.6	2	0.5

Table 4. Effects of K fertilization and crop-residue incorporation on soil K and foliar K levels at flowering stage during seven consecutive crops.

Applied K	Crop Sequence						
	Soyb.	Soyb.	Cowp.	Corn	Cowp.	Corn	Soyb.
kg/ha	soil K, ppm						
25	61	20	29	16	30	18	23
50	91	26	48	19	50	25	48
100	78	30	68	19	97	64	110
Crop Residues	124	32	52	24	50	21	25
LSD .05	19	9	12	ns	15	11	15
	leaf K, %						
25	1.26	1.40	0.90	1.23	1.25	1.14	1.44
50	1.85	1.70	1.16	1.68	1.56	1.50	1.63
100	1.99	1.86	1.12	1.80	1.95	1.64	1.81
CropResidues	1.64	1.92	1.09	1.93	1.44	1.29	1.45
LSD.05	0.35	0.21	0.26	0.31	0.36	0.17	0.19

particularly evident with the first corn crop, where no K was applied at planting. Data for K distribution in the profile also supported this observation (Figure 4). Between 2.6 and 39.2 months after burning, K added by the ash to the check treatment declined significantly at all depths measured. At the latter sampling date soil K levels with applications of 100 kg K/ha were significantly higher at all depths sampled than with applications of 25 kg K/ha.

Results have suggested that the best approach to K fertilizer management would be on an individual-crop basis. For corn and soybeans, a rate of 50 kg K/ha/crop appeared to be near optimal. Crop residue incorporation was beneficial in reducing the amounts of K exported by each crop harvest.

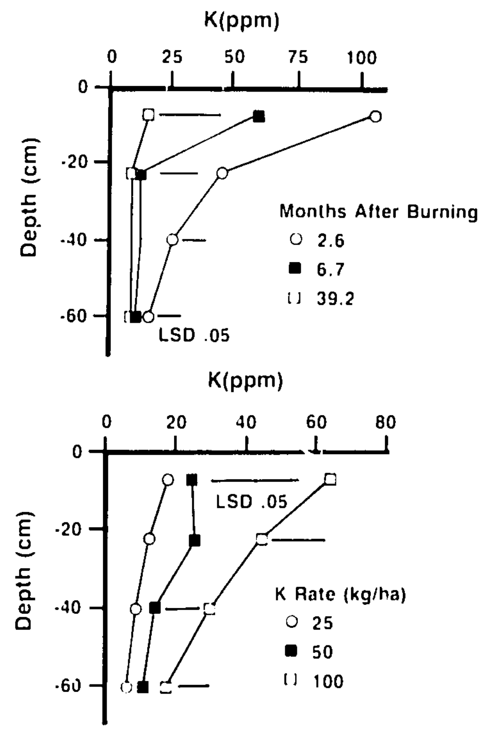


Figure 4. Potassium distribution in the soil profile for different times after burning on the check treatment, and K rates at 39 months after burning.

Table 5. Rice and corn yield and foliar N levels as a function of N fertilization rates applied to each crop.

Applied N	Yield			Leaf N		
	Rice	Corn	Corn	Rice	Corn	Corn
kg/ha	t/ha			%		
30	2.9			2.68		
40		2.7	2.2		2.33	2.24
60	3.0			2.70		
80		2.5	1.8		2.52	2.30
90	2.1			2.63		
120		2.9	2.3		2.59	2.44
LSD .05	ns	ns	ns	ns	0.25	ns

Table 6. Effects c' Cu fertilization on grain yields and foliar Cu levels at flowering stage in two corn crops from a six-crop succession of soybean, cowpea, corn, cowpea corn and soybean.

Applied Cu	Corn 1		Corn 2	
	Yield	Leaf Cu	Yield	Leaf Cu
kg/ha	t/ha	ppm	t/ha	ppm
0	2.4	4	2.2	8
1	2.8	8	2.6	10
2	3.0	10	2.4	13
LSD .05	ns	2	ns	3

Table 7. Effects of B and Zn fertilization on crop yields and soil and foliar Zn levels.

Nutrient	Rate	Yield		Soil Zn		Foliar Zn	
		Corn	Soyb.	Corn	Soyb.	Corn	Soyb.
	kg/ha	t/ha		ppm			
B	0	2.1	1.3	--	--	--	--
	0.5	2.5	1.6	--	--	--	--
	1.0	2.2	1.2	--	--	--	--
Zn	0	2.3	1.8	:4	.4	16	34
	5	2.5	1.8	.8	1.3	17	43
	10	2.5	1.8	1.8	1.9	20	41
	LSD .05	ns	ns	.3	.2	3	9

Nitrogen

Yield responses to N fertilization were evaluated for rice and corn (Table 5). Nitrogen rates were split into three equal parts and applied between planting and flowering for each crop. There was no yield difference due to nitrogen rate, although the rice crop receiving 90 kg N/ha had more lodging than rice receiving 60 kg N/ha. Nitrogen supplied by previous legume-crop residues, native soil N and split applications of fertilizer N have apparently contributed to the reduction in corn's yield response to applied N. These aspects of N fertilization are being investigated further in another study.

Organic-matter dynamics for the check treatment showed that total N levels declined to 60% of initial levels, with a progressive increase in C/N ratios (Figure 1). Nitrogen fertilizer requirements may increase in future crops if these trends result in decreased soil N availability.

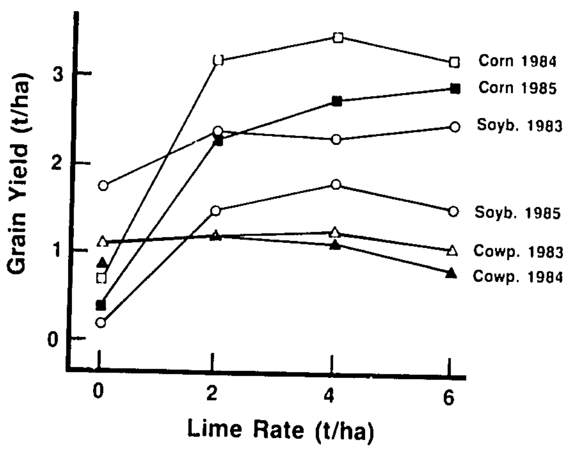


Figure 5. Yield response to four rates of lime for six consecutive crops.

Copper

Results for Cu fertilization have varied among succeeding crops. Trends for Cu response were evident in the yield- and foliar-analyses data for corn (Table 6), whereas cowpeas and soybeans have not indicated a response to Cu.

Liming

Treatments for lime were established at 18 months after burning, when Al saturation values had risen to 40%. The lime was obtained locally from a calcitic deposit (33% Ca, 0.8% Mg and 83% $CaCO_3$ equivalent). The rates of 2, 4, and 6 t/ha would be equal to 2.3, 4.6, and 6.9 t/ha, respectively, on a $CaCO_3$ equivalency basis.

Yields for corn and soybeans increased significantly to the application of 2 t/ha of lime (Figure 5). Corn and soybean yields without lime declined with each succeeding crop, as Al saturation levels increased from 52 to 77%. Relationships between relative yields and Al saturation for these lime treatments indicated a decline in corn and soybean yields for Al saturation levels greater than 20% (Figure 6). In the range of 0-60% Al saturation, cowpeas have not demonstrated a response to lime. Soybean and cowpea yield reductions with 6 t/ha of lime were associated with a decrease in foliar Mn levels.

Yield data for the lime treatments have indicated a prolonged residual effect to applications as low as 2 t/ha. Topsoil chemical properties support this observation (Figure 7). Lime treatments have maintained higher levels of pH and Ca and lower levels of Al during the initial 26 months. During this period, Al levels for the no-lime treatment have fluctuated between 1.1 and 1.4 meq/100 ml. Consequently, increases in Al saturation have resulted from a progressive decline in the levels of exchangeable bases. Topsoil levels of Ca and Mg have also declined during the initial 20 months

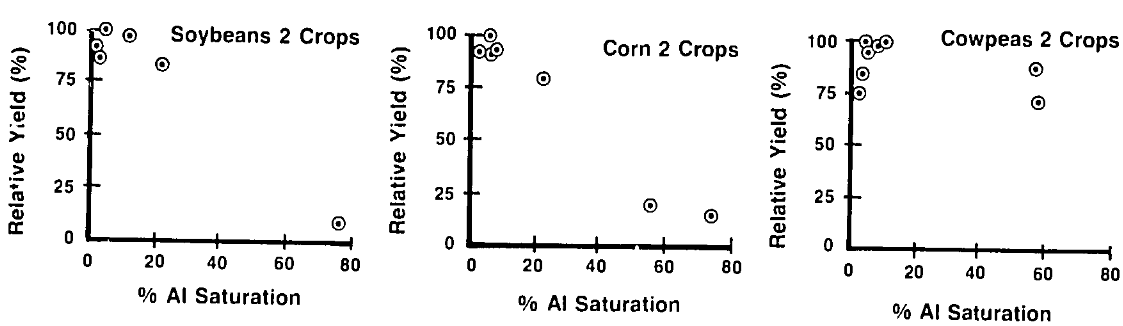


Figure 6. Relationships between relative yield and soil Al saturation for six consecutive crops grown on treatments with four lime rates.

on the three lime rates. Profile data for these lime treatments at 21 months after liming indicated that Ca had increased and Al had decreased in the subsoil (Figure 8). Liming, therefore, should also improve the proliferation of roots in the subsoil for acid-sensitive crops.

Sulfur

Fertilizers have been applied in concentrated forms in order to reduce transportation costs. Sulfur-carrying fertilizers, with the exception of Cu and Zn, have therefore been excluded thus far. Sulfur treatments, with rates of 0, 10, 20 and 30 kg/ha, were established with the first corn crop by adding varying proportions of ammonium sulfate to the fixed N rate. Yield data for four successive crops have not shown a significant response to these single S applications. Corn yields ranged from 2.4 to 2.8 t/ha, soybean yields from 1.4 to 1.6 t/ha, and cowpea yields from 1.1 to 1.3 t/ha. Although foliar S levels in general were low, from .15 to .18%, S applications did not increase leaf S concentrations.

Boron and Zinc

Treatments for these elements have been evaluated during the last two crops. Yield data and soil and leaf Zn data are shown in Table 7. Neither crop presented a significant yield response to B or Zn, although foliar Zn levels for corn were below the normal sufficiency range in the treatment without Zn.

Conclusions

Results from this study have provided insight into the timing and quantities for fertilizer inputs required for sustaining continuous crop production on these Oxisols. When compared with similar data obtained on Ultisols in Yurimaguas, inputs were noted to vary both in quantity and time of application. In summary:

1) Fertilizer P requirements were higher and occurred at an earlier stage in this clayey Oxisol, when compared to those on the Ultisols.

2) Lime applications for this Oxisol were delayed for a longer period in cultivation than for the Yurimaguas Ultisol.

3) Yield responses to micronutrients on the Manaus Oxisol have not been as consistent as those observed for the Ultisols in Peru.

Implications

The study shows, in general, that a farmer growing food crops in an ecosystem like that at Manaus will need to apply phosphorus immediately after slash and

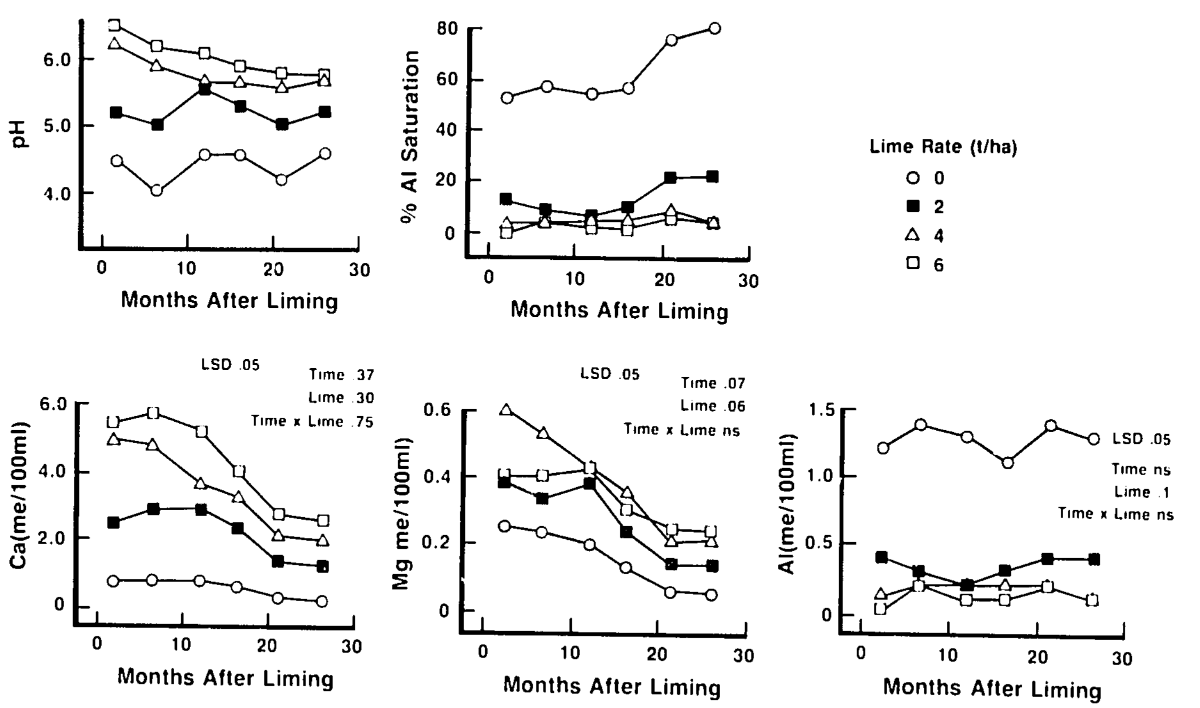


Figure 7. Topsoil acidity dynamics as a function of time after lime was applied to the Manaus Oxisol.

burn, potassium by the third crop, and lime at or before the 18th month after burning. Yields under this management system will be high by local standards, and comparable to those at Yurimaguas. Differences in the patterns of nutrient dynamics at Manaus and Yurimaguas point to the need for obtaining similar information on other major soil types in the humid tropics.

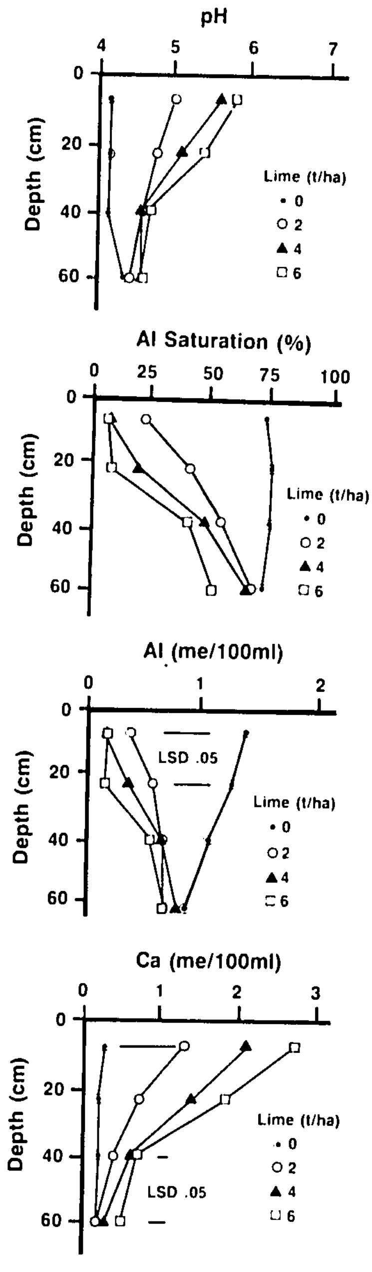


Figure 6. Soil-profile acidity acidity characteristics for the lime treatments at 21 months after liming.

Phosphorus Management In Humid Tropical Oxisols

Thomas Jot Smyth, N. C. State University
Manoel Cravo, EMBRAPA
Joaquim B. Bastos, EMBRAPA
P. Le Mare, Reading University, UK

Phosphorus deficiency is common in Oxisols of the Brazilian Amazon. For clayey Oxisols, P fertilization could become an important economic factor, as their P sorption capacities are high, in the same range as those in Oxisols of the Cerrado region. Although several studies have demonstrated marked yield responses to P fertilization with annual crops on these soils, information has been needed on soil-test calibrations and the long-term effects of different strategies for P fertilization.

The objectives of this project were: 1) to obtain detailed P response curves and soil-test calibration data for the main annual crops cultivated in the region; 2) to obtain a description of the residual P fertilizer value, and 3) to provide indications of appropriate maintenance P fertilizer rates for sustaining adequate crop yields.

Eight consecutive crops of the annual corn-cowpea rotation have been harvested in this study. The ex-

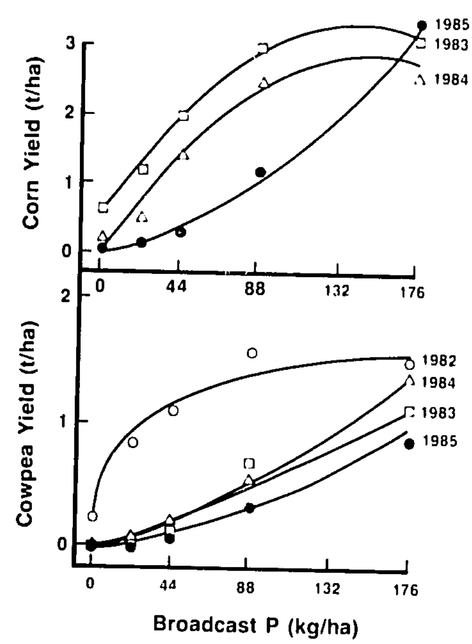


Figure 1. Corn and cowpea yield responses to initial broadcast P applications during the first four years.

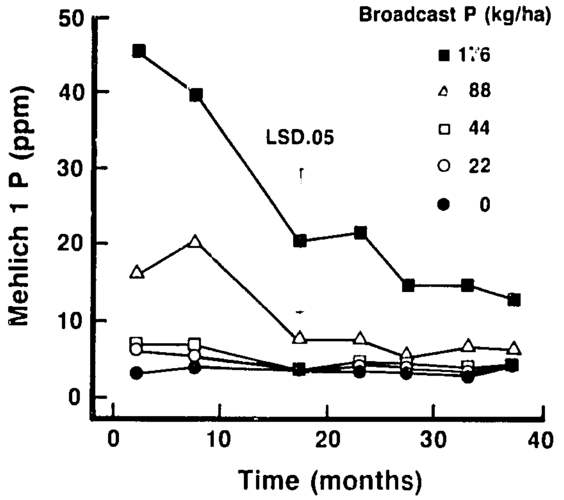


Figure 2. Available soil test P dynamics with time and rate of P application.

periment consists of a split-plot design in which the main plots were broadcast P rates (0, 22, 44, 88, and 176 kg P/ha), and the subplots were banded P rates. Broadcast P was applied once, before planting the initial corn crop. All other nutrients were maintained under nonlimiting conditions.

Yield Responses to Phosphorus

Corn was the first crop planted after felling and burning the primary forest in 1981. Yields on this initial crop were reduced by diseases (primarily mycoplasma) and showed a significant response only to 22 kg P/ha (data not reported due to the very low yields). Yield response of corn and cowpeas to the P broadcast in 1981 are shown in Figure 1. Maximum yields for cowpeas in 1982 and for corn in 1983 and 1984 were approached with 88 kg P/ha. In subsequent crops, maximum yields for both species were approached with 176 kg P/ha. These changes in yield response curves during successive years of cultivation are in agreement with changes in soil-test P with time after broadcast P fertilization (Figure 2). For 88 kg/ha of broadcast P, Mehlich 1 extractable P values declined from 20 ppm with cowpeas in 1982 to 7 ppm with cowpeas in 1983.

Data in Figure 1 also indicate that, for a fixed level of broadcast P, corn yields were sustained for a greater succession of crops than were cowpea yields. This observation is supported by the higher critical level of soil-test P for cowpeas than for corn (Figure 3). During three consecutive years, cowpea yields above 80% of maximum occurred when Mehlich 1 extractable P was greater than 10 ppm. Similar corn yield levels were obtained with soil-test P values of 5-7 ppm.

Broadcast vs. Banded P

Yield trends for successive crops of corn and cowpeas are compared in Figure 4 for various treatments of broadcast and banded P. Yields in each crop are presented as a percentage of yields for the broadcast P rate of 176 kg/ha. Data for both corn and cowpeas indicate that P supplied solely by banding 11 kg P/ha/crop does not increase soil P availability, as yield levels on the final crops were similar to the initial crops. However, banded applications of 22 kg P/ha/crop provided corn yields comparable to those obtained with a single broadcast application of 176 kg P/ha. Yields of cowpeas with this banded P rate increased from 86% on the first crop to 95% on the fourth crop, relative to yield obtained with the maximum broadcast P rate. The negligible difference in yield response between banded applications of 22 and 44 kg P/ha/crop led to discontinuing applications of the latter rate after the fourth crop in the study. Comparisons of yield trends

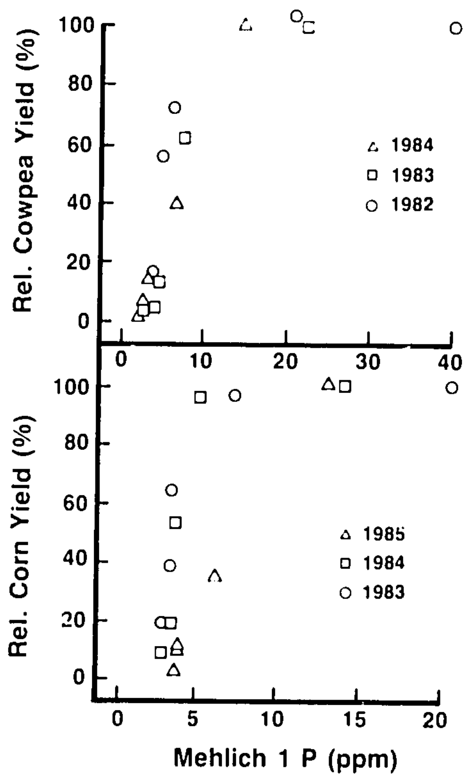


Figure 3. Cate-Nelson diagram suggesting Mehlich I P critical levels of 10 ppm for cowpeas and 5 ppm for corn in Manaus.

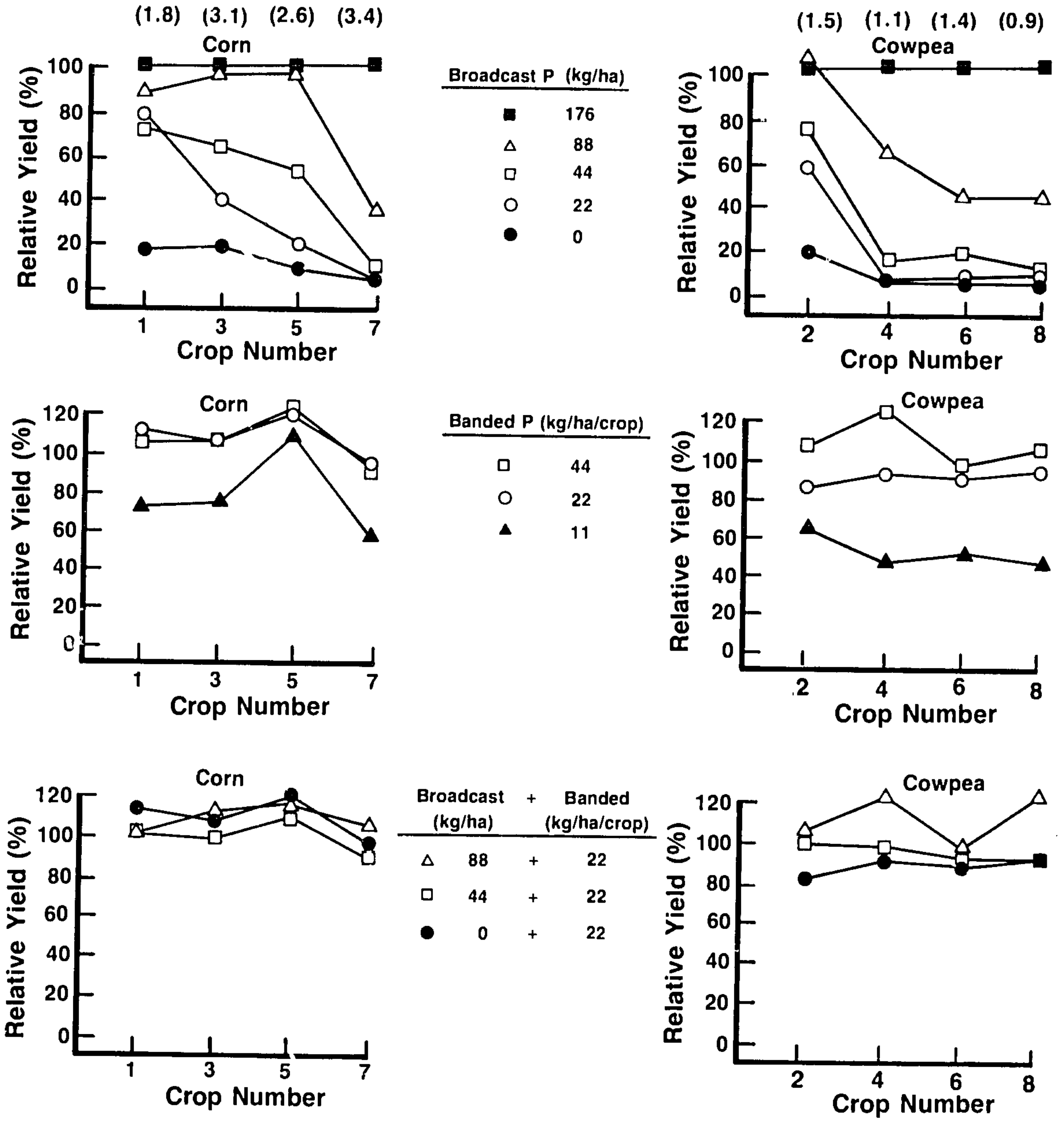


Figure 4. Residual effect of different P rates and placement methods in a corn-cowpea rotation in Manaus. Yields are expressed as percentages of yields obtained from a single application of 176 kg P/ha, broadcast prior to planting first crop. Numbers in parentheses are absolute yields (t/ha) for the broadcast 176 kg P/ha.

between combinations of broadcast P with the banded rate of 22 kg P/ha/crop do not indicate a consistent yield increase to broadcast P. Apparently P requirements for optimum corn and cowpea yields were approached with this banded P rate alone.

Conclusions

Cumulative yields for corn and cowpeas are shown in Figure 5, as a function of total P applied in all the banded and broadcast combinations. The similarities in yields among the different fertilizer-application methods at a given P level suggest that grain yields, for the crop rotation under study, were primarily a function of the amount of P applied. Results, therefore, point to different P fertilization strategies with similar outcomes. Banded P applications would be preferred by most farmers in the region, since most crops are planted by hand. With a banded P rate of 22 kg/ha/crop, total yields were 15.9 t/ha, as opposed to 1.4 t/ha in the absence of P fertilizer inputs.

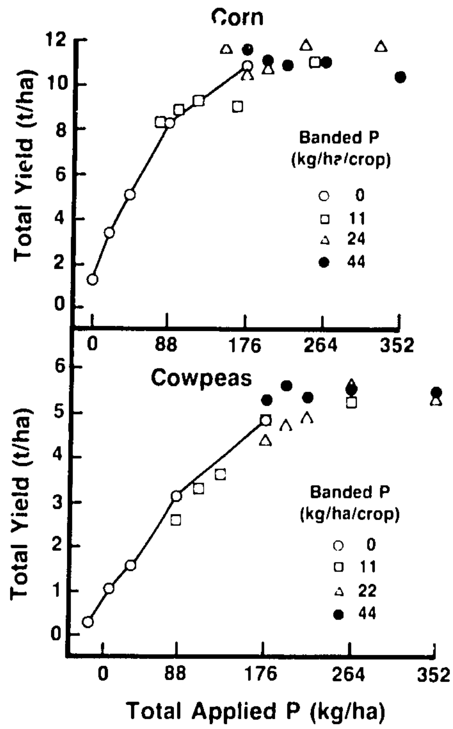


Figure 5. Cumulative corn and cowpea yields in relation to total applied P during four years in Manaus.

Implications

Results from this study have been used in the farmer-demonstration trials which UEPAE/Manuas has established as its participation in the State Rural Integration and Development Program. Soil-test critical levels for P have aided in the selection of appropriate sites for corn and cowpea trials. In P deficient areas, cowpea trials were established with and without 22 kg/ha of banded P.

Potassium Management In Humid Tropical Oxisols

Manoel S. Cravo, EMBRAPA
Thomas Jot Smyth, N.C. State University
Joaquim B. Bastos, EMBRAPA

Abundant rainfall in the Central Brazilian Amazon, and the naturally low cation exchange capacities of the regions's clayey Oxisols, promote the rapid leaching of potassium from the soils. Native soil K reserves can be expected to be small, since clay mineralogy is predominantly kaolinitic. These conditions suggest that crop production on these soils will require continual K fertilization, and that management systems should be considered to minimize K losses.

The objectives of this project were 1) to establish K response curves and soil-test calibration data for the main annual crops cultivated in the region, and 2) to determine whether split applications would improve the efficiency of K fertilization.

Yield Response to Broadcast K

The first phase of this project examined the yield response of a corn-cowpea rotation to annual broadcast rates of 0, 16.5, 33, 66, and 132 kg K/ha, applied at corn planting during two consecutive years. Although maximum corn yields were obtained in both years with 66 kg K/ha, yield differences between 33 and 66 kg K/ha were not significant. Cowpea yield responses to residual fertilizer K were not significant in either crop. Measurements at harvest of K uptake in all crops indicated that maximum fertilizer K utilization (39%) occurred with the application of 66 kg K/ha. Periodic soil K measurements to a 60 cm depth indicated significant increases in subsoil K only in the treatment with 132 kg K/ha.

Effects of Split Applications

A second K experiment was established in December, 1983 to evaluate whether split K applications might reduce fertilizer K requirements or improve the efficiency of K fertilization in a corn crop. Three methods of K application were combined with four K rates in a factorial design with four replications. Potassium rates were 0, 16.5, 33, and 49.5 kg K/ha. Methods of K application were 1) 100% broadcast at planting; 2) 50% broadcast at planting and 50% sidedressed at 55 days, and 3) divided equally among three broadcast applications—at planting, 25 days and 55 days. Times for side-dressed K applications were selected to coincide with N applications, in order to avoid additional labor inputs. Potassium was applied to corn in an annual rotation with cowpeas.

Yield data for four consecutive crops of the corn-cowpea rotation are shown in Tables 1 and 2. Foliar K levels are not shown but ranged from 1.13 to 2.05% in the 1984 corn crop, from .90 to 1.83% in the 1984 cowpea crop, and from .79 to 1.71 in the 1985 corn crop. Yields and leaf K levels in all crops increased significantly with rates of applied K, whereas mean effects of split applications were not significant. Corn yields in 1984 tended to increase with the number of split applications to the maximum K rate. Leaf K levels for this crop suggested luxury K consumption when 49.5 kg K/ha was parcelled into three applications. Foliar K levels for corn in 1985 were inferior to corn in 1984 for identical fertilizer K treatments. The native soil K supply may have declined by the second year of cultivation.

The 1984 cowpea crop showed a lower yield response to residual K fertilizer treatments, compared to the response in corn. In 1985, cowpea yields in general were decreased in the residual K fertilizer treatments. Plant and soil analyses for the latter crop have not been completed.

Soil and leaf analyses for corn in 1985 suggested that Mg was a potential constraint for this crop. Foliar Mg concentrations declined below the recommended sufficiency range with increasing rates of applied K (Figure 1). Soil Mg levels for all treatments were .1 me/100 ml and represented less than 5% of the effective CEC. Ratios of soil exchangeable Mg:K decreas-

Table 1. Yield response in 1984 of a corn-cowpea rotation to rates and methods of K application to the corn crop.

Applied K	Split Applications 1	2	3	Mean	Split Applications 1	2	3	Mean
kg/ha	corn yield (t/ha)				cowpea yield			
0	1.2	1.2	1.1	1.2	0.7	0.5	0.6	0.6
16.5	1.8	1.8	1.8	1.8	0.8	0.6	0.8	0.7
33	1.7	2.0	2.0	1.9	0.7	0.8	0.9	0.8
49.5	2.1	2.4	2.8	2.4	0.7	0.8	0.8	0.8
Mean	1.7	1.9	1.9	—	0.7	0.7	0.8	—
LSD .05								
K rate		.4				0.1		
Placement		ns				ns		
Rate X placement		ns				ns		

Table 2. Yield response in 1985 of a corn-cowpea rotation to rates and methods of K application to the corn crop.

Applied K	Split Applications 1	2	3	Mean	Split Applications 1	2	3	Mean
kg/ha	corn yield (t/ha)				cowpea yield			
0	1.6	1.5	1.5	1.5	0.8	0.8	0.8	0.8
16.5	2.3	2.0	1.8	2.0	0.7	0.6	0.4	0.6
33	2.3	2.3	2.4	2.3	0.6	0.7	0.7	0.6
49.5	2.7	2.9	2.1	2.6	0.7	0.9	0.6	0.7
Mean	2.2	2.2	1.9	—	0.7	0.7	0.6	—
LSD .05								
K rate		0.2				0.1		
Placement		ns				ns		
Rate X placement		0.4				ns		

Table 3. Total K uptake and fertilizer K utilization efficiency (UE) as a function of rates and placement of K fertilizer for corn.

Applied K	Split Applic.	K Uptake		1984 K Utilization Eff.			Corn 1985	
		Corn	Cowpea	Corn	Cowpea	Both	K Uptake	Utiliz. Eff.
kg/ha		kg/ha		%			kg/ha	%
0	1	19.7	10.1	—	--	—	10.7	—
	2	20.5	9.8	—	—	—	11.5	—
	3	19.5	8.8	—	—	—	11.5	—
16.5	1	26.6	16.8	41	44	84	20.9	59
	2	24.4	16.0	27	38	66	18.0	41
	3	26.0	11.8	37	13	50	19.3	49
33	1	24.9	16.2	15	20	35	21.3	30
	2	32.9	18.9	39	28	68	23.8	38
	3	30.3	17.6	32	24	58	25.2	42
49.5	1	32.2	16.7	25	14	39	25.2	28
	2	38.7	17.7	38	16	54	24.8	27
	3	39.7	19.4	40	20	60	23.2	24
LSD .05								
K rate		4.0	2.8				2.5	
Placement		ns	ns				ns	
Rate X placement		ns	ns				ns	

ed from 1.8 to 1.3 as K rates were increased from 0 to 49.5 kg/ha. Lower values of this ratio were not obtained due to the low levels of exchangeable K (21-30 ppm) maintained in the topsoil.

Total K uptake at harvest was determined for the three initial crops (Table 3). The efficiency of fertilizer K use was determined by comparing the amount of K applied each year to the amount detected in the crops at harvest. Native soil K uptake for each crop was assumed to be constant for all K treatments, and equivalent to the average of the treatments without K. For crops in 1984, the effects of split applications on fertilizer K utilization varied with the rates of K applied. Total K uptake and utilization of fertilizer K were increased by split applications as K rates increased. For corn in 1985, however, K uptake was lower with split applications at the rate of 49.5 kg K/ha.

Observations

It is too early to draw firm conclusions from this study. Although current data have not indicated a clear yield advantage from split K applications, this practice may help reduce fertilizer K losses by maintaining a greater proportion of this element in crop residues.

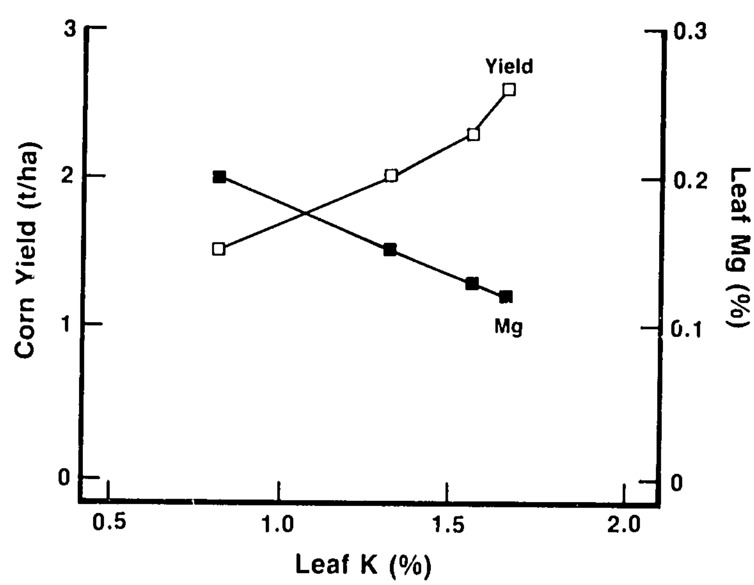


Figure 1. Relationship between K content in corn ear leaf, corn yields and Mg content in the leaf.

Guarana Fertilization

Thomas Jot Smyth, N. C. State University
Manoel S. Cravo, UEPAE-Manaus
J. Ricardo Escobar, IICA/EMBRAPA

Guarana (*Paullinia cupana*) is a major permanent cash crop for small farms in the state of Amazonas. Commercial production is stimulated by strong demand for a national soft drink produced from the ground seed and by a growing export market. The plant (Figure 1) is a bushy shrub with a spreading, irregular growth habit. To date, research on guarana has centered on the selection of high-yielding cultivars. However, nutritional problems may become a future limitation, as seed yields on some of the most promising clones would represent an annual removal of 68 kg/ha of N, 4 kg/ha of P, 14 kg/ha of K, and 3 kg/ha of Mg.

Short-term studies have demonstrated yield responses by guarana to applications of fixed quantities of fertilizers. However, the absence of data on yield response curves for guarana to fertilizers has restricted the development of fertilizer recommendations for this crop. Long-term field studies with guarana fertilization recently became possible with the development of vegetative-propagation techniques.

The objectives of this study were 1) to characterize the yield response curves of guarana to rates of N, P, K, and Mg fertilization, and 2) to establish soil-test and tissue-analysis calibration data on guarana for these nutrients.

Figure 1. Guarana (*Paullinia cupana*).

The field experiment was initiated in February, 1983. Rates of N, P, K, and Mg fertilizers tested are shown in Table 1. Individual response curves were established with four annual rates of each nutrient, while maintaining the remaining nutrients constant at the highest rate. The experiment contained three replications with fertilizer treatments as main plots and three guarana clones as subplots.

Initial plans were to split annual fertilization rates, excluding P, into two equal applications during the vegetative growth phase, which extends from January to July in the Manaus region. In 1984, this fertilization scheme was changed to three split applications when symptoms of N deficiency were observed before the second fertilization. Planned measurements included determinations on propagation of branches, yield and nutrient analyses of soils, leaves, and fruits. A prolonged dry season immediately after planting the guarana resulted in a high mortality rate for the three clones. Over 50% of the original plants were replanted. Destructive plant measurements were, therefore, delayed until plant flowering in October, 1985.

Growth Response to Nutrients

Preliminary growth measurements have been affected by the large number of plants replanted in the study. Consistency of results was improved when average increases in the number of branches were determined between the last two sampling dates (Table 1). Maximum increases in branching, among the fertilized treatments, occurred with the treatment containing the highest rate of all nutrients. For lower rates of individual nutrients, the largest reduction in branching occurred in the absence of P, followed by K, Mg, and N, respectively. Plant growth as a function of rates of N, P and K, is further exemplified with individual clones in Figure 2 for the initial 24 months of this study. Differences in number of branches per plant were evident at 12 months after planting and increased during subsequent growth. Plant yields are considered to be partially related to the number of branches produced during the previous year. These data will be compared with yields for the first harvest of this study, in January, 1986.

Soil Nutrients

Because fertilizers were applied in 0.3 m wide strips corresponding to the circumference of the plant canopy, variability was great in soil-chemical analyses. Nevertheless, soil-test P values increased significantly with P fertilization. No differences were observed in soil test levels of K and Mg among rates of these elements. In general, levels of exchangeable bases, Al and Mehlich 1 extractable micronutrients were similar to those observed for the unfertilized plots of the adjacent nutrient-dynamics study at a similar time after burning the primary-forest vegetation.

Implications

The UEPAE/Manaus station is responsible for coordinating all the guarana research conducted by the EMBRAPA network. As one of the few long-term guarana fertilization field trials, this study will be useful in delineating specific lines of future research and in providing initial guidelines for fertilizer recommendations on this permanent crop. The study will also provide a means of comparing soil-nutrient dynamics in the guarana experiment with those in the adjacent experiments with annual crops.

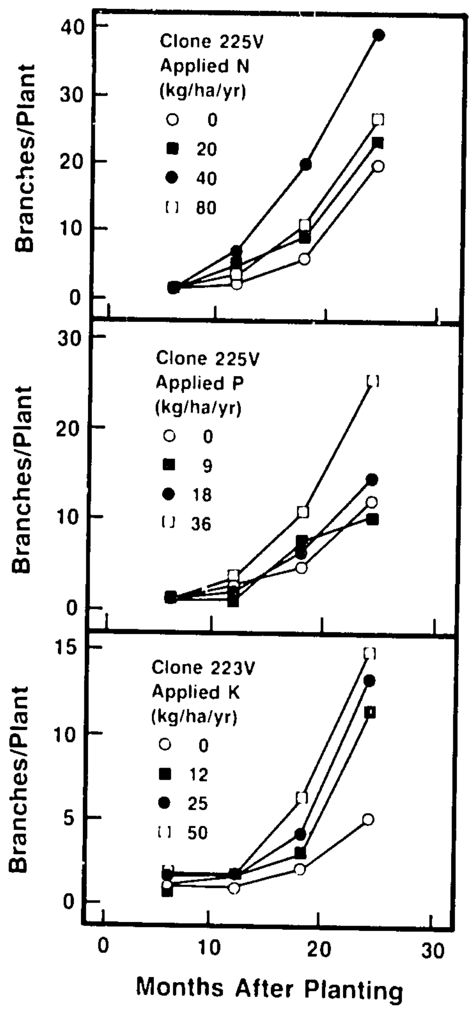


Figure 2. Guarana growth as a function of N, P and K.

Table 1. Effects of fertilizer treatments on increases in the number of guarana branches/plant between August, 1984 and February, 1985.

Treatment	Rates Applied				Average Increase of Branches
	N	P	K	Mg	
	kg/ha/year				number/plant
Check	0	0	0	0	8.3
N0P3K3Mg3	0	36	50	20	8.5
N1P3K3Mg3	20	36	50	20	8.7
N2P3K3Mg3	40	36	50	20	8.8
N3P0K3Mg3	80	0	50	20	4.5
N3P1K3Mg3	80	9	50	20	4.4
N3P2K3Mg3	80	18	50	20	5.0
N3P3K0Mg3	80	36	0	20	4.8
N3P3K1Mg3	80	36	12	20	5.7
N3P3K2Mg3	80	36	25	20	6.9
N3P3K3Mg0	80	36	50	0	5.9
N3P3K3Mg1	80	36	50	5	5.7
N3P3K3Mg2	80	36	50	10	7.3
N3P3K3Mg3	80	36	50	20	9.1
N2P2K2Mg2	40	18	25	10	7.0

Lime Requirements and Downward Movement of Ca and Mg

Manoel Cravo, EMBRAPA
Thomas Jot Smyth, N. C. State University

Previous studies on a Typic Acrorthox at Manaus, Brazil have shown that soil acidity becomes a limitation to annual crop production at approximately 18 months after burning the forest vegetation. Increases in Al saturation over time of cultivation and profile depth were partially related to decreases in exchangeable bases, since absolute levels of exchangeable acidity have seldom exceeded 1.5 meq/100 ml. Under such conditions, liming could be expected to help correct topsoil acidity and promote the downward movement of Ca and Mg, improving root penetration into the subsoil. Increased root growth into the subsoil could increase soil water availability and reduce the risks of crop failures due to the occasional dry spells that occur in the Manaus region.

Research performed on the acid savannas of Brazil has indicated that the Ca from gypsum supplied by ordinary super-phosphate moved rapidly into the subsoil and alleviated acidity problems. Although this P source would be more expensive than triple superphosphate in the Manaus region, the additional cost might be justified if a similar phenomenon were observed in these soils.

The objectives of this study were 1) to determine the lime requirements of this Typic Acrorthox for annual crop production, and 2) to determine which combination of calcium sources and rates of application most effectively promoted the downward movement of Ca and Mg into the subsoil.

The study was initiated in 1983 on an area containing 51, 55, and 53% Al saturation at sampling depths of 0-20, 20-40, and 40-60 cm, respectively. Treatments were established in a randomized, complete block design with four replications. The locally derived calcitic lime source, from Maues County, Amazonas, was the same as that used in the nutrient-dynamics study. Particle-size characteristics of the lime were 63% finer than 60-mesh and 36% in 20- to 60-mesh. Mean chemical analyses of these fractions was 33% Ca, .8% Mg and 83% $CaCO_3$ equivalency. Rates of lime were 0, 0.5, 1, 2, and 4 t/ha, calculated by the Brazilian methodology, which adjusts for both $CaCO_3$ content and particle size. In terms of $CaCO_3$ equivalency, these rates would be equal to 0.6, 1.1, 2.3, and 4.6 t/ha. Three additional treatments contained 1 t/ha of gypsum in combination with 0, 1, and 2 t/ha of lime. All other nutrients were supplied under nonlimiting conditions. Part of the N applied to corn was supplied as ammonium sulfate to diminish the S variable among treatments. Four crops, in the succession of corn, cowpeas, and soybeans, have been harvested in the study.

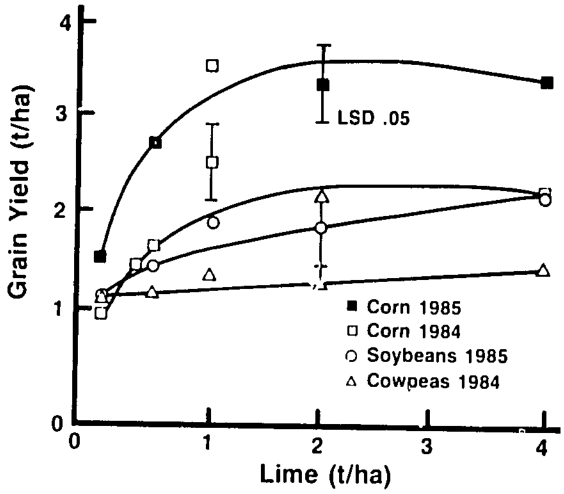


Figure 1. Yields of four consecutive crops as a function of lime rates applied before planting corn in 1984.

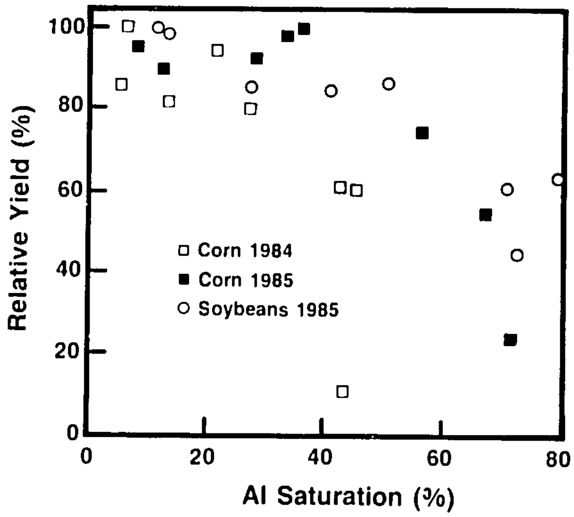


Figure 2. Relationships between relative yield and Al saturation for lime and gypsum treatments.

Yield Response to Lime and Gypsum

Yields for the corn and soybean crops increased significantly in response to the application of 1 t/ha lime (Figure 1). Although nonsignificant, cowpea yields were increased by 0.5 t/ha with the same lime rate. The largest yield responses to gypsum occurred with corn in the absence of lime (Table 1). Yields for soybeans and for both corn crops declined with increases in Al saturation above 30% (Figure 2). Differences in corn yield trends in 1984 and 1985 may have been related to several factors: 1) omission of blanket applications of B and Zn in 1984; 2) increases in Al saturation levels with time for the low lime rates; and 3) increased Ca movement into the subsoil with time of cultivation.

Soil Chemical Properties

Changes in topsoil chemical properties as a function of time after liming are shown in Figures 3-5. Liming increased the levels of Ca and Mg and decreased exchangeable Al levels. In the absence of lime or gypsum, Ca and Mg declined with cultivation, while Al levels remained relatively constant. Consequently, Al saturation levels approached 80% at the final sampling date. Aluminum saturation was maintained at tolerant levels during the first year of cultivation with 1 t/ha of lime. However, results indicated that more lime would be required to avoid acidity constraints during subsequent cultivation.

Table 1. Crop yields as a function of rates of lime with and without supplementary application of 1 t/ha of gypsum (G).

Applied Lime	Grain Yield			
	Corn '84	Cowpea '84	Corn '85	Soybean '85
	t/ha			
0	0.3	1.1	0.9	1.0
0+G	1.6	1.2	2.0	1.4
1	2.5	1.4	3.5	1.9
1+G	2.1	1.4	3.6	1.8
2	2.2	1.3	3.3	1.8
2+G	2.6	1.5	3.2	2.1
LSD .05	0.8	ns	0.8	0.8

The application of 1 t/ha of gypsum provided a moderate increase in topsoil Ca. This increase in Ca was more pronounced when gypsum was combined with lime. Profile samples were collected at three and 12 months after liming. Data shown in Figures 6 and 7 are for the latter sampling date. Liming increased Ca levels in the subsoil to the maximum depth sampled and reduced Al levels at depths of 20-40 cm. Improvements in the subsoil chemical environment by applications of gypsum were more pronounced when

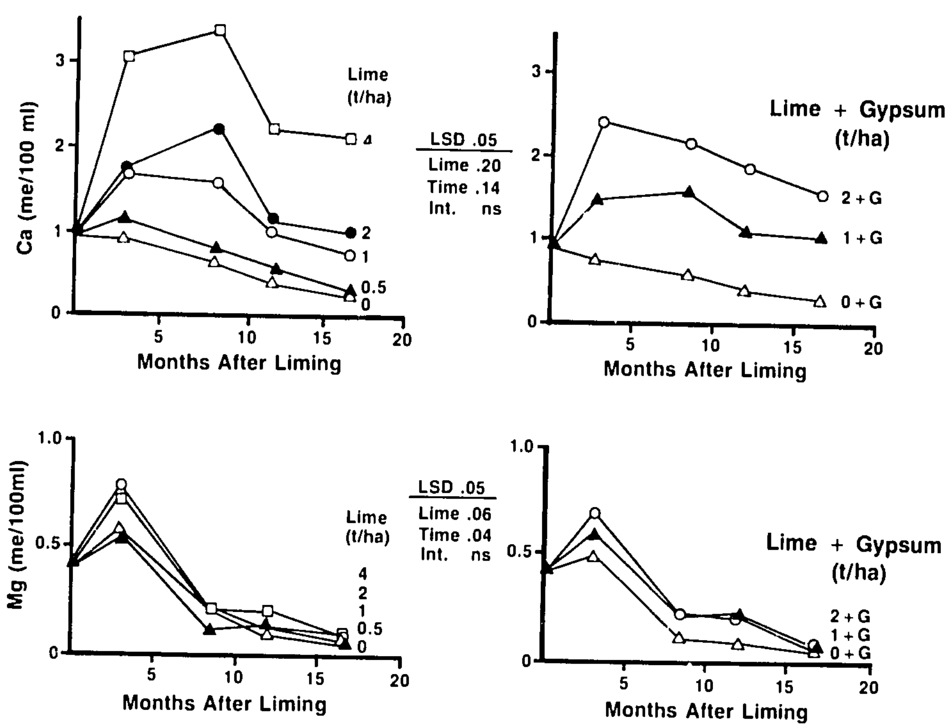


Figure 3. Topsoil exchangeable Ca and Mg levels as a function of time after applying lime and gypsum.

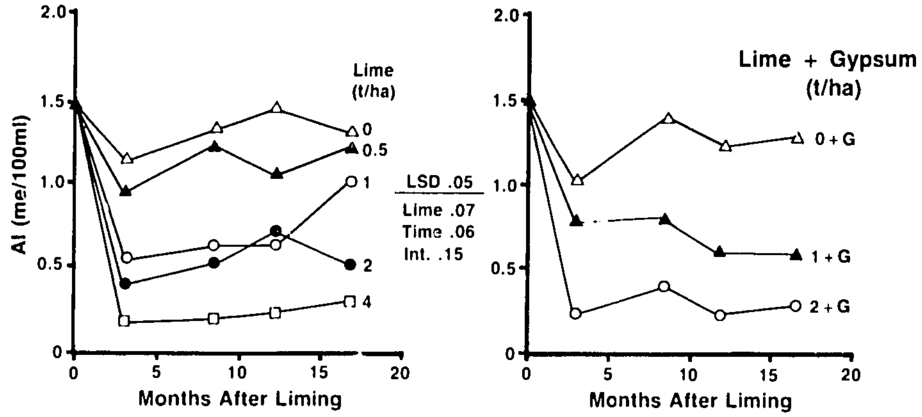


Figure 4. Topsoil exchangeable Al as a function of time after applying lime and gypsum.

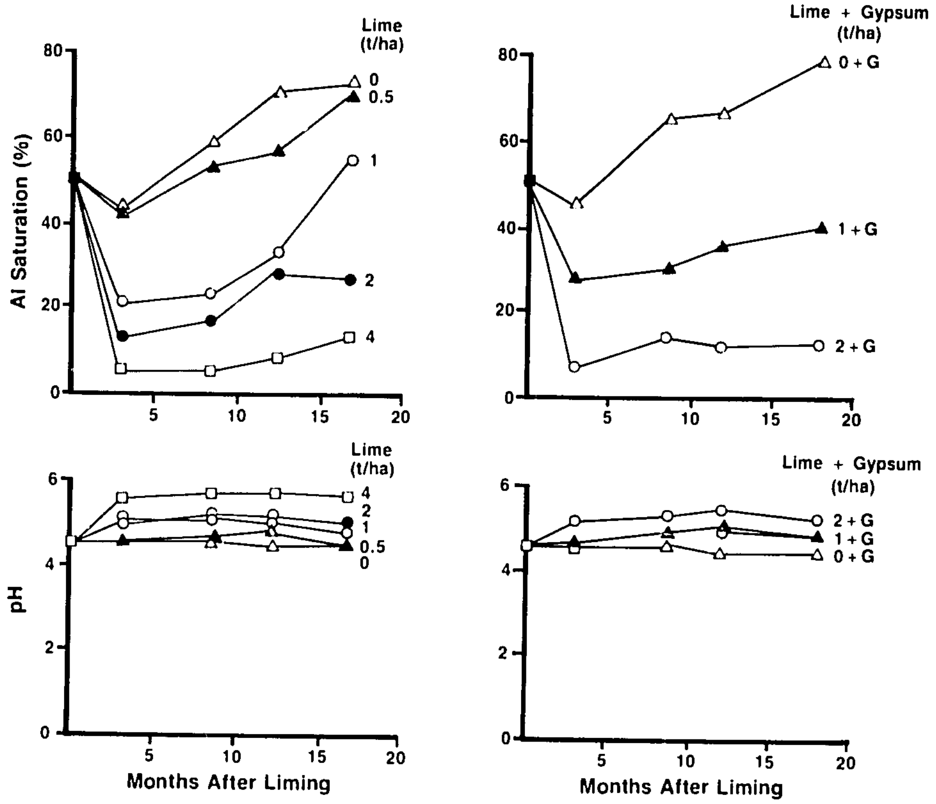


Figure 5. Topsoil Al saturation and pH as a function of time after applying lime and gypsum.

this material was combined with lime than when applied alone. Differences in subsoil chemical properties among lime treatments at three months after liming were negligible. The observed increases in subsoil Ca between three and 12 months after liming coincided with the time at which Ca declined in the topsoil (Figure 3).

Conclusions

1) Moderate applications of lime (1 or 2 t/ha) reduced acidity in the topsoil to non-limiting levels, promoted Ca movement into the subsoil, and significantly increased crop yields from corn and soybean, but not from cowpea, in the first four-crop succession.

2) Gypsum had a more pronounced effect on soil chemical properties when combined with lime than when applied alone.

Implications

Results from this study indicate that acidity constraints for this Typic Acrorthox can be corrected with moderate applications of a locally available source of lime. Residual effects of the lime rates, and the effect of liming on root proliferation in the subsoil, will be quantified as this study continues.

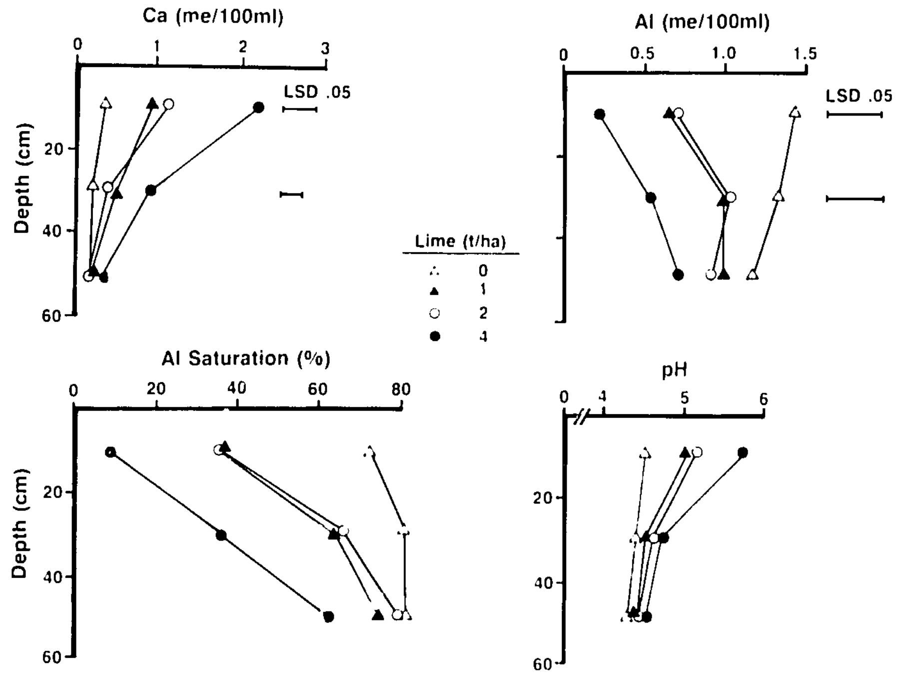


Figure 6. Profile soil acidity characteristics at 12 months after applying several rates of lime.

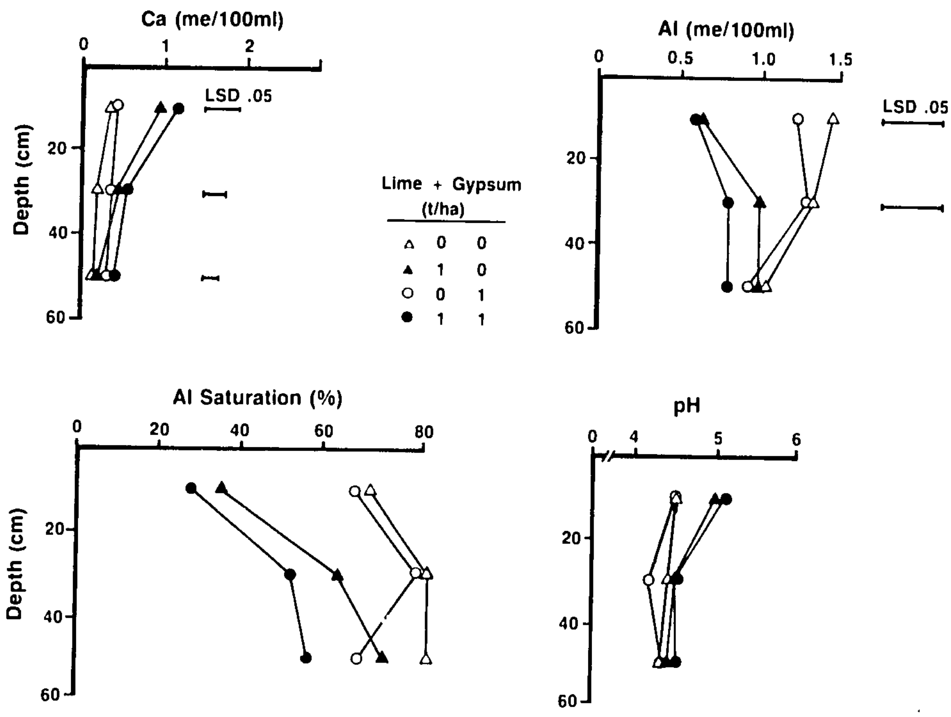


Figure 7. Profile soil acidity characteristics at 12 months after applying lime and gypsum.

Planting Dates in Relation to Weather Pattern at Manaus, Brazil

Expedito U. Galvao, EMBRAPA
J. Ferdinando Barreto, EMBRAPA
Jose C. Correa, EMBRAPA
Manoel Cravo, EMBRAPA
Miguel Dias, EMBRAPA

Research on upland annual cropping systems at the UEPAE/Manaus station has been primarily directed toward a corn-cowpea rotation. On-site studies with other crops, and related work at Yurimaguas, Peru, have demonstrated the feasibility of additional crops for this ecosystem. However, differences in rainfall between Manaus and Yurimaguas have suggested that the optimum planting dates derived for the Peruvian Amazon would not be applicable to the conditions in Manaus (Figure 1).

This study was initiated in June, 1982, in order to establish optimum planting dates for corn, cowpeas, rice and soybeans in the Manaus region. These crops were planted at three-week intervals in a randomized complete block design with seven planting dates and three replications. Plots for corn and rice were alternated with cowpeas and soybeans, respectively, in plantings succeeding the seventh date, in an attempt to minimize the buildup of soil-borne pests and diseases.

Yields and Planting Dates

Crop yields as a function of planting dates from 1982-1985 are shown in Figures 2 and 3. Year-to-year changes in yield patterns were influenced by variability in annual rainfall distribution. Rainfall distribution approached the average pattern for ten years in 1984. In 1982, rainfall was unusually high in January, but below normal for July and September. For January-February, 1983, rainfall was below normal.

Maximum yields for all crops occurred during the

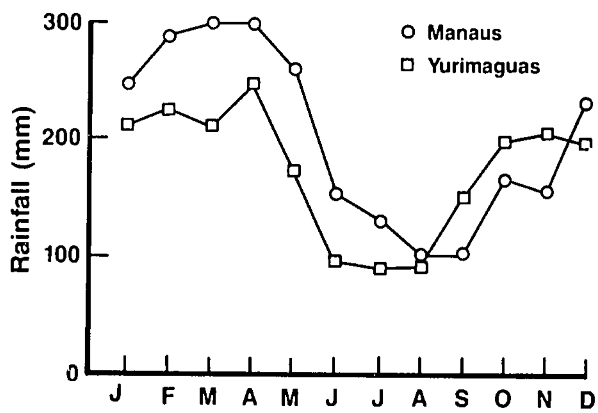


Figure 1. Long-term monthly rainfall averages in Manaus and Yurimaguas.

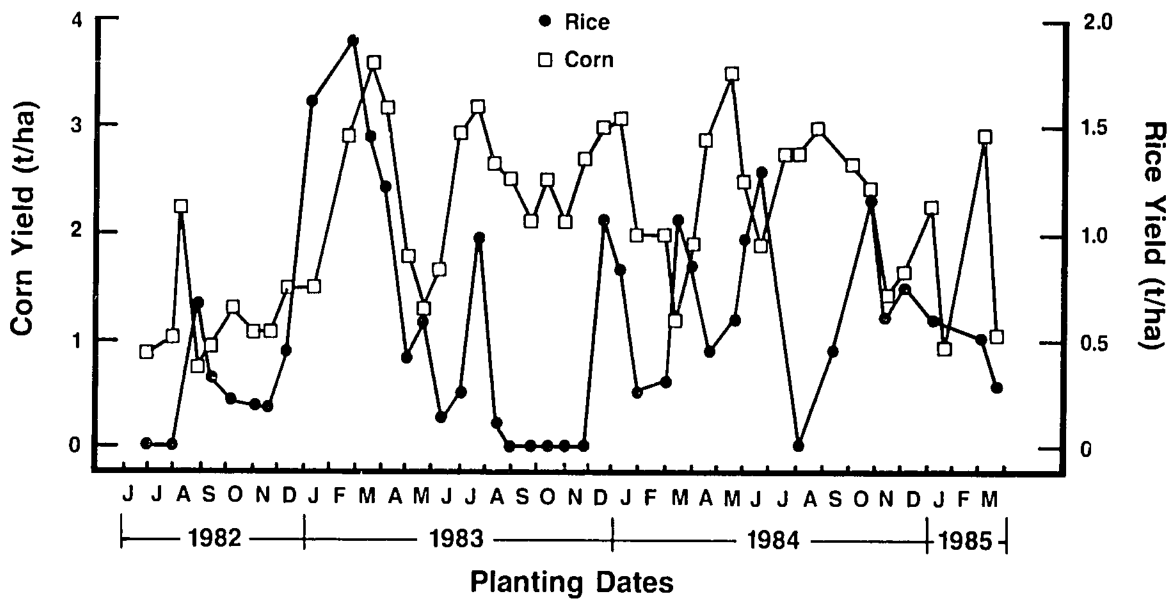


Figure 2. Effects of planting dates on corn and upland rice yields in Manaus.

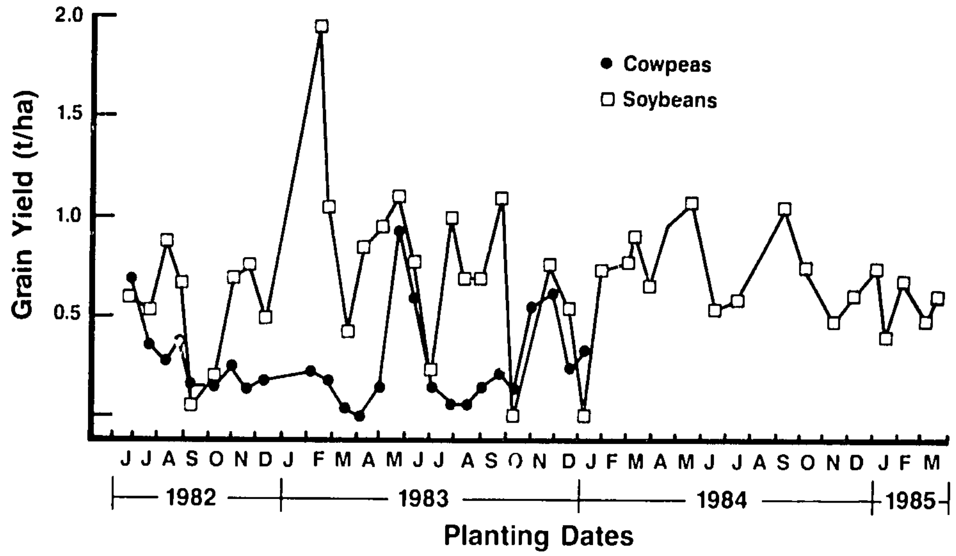


Figure 3. Effects of planting dates on cowpea and soybean yields in Manaus.

initial 12 months of the study. Subsequent increases in plant pathogens decreased maximum yields. Rice-seedling stands during the wettest planting dates were reduced by *Pyricularia oryzae*. Consequently, rice yields were influenced by the number of plants that survived (Figure 4). Optimum rice yields occurred in periods of high rainfall and good rainfall distribution throughout the growing season. In most years, these conditions were obtained with December-January planting dates.

Pathogens also limited yields on cowpea. There were no cowpea yields after an incidence of *Chalcodermus sp.* in late 1983. *Rhizoctonia solano* was a problem for

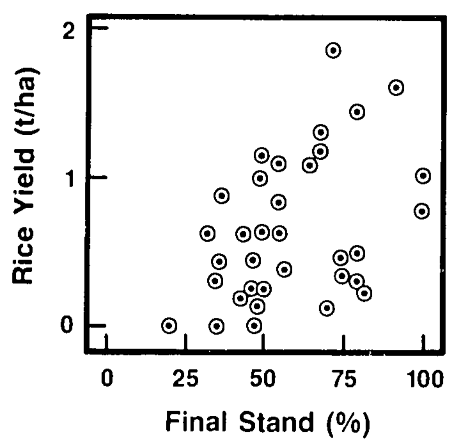


Figure 4. Relationship between upland rice yields and final stand in Manaus.

cowpeas during periods of high rainfall. Rainfall from flowering to harvest was also a negative factor for cowpea yields. In 1984-1985, soybean yields were reduced by frog-eye spot disease (*Cercospora sojina*). In other experiments, where the buildup of pathogens was avoided, favorable cowpea yields were obtained with May-July planting dates. Soybean yields were highest when pods filled at the end of the rainy season. In normal years, this is most likely to occur with February-March planting dates.

Corn yields differed from the other crops by the large number of planting dates with similar yields. Low yields appeared to be related to poor rainfall distribution during early growth stages.

Conclusions

Results from this experiment and other on-site investigations have indicated the following periods of optimum planting dates for each crop:

Rice: December-January
Soybeans: February-March
Cowpeas: May-July

Micronutrient Fertilization on a Typic Acrorthox at Manaus, Brazil

Manoel S. Cravo, EMBRAPA
Thomas Jot Smyth, N.C. State University

Annual crops have not provided significant yield responses to micronutrient applications during the initial years of cultivation on a Typic Acrorthox at Manaus, Brazil. A field study with micronutrient fertilization was initiated in 1982 on previously cultivated land in order to gain further information on the micronutrient status of this soil. The experimental site had been cropped to a corn-cowpea rotation during the five preceding years with N, P, and K as the sole fertilizer inputs.

Treatments, as described in Table 1, were established in a randomized complete block design with four replications. Two rates of each micronutrient tested were established as separate treatments. The Complete 1 treatment contained intermediate levels of each micronutrient in order to compare with the other levels applied. Micronutrients were applied only at planting of the initial corn crop. All other nutrients and lime were supplied by uniform applications to all plots. Corn and cowpeas were grown annually in rotation.

Yield Response to Micronutrients

Yield differences among treatments were not significant for the six crops harvested. Cowpea yields on treatments with micronutrients were similar to the treatment without micronutrient fertilization (Table 2). Yield trends for corn in 1984 and 1985 suggested a response to B and Zn. Foliar levels of B for corn in 1983 approached the lower limit of the recommend-

Table 1. Micronutrient fertilizer rates applied to the initial corn crop in the micronutrient study.

Treatment	B	Cu	Mn	Zn
	kg/ha			
Cjeck	0	0	0	0
B0	0	1	5	5
B1	1	1	5	5
Cu0	0.5	0	5	5
Cu2	0.5	2	5	5
Mn0	0.5	1	0	5
Mn0	0.5	1	10	5
Zn0	0.5	1	5	0
Zn10	0.5	1	5	10
Complete 1	0.5	1	5	5
Complete 2	1	2	10	10

Table 2. Relative yields of corn and cowpeas during six consecutive crops after micronutrient treatments were established.

Treatment	Corn 1983	Corn 1984	Corn 1985	Cowpeas 1983	Cowpeas 1984	Cowpeas 1985
	relative yield, %*					
Check	100	100	100	100	100	100
B0	96	102	101	102	100	99
B1	94	138	105	105	108	106
Cu0	79	111	104	91	102	89
Cu2	98	126	95	109	108	94
Mn0	86	127	98	97	100	88
Mn10	100	127	91	90	97	78
Zn0	109	111	93	93	106	94
Zn10	97	140	131	96	105	95
Complete 1	87	146	112	100	103	99
Complete 2	109	114	100	102	115	89
CV (%)	18	22	19	11	11	16

* Yields for the check treatment in t/ha were as follows: Corn, 1983: 2.7; corn, 1984: 2.0; corn, 1985: 2.8; cowpeas, 1983: 1.5; cowpeas, 1984: 1.4; cowpeas, 1985: 1.1.

ed sufficiency range (Table 3). Although Zn fertilization rates have provided consistent increases in Mehlich 1 extractable soil Zn, no such differences have been observed in foliar Zn levels for corn (Table 4). Foliar micronutrient analyses have been impeded by laboratory modifications and instrument problems.

Mehlich 1 extractable Cu and Mn have declined during the three years of cultivation on treatments with and without the application of these elements (Table 4). The absence of a yield response to Mn, despite the low soil-test levels, may be related to the maintenance of soil pH within a range of 5.4-5.0. Other studies performed on-site have provided evidence of Mn deficiency when soil pH was greater than 5.5.

Table 3. Foliar B levels for the 1983 crops of corn and cowpeas as a function of B applied prior to planting corn.

Treatment	Leaf B	
	Corn	Cowpeas
	ppm	
B0	8	25
Complete 1	5	31
B1	6	32

Conclusions

1) Results thus far on this study have indicated marginal yield responses with corn to B and Zn. These elements have been included in blanket fertilizations for corn in other on-site experiments where micronutrient deficiencies were to be avoided.

2) Yield trends with cowpeas have suggested that native soil levels of micronutrients were sufficient for this crop.

Table 4. Leaf and soil Zn levels and soil Cu and Mn levels in three corn crops as a function of micronutrient rates.

Treatment	Mehlich 1 Extractable			Foliar Analyses		
	1983	1984	1985	1983	1984	1985
	Zn, ppm					
Zn0	1.0	.8	.6	21	49	14
Zn10	2.0	2.5	1.8	28	52	10
LSD .05	.6	.8	.4	ms	ns	ns
	Cu, ppm					
Cu0	1.8	1.8	0.3			
Cu2	2.8	1.8	0.6			
LSD .05	ns	ns	0.1			
	Mn, ppm					
Mn0	5	2	2			
Mn10	7	2	4			
LSD .05	3	ns	1			

Management of Green-Manure Nitrogen on Oxisols at Manaus, Brazil

Thomas Jot Smyth, N. C. State University
Luiz A. Oliveira, EMBRAPA
Manoel S. Cravo, EMBRAPA

Studies on Oxisols in the Cerrado of Brazil have shown that mucuna, a common green manure, can provide much of the nitrogen required by a succeeding food crop. Such green manures, if effectively managed, appear to hold promise as a supplement or an alternative for fertilizer nitrogen in the Cerrado.

This experiment, established as a companion study to the work in the Cerrado, sought to test similar green-manure management techniques for their suitability to soil and climate conditions in the Manaus region. The objectives were 1) to quantify the N supplied by green manures to corn and rice, and 2) to evaluate the importance and availability of green-manure N to crops.

This study contained two experiments with treatments described in Table 1. Both experiments were planted to corn in October, 1984, followed by rice in February, 1985. Treatments were established only at corn planting. For the N-supply study, the five rates of fertilizer N were split into three equal applications broadcast at planting and sidedressed at 25 and 55 days after planting (concurrently with two weedings and two corn-hillings). Corn- and rice-yield responses to the incorporation of *Indigofera, Stizolobium* and cowpea crop residues (after harvesting 1 t/ha of grain) were compared to yields obtained with fertilizer N.

Table 1. Treatment specifications for the green manure studies.

Treatment	N Applied
N Supply*	**kg/ha**
N0	0
N10	20
N40	40
N60	60
N120	120
Indigofera tinctorium	152
Stizolobium aterrimum	168
Cowpea crop residues	32
Green Manure Management**	
Bare soil check	0
Bare soil + urea-N	80
Whole plant incorporation	298
Plant top incorporation	254
Mulch with plant tops	257
Plant roots	-

* N source for the fertilizer N treatments was urea.
** Green manure utilized was *stizolobium aterrimum.*

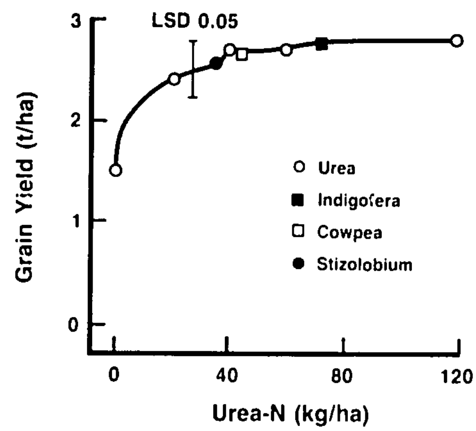


Figure 1. Corn grain yields as a function of fertilizer N rates and green manure sources.

The green-manure management study was performed solely with *Stizolobium*, a mucuna. Treatments using the legume were: 1) whole plant incorporation, 2) whole plant mulch, 3) removal of above-ground biomass (roots), and 4) incorporation to bare soil of tops harvested from (3). Two additional treatments, with and without fertilizer N, were included on bare plots where *Stizolobium* was not grown. All other fertilizers were maintained constant in both studies and consisted of P, K, B Cu, Zn, and lime.

Yield Response to N Sources

The maximum corn yield with fertilizer N was obtained with 120 kg N/ha, although yield response to successive increments of N was not significant above 20 kg N/ha (Figure 1). Corn yields for the three sources of green manure were not significantly different from yields with the highest N rate. Yields for the green-manure treatments were equivalent to yields obtainable with 72, 36, and 42 kg/ha of urea N, respectively, for *Indigofera, Stizolobium* and cowpea residues. Nitrogen levels for corn leaves and aboveground dry matter were in agreement with corn-yield data (Table 2). Uptake of native soil N, in the absence of fertilizer N, represented over 50% of the plant N detected at the highest corn yield. Consequently, apparent N recovery declined markedly for N rates above 20 kg N/ha. Apparent N recovery from cowpea residues may be overestimated since N contributions from leaf fall before the cowpea harvest were not determined.

Table 2. Foliar N, above-ground total N uptake and apparent N recovery for treatments in the N supply study.

Treatment	Leaf N	N Uptake	Apparent N Recovery
	%	kg/ha	%
N0	2.75	44.8	—
N20	3.04	63.2	92
N40	3.11	66.9	55
N60	3.08	79.6	58
N120	3.26	80.8	30
Indigofera	3.07	72.8	18
Stizolobium	2.80	72.6	17
Cowpea residues	2.77	68.0	72
LSD .05	0.33	17.2	

Table 3. Yield, foliar N and N uptake for the corn crop in the green manure management study.

Treatment	Grain Yield	N Uptake	Leaf N
	t/ha	kg/ha	%
Check	2.3	56.2	2.55
Check + N	2.4	69.3	3.07
Whole plant	3.2	81.7	2.73
Tops	2.8	84.7	2.75
Mulch	2.9	71.6	2.54
Roots	1.9	53.1	2.38
LSD	0.8	20.0	0.38

Corn-Yield Response to Legume

Corn yields among the three treatments imposed on *Stizolobium* aboveground biomass were similar, although N recovery from the mulch treatment was inferior to the incorporation of the whole plant or tops alone (Table 3). Yields for the root treatment were inferior to the check treatment without fertilizer N and may have resulted from the removal of soil mineralized N with the harvest of aboveground legume biomass. These results would suggest that the majority of the legume N supplied to corn came from the legume tops. Initial corn growth on the mulch treatment, during a ten-day period without rain, was superior to the other legume treatments.

Residual Effects of N Sources

Residual effects of fertilizer N and the green manure on the subsequent rice crops did not differ significantly among treatments. The average grain yield was 2 t/ha and average leaf N 3.76% for the N supply study. For the green-manure study, average grain yield was 2.8 t/ha and average leaf N 3.50%. The low yield responses to residual fertilizer and green manure N were also reflected by the adequate foliar N levels for the check treatments in both experiments. Lodging of this medium-statured rice variety occurred in all treatments of both experiments. Preliminary results for this rice crop would suggest that N availability was not a major limitation.

Other Nutrients

Analyses of green-manure biomass indicated that significant amounts of other nutrients, besides N, were recycled with the legume cultivation (Table 4). Potassium levels contained in *Stizolobium* and *Indigofera* are of particular importance, given the rapid rate of soil test K depletion observed in these Oxisols. Although identical quantities of fertilizer K were applied to all treatments prior to planting corn, soil test K levels at rice flowering for treatments receiving

Table 4. Dry matter and nutrients in the above-ground dry matter of legumes in the N supply study.

Legume	Dry Matter	N	Ca	Mg	K	P	Cu	Mn	Zn
	t/ha	kg/ha							
Stizolobium	7.1	168	110	11	63	10	0.12	0.31	0.14
Indigofera	6.2	152	96	13	68	9	0.09	0.28	0.16
Cowpea Residues	1.4	32	15	6	17	3	0.02	0.04	0.04

Stizolobium or *Indigofera* biomass were superior to the other treatments.

Preliminary Findings

1) All three green-manure treatments produced corn yields equivalent to those produced by the highest rate of fertilizer N.

2) Yield data suggest that the majority of green-manure N supplied to corn came from the legume tops.

3) Mulching with green-manure tops produced yields comparable to whole-plant incorporation, and, during a ten-day dry period, mulched corn plants grew faster than corn in the other treatments.

4) There were no significant differences among treatments on the response of rice to residual N, apparently because N was not a major limitation in this crop.

Implications

The relatively high corn yields obtained with the *Stizolobium* mulch treatment indicate that mulching with this green manure may be a favorable alternative for farmers with insufficient machinery or labor to incorporate the legume biomass. In addition to supplying N, the legumes contained significant levels of other nutrients, and may be particularly important in reducing K leaching by retaining K in the biomass. Further experiments will validate these first-year results and produce more data useful in establishing guidelines for green-manure management in these soils.

Conditions Other Than Extractable Nutrient Concentrations in the Soil Test Interpretations for P and Zn

Ibere D. G. Lins, N.C. State University
Fred R. Cox, N.C. State University

The major soil fertility constraints for crops grown in the Cerrado of Brazil are acidity, phosphorus and zinc. For maximum economic returns, the exact requirement of lime and fertilizer, as indicated by soil tests, must be applied. Soil tests are very straightforward for soils on which prior field experiments have been conducted. However, tests for only a few tropical soils have been covered by field calibration, and there is evidence that certain soil test interpretations are too broad; that is, they are not really applicable for all conditions.

The objectives of these continuing studies are 1) to determine the effect of fertilizer P applied to Oxisols and associated Entisols varying in texture on the extractable P concentrations with time; 2) to determine the effect of fertilizer Zn applied to Oxisols varying in pH and texture on the extractable Zn concentrations with time; 3) to determine P retention by Oxisols as influenced by clay content; 4) to develop a model to predict the necessary P rates to reach and maintain adequate soil test P levels for maximum soybean economic returns; and 5) to validate the model with field data.

Soil Test for P

In soil test interpretations for P, the critical level, the concentration below which there will be a positive response to fertilization, is known to be lower on fine textured or clayey soils than on coarse textured or sandy ones. Clayey soils sorb more P than sandy ones, and therefore have a greater capacity to replenish solution P as it is used by plants. This greater capacity allows the critical level to be lower for clayey soils than sandy ones. Though the relationship between the P critical level and texture is known, it is seldom considered in the soil test interpretation.

A preliminary economic model was developed that considered the value of corn and soybean crops as a function of soil P, and soil P as a function of P fertilization rate and cost, current soil test P level, and time. Net value was determined from these relationships, and the optimum rate of fertilization calculated at the maximum net value. When the optimum P rate was calculated for a few soils that varied in clay content, it was apparent that clay content should certainly be considered in the soil test interpretation.

One of the primary objectives of the current research is to provide further verification of this model. More soil conditions are to be evaluated, both in the field and in the greenhouse. Data is to be collected over additional years to confirm effects over time. In addition to clay content, soils will be analyzed for their P sorption or "buffering" capacity. For routine soil P analyses, several extractants, as well as a resin technique, are being employed.

The effect of rate of a single P fertilization on Bray 1 extractable P over a period of years is shown for three soils in Figure 1. These soils vary in clay content from 12 to 63%. All of these soils were initially quite low in extractable P. Extractable P increased with increasing rate of P fertilization on all soils, but the effect was most pronounced on the soil with the least clay. This reflects the effect of clay on P sorption.

The rate of decrease in extractable P with time is related to soil characteristics. These effects must be quantified and incorporated into the model to ensure its applicability over a wide range of soil conditions.

Preliminary research has already been conducted to show that routine P sorption isotherms, which follow the Langmuir equation, should be done in 10^{-3} M $CaCl_2$ rather than in the 10^{-2}M solution normally used. This verifies a prior observation on similar soils in the tropics.

Although using complete isotherms is an excellent way to gain basic information on P sorption, the procedures are too involved to ever be used directly in routine soil tests. There are, however, "quick-test" approaches to the problem and their applicability is also under study.

The soils are also being analyzed with several extractants. Differences are already apparent among the Mehlich and Bray extractants on the amount of P extracted from soils that vary in clay content. The resin method is also under investigation. Final results of these experiments will have the potential of refining the P soil test for a broad range of soil conditions, thus providing the most economical means of removing one of the largest soil fertility constraints in the Cerrado.

Soil Test for Zn

A similar, but much less intensive, approach is under way on refining the soil test for Zn. The critical level for Zn presumably should be affected by acidity or pH. This has been shown in a few instances, but acidity is not generally included in the Zn soil test interpretation. A second primary objective of this study, therefore, is to evaluate the effect of soil pH in addition to extractable soil Zn on the Zn soil test interpretation.

Several studies are being conducted in the greenhouse and in the field. The information gained from these experiments certainly will add to our knowledge on factors affecting Zn availability. This will assist in the design of future field studies, and perhaps in the interpretation of data from past ones. It remains to be seen, however, if the results will be clear and strong enough to warrant modification of the current Zn soil test interpretation.

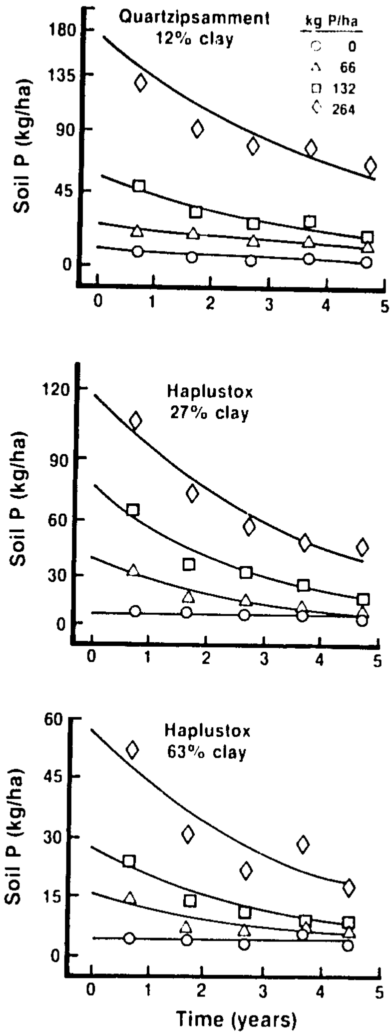


Figure 1. The effect of rates of a single application of P on the concentration of Bray 1 extractable P in time of three Oxisolic soils differing in clay content.

Extrapolation of Soil Management Technologies to the Pichis Valley

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 is financed in part by the Interamerican Development Bank.

The Region

The Pichis Valley is at 10°S latitude, with the valley floor about 300 m above sea level. The principal town, Puerto Bermudez, has a mean annual precipitation of 3313 mm, and a mean annual temperature of 25.5°C. Mean minimum temperatures are considerably lower than at Yurimaguas, averaging 19.4°C, due to the higher elevation and to air drainage from the surrounding mountains.

The topography of the Pichis Valley is characterized by a small proportion of flat terrain. Eighty-five percent of the land is in hills with 30-70% slopes, or in mountains with slopes greater than 70%. High terraces occupy 13% of the valley and low, floodable terraces occupy 2%. The hilly areas and the high terraces are dominated by Ultisols and Dystropepts. The low terraces are mainly Entisols.

Population pressure has been tremendous since the opening of roads to Lima and Pucallpa in 1985. While the traditional farmers, native Indians and "colonos" of German descent farm primarily the terraces to crops and pastures, migrants from the Sierra are settling in the hills along the highway, where they must contend with extremely steep slopes, high rainfall and lack of tropical experience.

Strategy

Given the need for immediate results, a technology validation was devised for Pichis based first on rapid testing of crop and pasture germplasm for existing systems. After a few months' experience, it became obvious that a low-input cropping system could be modified to accommodate annual flooding in the low terraces. The work reported here addresses three options for soil management in the Pichis area: 1) low-input cropping in the low terraces; 2) pastures in the high terraces and hills already cleared; and 3) agroforestry in eroded steeplands cleared by the newcomers.

Low-Input Cropping Systems For the Pichis Valley

Dennis del Castillo, N. C. State University
Luis Capuñay, Proyecto Especial Pichis-Palcazu
Alcibiades Sanchez, Proyecto Especial Pichis-Palcazu

In the Pichis Valley, there is a predictable flooding period, December to February, when low terraces and even some high terraces are under water for a few days at a time. Advantage can be taken of such flooding to introduce paddy rice in low-input cropping systems. Given the high native fertility of some terraces, corn may also be included in the low-input systems for the drier part of the year. The objectives of these studies are to test, validate and modify soil-management technology for paddy-rice production and low-input cropping under Pichis Valley conditions.

Rice Germplasm Screening

A rainfed field trial was carried out with 12 lines and varieties provided by the Yurimaguas Experiment Station and INIPA's National Rice Program on a Typic Tropofluvent terrace. The test was conducted during the 1984-1985 wet season using the traditional planting method (using the *tacarpo*, a planting stick) at 0.30 x 0.30 m between plants. There was no fertilizer application, and no pest or disease control.

Lines 22196, 19947, 19965, and cultivar CICA-8 performed better than the recommended 18476 line during the wet season, all yielding over 4 t/ha. These cultivars showed resistance to *Pyricularia*. Line 18476 did not perform well because of its susceptibility to *Helminthosporium oryzae*. The tall cultivars, *Carolino blanco, Chino colorado* and *Africano desconocido* yielded less than the short cultivars. *Carolino blanco* lodged the most. The same trial is now being carried out under intermittent flooding during the dry season.

Screening Grain Legumes

Because pests and diseases constrain the production of grain legumes in the alluvial soils of Pichis, these problems were studied in cultivars of cowpea, panamito bean and common bean, at different planting dates. There was also an experiment to study the possibility of using cowpea as a weed controller.

Cowpea Cultivars

Five cowpea cultivars (Vita-6, Molina I, Porvenir I, Seda and Castilla) were evaluated for their yield performance, using four planting dates, in a floodplain Mollic Tropofluvent. The soil was tilled (10-cm depth) with a garden rototiller before each planting. The seeds were sown in rows using a curved stick (*gancho*) at 0.60 cm spacing. No fertilizer or insecticide was used.

Planting date had a pronounced effect on cowpea yield. Examination of the data and visual observation indicate that yield performance is a function of rainfall distribution. When cowpea was sown in May, there was still enough rainfall to keep soil moisture at field capacity. The plants had good vegetative and reproductive growth. The lack of rainfall during the last reproductive stage of growth was a very important factor in obtaining high quality grain and uniform harvest. All cultivars produced their highest yields when planted in May (Figure 1).

When cowpea was planted in July, plants were under varying degrees of drought stress during most of the vegetative and early reproductive stages of growth. Precipation was high at harvest, causing grain rotting in most cultivars. Plants sown in September were severely damaged by the high rainfall during most of the vegetative and reproductive growth stages, and plants were shorter, with yellowish leaves in most cultivars. The crop planted in November was not harvested because of an early flood.

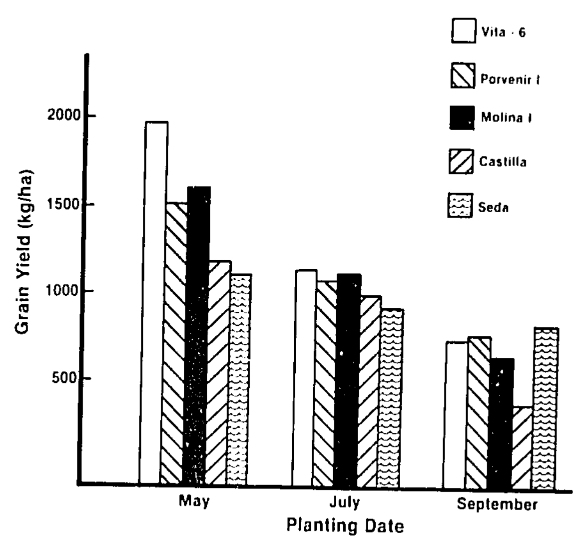


Figure 1. Grain yield of five cowpea cultivars at three planting dates.

Table 1. Grain yield on cowpea-cowpea-rice crop rotation on a Typic Tropofluent.

Cultivar					
Cowpea	Cowpea	Rice	Cowpea	Cowpea	Rice
			Grain Yield, kg/ha		
Vita 7	Vita 7	CICA 8	1800	1600	4200
Vita 7	Vita 7	PA 2	1750	1700	4500
Molina I	Vita 7	PA 2	2100	1600	4500
Molina I	Linea I	PA 2	2000	1000	4300

The cultivar Seda appeared better adapted to periods of more rainfall than the others because its waxy bean cover protects the grain from rotting during the more humid periods. However, Seda does not have a yield potential as high as Vita-6 and Porvenir I have when planted early. Observation indicates that Seda is also the most tolerant to *Cercospora* and viral diseases, followed by Vita-6 and Molina I. The most susceptible cultivars to diseases and insect infestations were Castilla and Porvenir I.

Modification of this study should emphasize more intensive screening in specific areas of the valley, where rainfall favors the proliferation of diseases and pests. Further study is also needed in the selection of cultivars for green-pod use in more humid periods of the year.

Panamito Bean (*Phaseolus sp.*)

Twelve panamito bean cultivars were studied for disease and insect resistance. All cultivars were susceptible to *Diabrotica*. VF-8 was the most susceptible to mosaic virus disease, and Panamito Sanilac was the most precocious (70 days). Although some cultivars with relatively good yields (800 to 1400 kg/ha) showed signs of adaptation, there is a need for more observations at different planting dates.

Common Bean (*Phaseolus vulgaris*)

For preliminary observation of climatic adaptation, 18 bean cultivars of a determinant-growth bean germplasm from CIAT were planted. The main objective was to select a well-adapted bean that could replace the local *poroto* bean. Although there is a well-established market for *poroto*, its production has been confined primarily to small areas where there is natural support for its viny growth. Some cultivars showed good adaptation and disease resistance. Because of limited quantities of seeds, this test was conducted on small plots (1 m^2), and should be repeated in larger plots for better yield prediction.

Maize

One variety trial was conducted during 1985, in cooperation with the National Corn Program, to select the best adapted cultivars. A Typic Tropofluevent was plowed to the 15-cm depth and planted in April with ten tropical varieties at 46,800 plants/ha. No fertilizer or herbicide was used.

Average grain yields indicate that, except for Across-8027 and Across-8126, all cultivars were similar, and they compared well with PMC-747 and Marginal 28. There was no visible difference among varieties of the slight attack of "cogollero" (*Spodoptera frugiperda*) and "cañero" (*Diatraea saccharalis*). No disease attack was observed.

There was no need for weed control, probably because of the absence of weed seeds. Most of the soil had been covered with kudzu for about five years, and the kudzu was incorporated into the soil during land preparation.

A Low-Input Cropping System

A rice-cowpea-cowpea cropping sequence was tested on a Typic Tropofluvent at La Esperanza Station in 1984-1985. Rice was grown in the period of flooding, December-February. Simple dikes were made by hand to hold as much floodwater as possible. The results are shown in Table 1. Rice yields averaged 4.4 t/ha and yields from the two cowpea crops ranged from 1.0 to 2.1 t/ha.

Cowpea appears to be a suitable crop to grow after rice. This low-input system could be successful if excessive flooding does not occur in February or March, the period of reproductive growth for rice. There is a need to find a better cash-crop legume to follow rice. After this cash crop, cowpea could be grown for local consumption.

Cowpea Under Plantain

Plantain is a very important crop in the valley, but weeds are often a major cause of field abandonment.

Table 2. Relative weed reduction under plantains by cowpeas in two soils in the Pichis Valley.

Cowpea Cultivar	Space Planting, cm	Relative Weed Reduction % Ultisol Wet Season	Ultisol Dry Season	Entisol Wet Season	Entisol Dry Season
Seda	30 x 30	10	27	7	63
	40 x 40	50	27	7	50
	50 x 50	40	23	10	43
Vita-6	30 x 30	23	30	23	66
	40 x 40	20	60	00	43
	50 x 50	17	13	00	37
Castilla	30 x 30	10	33	10	60
	40 x 40	13	40	3	47
	50 x 50	3	20	7	33
Manual Weeding	—	100	100	100	100
Control (without weeding)		0	0	0	0

Interplanting cowpea into plantain was proposed as a possible weed-control method and a means to provide additional income.

A one-year-old plantain field was selected in an infertile (pH 4.8) Typic Dystropept and another in a relatively fertile (pH 6.5) Typic Tropofluvent. Three fast-growing cowpea cultivars (Vita-6, Seda and Castilla) were planted in the wet and dry season. Seeds were sown with a planting stick (*tacarpo*) at three plant densities (30 x 30, 40 x 40, and 50 x 50 cm). Plant growth, percent cover, and relative reduction of weed population were evaluated at the end of vegetative growth.

Weed growth was reduced by interplanting of the competitive plant at certain periods of the year. During the dry season, Seda and Vita-6 reduced the weed population to 60%; Vita-6 and Castilla did not compete with weeds because of reduced vegetative growth caused by fungus diseases. High rainfall during the wet season contributed greatly to fast weed growth, which diminished competition from cowpea, whose growth slowed during this period. The same trend was observed in both soil types (Table 2). Application of this system by farmers who are not able to buy herbicides would reduce hand weeding and provide a legume supply for family consumption.

Legume-Based Pastures In the Pichis Valley

Kenneth Reátegui, N. C. State University
Elmer Montalvo, Proyecto Especial Pichis-Palcazu
Franco Alvarado, Proyecto Especial Pichis-Palcazu

Pastures for cattle producing milk and beef constitute the most extensive use of land in the Pichis Valley. The main forage species are the *torourco* mixture (*Paspallum conjagatum* and *Axonopus compressus*), and kudzu (*Pueraria phaseoloides*). Some degraded pastures are totally dominated by the weed *Homolepsis aturensis*. Five trials were established at La Experanza Station in order to test, validate and modify soil-management technologies for pastures under Pichis Valley conditions.

Agronomic Evaluation of Germplasm

A trial to evaluate pasture germplasm (CIAT Regional Type B trial) was planted in May, 1984 on a Typic Dystropepts with pH 4.2 and 79% Al saturation. Nineteen legumes and three grasses were evaluated at the establishment phase (four, eight and 12 weeks) and the production phase at maximum and minimum periods of precipitation. Maintenance fertilization was 22 kg P/ha, as triple superphosphate, 42 kg K/ha/yr as KCl and 100 kg N/ha/yr for grasses only. Legumes that were most quickly established, in order of importance, were: *Zornia latifolia* 728, *Pueraria phaseoloides* 9900 cv. kudzu, *Desmodium ovalifolium* 3784, *Centrosema pubescens* 5189, *Stylosanthes guianensis* 136 and *Stylosanthes capitata* 2252. It is important to mention the aggressiveness of *Zornia* 728 and kudzu, which will enable them to compete with weeds, a main problem in establishing pastures in rainy, tropical-forest environments. Among the grasses, the ecotype *Brachiaria dictyoneura* 6133 was significantly superior to *Brachiaria decumbens* 606 and *Andropogon gayanus* 621 due to its creeping habit, which enables it to rapidly establish a ground cover.

An evaluation carried out during a period of maximum precipitation shows that the best species and ecotypes were: *Desmodium ovalifolium* 350, *Zornia latifolia* 728, *Stylosanthses guianensis* 136 and 184, *Desmodium ovalifolium* 3784, and *Stylosanthes capitata* 10280. Unlike in Yurimaguas, the *Centrosema* accessions did not show promise, mainly because of insect problems (chewers and suckers) and to disease (*Ryzoctonia solanii*). Among the grasses, *Brachiaria dictyoneura* 6133 performed best in terms of its aggressivity, forage production and tolerance to insects, but not significantly better than *B. decumbens* 606 and *A. gayanus* 621.

Brachiaria Reaction to Spittlebug

Spittlebug is becoming a serious problem in the *Brachiaria* species. In order to find germplasm tolerant to these insects, thirty-six *Brachiaria* accessions were sown in November 1984 in 2.5 x 3.5 m plots with three replications. Bimonthly evaluations included the number of nymphs, plant height and dry matter production. The results show that spittlebugs of the species *Heneolamia* and *Zulia* are present in all ecotypes in their nymphal and adult states. Up to now the species, *B. dictyoneura*, *B. humidicola* and *B. brizantha* are the most tolerant, as reflected by their high dry matter production and excellent vigor. In contrast, the species *B. Decumbens*, *B. radicans* and *B. eminii* show chlorosis, lowered production and fewer senescent leaves, all problems associated with spittlebug attacks.

Evaluation of *Stylosanthes guianensis*

Stylosantes guianensis is a species of high biomass production, easily adaptable to acid and infertile soils. However, under high rainfall, anthracnosis caused by a fungus, *Coletrotrichum gloeosporioides*, is a major disease to which some ecotypes of *S. guianensis* are susceptible. A trial was set up in a soil with pH 4.2, and 79% Al saturation in May, 1984. The only fertilization was 22 kg P/ha as triple superphosphate.

Accessions that showed the best agronomic performance upon the establishment of the trial were: 184, 1778, 1648, 1950, 1651, 97, 1160, 1275, in order of importance. To date no anthracnosis has been encountered in any of the accessions studied, even at times of high precipitation and drastic temperature changes. This may be due to little diffusion from this legume in the zone.

Evaluation of *Desmodium ovalifolium*

A trial of *Desmodium ovalifolum* ecotypes was planted in October, 1984 on a Typic Dystropept soil with a pH of 4.3, 79% Al saturation and 7.0 ppm P, and evaluated at four, eight and 12 weeks after planting.

Desmodium ovalifolum ecotypes with the best agronomic characteristics during the establishment phase are: 13122, 13124, 13117, 13107, 13127, 13113, 13037, 13132, 13137 and 350.

D. ovalifolium ecotypes with highest dry matter production and excellent cover considered as promising included: 13124, 13104, 13127, 13132, 13137, 13117, 13088, 13095, 350, and 13128.

The first evaluations for nematode attacks indicated only the presence of some root lesions without a significant difference (0.05) between accessions. This can be due to the short time of establishing the experiment. Evaluation will continue for at least two more years.

Grass/Legume Associations Under Grazing

Traditionally germplasm-selection programs have been limited to cutting trials. Because grazing animals have a selective effect on grass/legume associations, it is desirable to incorporate the effect of grazing at the earliest possible stages of forage germplasm evaluation. In this trial, the intent is to prove the hypothesis that the persistence of mixed pastures depends essentially on management, expressed in terms of animal weight and grazing pressure.

Treatments consist of three mixtures: (*Andropogon gayanus*) 621/*Centrosema macrocarpum* 5065, *Andropogon gayanus* 621/*Zornia latifolia* 728, and *Brachiaria dictyoneura* 6133/*Desmodium ovalifolium* 350); two grazing frequencies: 20 and 44 days after four days of grazing; and three stocking rates: two, three and four animals per hectare. Fertilization consists of 21 kg P/ha, 21 kg N/ha, 10 kg Mg/ha, and 10 kg S/ha.

To date, *B. dictyoneura* 6133/*D. ovalifolium* 350 and *Z. latifolia* 728 have been rapidly and easily established. Two species were not readily established: *A. gayanus* 621, which apparently had seed-viability problems, and *Centrosema macrocarpon* 5065, which was not aggressive enough to compete with weeds. The *A. gayanus* 621/*Centrosema macrocarpon* 5065 mixture may be replaced in this trial.

Agroforestry in Steeplands Of the Pichis Valley

Dennis del Castillo, N. C. State University
Franco Alvarado, Proyecto Especial Pichis-Palcazu
Luis Capuñay, Proyecto Especial Pichis-Palcazu
Alcibiades Sanchez, Proyecto Especial Pichis-Palcazu

Damage to watersheds is significant when pioneer farmers and their livestock move onto steep, humid tropical uplands. Identification of farming systems that fit the social, economic and soil limitations of these areas is needed. The objective of this project was to test a system for improving and sustaining land productivity using trees, crops and animals on the same site.

A *Desmodium ovalifolium* pasture was planted in an infertilic Typic Paleudult. At the same time, young plants of achiote (*Bixa orellana*) were transplanted at 4 x 4 cm. Because of growth characteristics of *Desmodium ovalifolium*, there was no light competition with achiote during the period of establishment. After six months, when *Desmodium* had a 90% cover and achiote reached 1 m high, Barbados Blackbelly hair sheep were allowed to graze. The system apparently works; the sheep eat the *Desmodium* and do not eat the achiote leaves.

Discussion

Adoption of this system involves a simple introduction of *Desmodium ovalifolium* into a socioeconomic environment where achiote and sheep are well known and accepted. Achiote grows in acid soil, and is a cash crop for the Indians and local farmers; raising sheep is very important to the people from the mountains in the Pichis Valley.

Although the system seems to work, more research is needed to determine such things as the length of time sheep could eat *Desmodium ovalifolium* without nutritional problems, and the amount of fertilizer *Desmodium* would require to maintain sheep under grazing conditions. There is also a need to find achiote cultivars with good agronomic characteristics and high bixine content.

Soil Erosion and Reclamation

Helmut Elsenbeer, N. C. State University
D. Keith Cassel, N. C. State University
Dennis del Castillo, N. C. State University
Kenneth Reategui, N. C. State University

Despite the concern raised by the prospect of severe land degradation following tropical deforestation, there is a lack of information on long-term erosion and runoff rates in the Amazon Basin. Some recent development projects, such as PEPP, have been sited in areas of steep slopes and heavy rainfall. Large-scale clearing in these areas alters not only the hydrological balance of a watershed but also sediment production and transport.

New-Project Update

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

The objectives of this study, which is in its first phase, are 1) to determine the baseline transport rates of water, selected solutes and sediment from an upland, forested site before clearing; and 2) to determine changes in the transport rates of water, selected solutes and sediment from the same upland site after it is cleared and managed according to technological options suited to specific landscape positions.

Progress

A catchment was selected in a forest reserve at the La Esperanza station. The catchment is representative of the dissected uplands between the Rio Pichis and the Cordillera San Matías. Instruments were installed in the catchment to monitor stream flow, stream sediment and solute load, changes of soil moisture and soil-water chemical composition, surface and subsurface water transport, and surface erosion. Rainfall amount, duration, frequency and intensity are being measured in a clearing adjacent to the catchment.

The first phase of this research will evaluate the response of a forested catchment to storms, on an individual rainfall-event basis, and will yield baseline data on erosion and runoff.

In the second phase, the catchment will be cleared and evaluated under one or more agricultural systems. In this fashion, the effects of forest conversion on runoff and erosion processes can be predicted quantitatively in a relatively short period of time.

Sitiung: Extrapolation to Transmigration Areas of Indonesia

Transmigration projects on the outer islands of Indonesia constitute a major expansion of agriculture in humid tropical regions. The rate of deforestation and the numbers of people involved pose problems of even greater immediacy than in the Amazon. N.C. State University is the support institution in TropSoils' humid-tropics program in the Sitiung transmigration area of West Sumatra. Its projects there are closely related to those in Peru because of similarities in both subject matter and setting. Sitiung's position is 1°S latitude, 100 m elevation; it has a mean annual temperature of 26°C, and mean annual rainfall of 2471 mm, with a weak dry season, undulating topography, virgin rainforest vegetation, and soils that are predominantly clayey Ultisols and Oxisols. Yurimaguas' latitude is 6°S, and its elevation is 182 m; it has a mean annual temperature of 26°C and mean annual rainfall of 2135 mm, with a weak dry season, undulating topography, secondary forest vegetation, and loamy Ultisols. Basic food crops—rice, corn and cassava—are the same. The important differences are generally related to history, culture, land use and clearing methods. Shifting cultivation is the traditional system at both locations. As the support institution, N.C. State University conducts its work to complement the TropSoils program led by the University of Hawaii and the Center for Soils Research. The primary objectives of the studies reported here are 1) to adapt management principles investigated at Yurimaguas to the solution of agronomic problems in Sitiung; 2) to assist in the development of methods for reclaiming and cultivating soils damaged by mechanical clearing; and 3) to develop methods for managing and improving soil chemical properties in continuously cultivated land.

Reclamation of Bulldozed Lands

D. Keith Cassel, N.C. State University
A. Karim Makarim, N.C. State University
Michael K. Wade, N.C. State University

Many farm fields in the humid tropics have been mechanically cleared of forest in ways that remove topsoil, compact the subsoil, and promote erosion. Frequently, such fields are soon abandoned because crops fail. The objective of this research was to develop methods for reclaiming degraded soils for continuous cultivation. The investigations were conducted in the Sitiung transmigration settlements of West Sumatra, Indonesia, in an undulating, forested terrain cleared in 1977 by a bulldozer with a straight blade. The field had a 10% slope, and the soil was classified as a clayey, kaolinitic, isohyperthermic, Typic Haplorthox.

Three main treatments were established to test various rates of fertilizer and lime. Treatment F0, the control, received no lime or fertilizer. Treatment F1 (low-input) included small additions of lime and fertilizers to obtain and maintain an Al saturation near 40%, and to maintain nutrients at critical levels. Treatment F2 (high input) was designed to neutralize all exchangeable Al in the soil, to satisfy the P-fixation capacity of the soil, and to maintain nutrients at optimum levels without excess. Treatment FO was terminated after the first year and a new treatment, F1-2 (medium input), was installed in its place. For F1-2, lime was applied to reach and maintain the Al saturation at 20%. Other nutrients were kept above critical, but below optimum, levels.

Each main treatment was split into six plots to test tillage methods for their effectiveness in promoting rainwater infiltration and root development. The tillage treatments were:

Treatment H: hoeing to 0.15 m epth, a standard practice among upland farmers in the Sitiung area;

Treatment Hm: hoeing then mulching with *Calopogonium muconoides* at 12.5 Mg fresh weight per ha for the rice crop or 8 Mg dry matter of rice straw per ha for soybean and mungbean crops;

Treatment Hg: hoeing to incorporate a green manure, *Calopogonium*, at the rate of 12.5 Mg fresh weight per ha;

Treatment F: forking with a spading fork to uniformly till the soil to the 0.30 m depth;

Treatment SF: strip-forking to till the soil to the 0.30 m depth in alternate strips spaced 0.20 m apart;

Treatment R: using a hand rototiller to uniformly till the soil to a depth of 10 cm.

The cropping sequence included rice, var. "Sentani" (R1); soybean, "Orba" inoculated with a *Rhizobium* (S1), and mungbean var. "Betet."

Table 1. Yields of rice and soybean under different fertilization and tillage treatments, first year.

Tillage Treatment	Rice Yield, Mg/ha		Soybean Yield, Mg/ha	
	Grain	straw	Grain	stover
	No Fertilization (F0)			
Hoe	0.02	0.03	0.00	0.00
Hoe & mulch	0.04	0.38	0.02	0.02
Hoe & green manure	0.67	1.60	0.11	0.15
Spading fork	0.02	0.03	0.00	0.00
Strip-forking	0.04	0.05	0.00	0.00
Rototiller	0.01	0.00	0.00	0.00
	Low-Input Fertilization (F1)			
Hoe	1.54	4.50	0.57	0.69
Hoe & mulch	1.80	5.20	0.79	0.98
Hoe & green manure	2.71	8.10	0.63	0.73
Spading fork	1.79	6.88	1.33	1.48
Strip-forking	1.36	3.55	0.47	0.53
Rototiller	2.04	6.33	0.80	1.04
	High-Input Fertilizaton (F2)			
Hoe	2.17	8.10	2.24	2.38
Hoe & mulch	2.33	10.50	2.44	2.74
Hoe & green manure	2.94	10.43	2.40	2.91
Spading fork	2.19	8.25	2.16	2.39
Strip-forking	1.27	5.50	2.40	2.49
Rototiller	2.09	8.68	2.27	2.57
LSD 0.05	0.52	1.87	0.27	0.35

Crop Yields, First Year

The effects of fertilization and tillage on the yields of two crops, Rice 1 and Soybean 1, are shown in Table 1. (For mungbeans, dry weather severely reduced yields, and the treatments could not be fully evaluated.) In general, the highest fertility inputs produced the greatest yields of rice. Plants in the control, FO, died unless they received green manure. Green manure had a marked effect on rice production in all three main treatments. In F1, it increased grain yields by as much as 76%, and unexpectedly aised yields in F2, the high-input treatment, as well, even though all limiting factors for rice plants were thought to have been eliminated. It is possible that incorporating green manure increased the availability of micronutrients suppressed on the highly limed soil.

For soybeans, the high-input treatment (F2) increased the average soybean yield 202% over treatment F1. Soybeans in FO grew poorly or died, and no tillage practice overcame the lack of chemical inputs. Deep tillage on F1 increased soybean yield about 130%, but there was no effect of tillage on yield for treatment F2.

Crop Yields, Second Year

Crop yields for the second cropping year are shown in Table 2. Mulching increased the yield of the Rice 2 crop on low-input treatments (F1) by 40%, compared to hoeing. This significant increase may be related to drought, which was more pronounced during the second crop, or to the residual effects of the previous crop's mulch, which may have increased nutrient levels and promoted better soil physical conditions. Green-manure incorporation produced the highest yield of rice on F1, and rototilling increased rice yield significantly.

Mulching and green manure also significantly increased rice production on the medium-input treatment (F1-2), but other tillage treatments had little effect. The average rice yield for F1-2, 1.83 Mg/ha, was unexpectedly lower than that produced by the F1 treatment, possibly because the F1-2 plots were receiving lime for the first time, while the F1 plots had been limed for the first crop.

High fertility (F2) did not produce rice grain yields significantly higher than in F1, and vegetative growth showed a greater response to fertility than did grain production. As in the low- and medium-input treatments, mulching and green manure increased yields. By contrast, deep tillage produced a lower yield of rice, and plant growth was poor.

The yield of soybean in the second year was much lower than in the first year due to a leaf-attacking insect, *Lamprosema indicata*. Many plants were killed, but those growing on the more fertile soil, as in treatment F2, were relatively resistant to the insect attacks. Grain yields rose significantly with fertility, averaging 244, 416 and 727 kg/ha in treatments F1, F1-2 and F2, respectively.

Table 2. Yields of rice and soybean under different fertilization and tillage treatments, second year.

Tillage Treatment	Rice Yield, Mg/ha		Soybean Yield, Mg/ha	
	Grain	Strraw	Grain	Stover
	Low-Input Fertilization (F1)			
Hoe	1.88	2.84	0.15	0.45
Hoe & mulch	2.63	3.81	0.31	1.58
Hoe & green manure	2.76	4.39	0.39	1.56
Spading fork	2.06	3.10	0.26	1.07
Strip-forking	1.67	2.93	0.19	0.66
Rototiller	2.41	3.18	0.17	0.68
	Medium-Input Fertilization (F1-2)			
Hoe	1.30	2.98	0.19	0.67
Hoe & mulch	2.18	3.64	0.45	1.47
Hoe & green manure	2.63	4.10	0.71	2.43
Spading fork	1.68	2.86	0.48	1.54
Strip-forking	1.45	2.89	0.32	1.21
Rototiller	1.75	3.82	0.35	1.25
	High-Input Fertilization (F2)			
Hoe	2.09	4.14	0.62	2 16
Hoe & mulch	3.17	5.50	0.58	2.23
Hoe & green manure	2.93	4.79	1.18	3.89
Spading fork	1.49	3.29	0.71	1.94
Strip-forking	2.01	4.21	0.53	1.45
Rototiller	2.32	4.90	0.74	2.42
LSD 0.05	0.60	1.13	0.20	0.43

Soil Properties

Data in Table 3 show that low chemical inputs (F1) increased basic cations and decreased exchangeable Al+H or Al saturation and increased extractable P compared to F0. Percent Al saturation, P, and basic cations in F1 soil were close to the respective critical levels after one year of cropping. Therefore, the quantities of lime and fertilizers needed to maintain those levels were less than the initial application rates.

Physical properties of the soil showed no significant

Table 3. Soil chemical properties in the 0- to 0.15-m depth one year after cropping began.

Treatment	pH	Exchangeable			ECEC	Al Sat.	P
		A1+H	Ca+Mg	K			
		m.e./100ml				%	mg/L
F0	3.90	3.93	0.30	0.04	4.30	91.7	1.8
F1	4.61	1.69	2.1	0.12	3.93	43.0	9.3
F2	5.66	0.08	5.4	0.16	5.59	1.4	67.5

Table 4. Selected soil physical properties after one year of cropping compared to the original properties.

Treatment	Bulk Density	M I 1/	Water Infiltrated		
			15 min.	60 min.	90 min.
	kg/dm³	mm	mm		
F0	1.07	98	105	256	323
F1	1.07	99	132	290	354
F2	1.06	93	190	470	574
LSD 0.05	0.03	12	77	186	232
H	1.07	93	78	211	271
Hm	1.05	89	94	212	258
Hg	1.08	98	83	204	259
F	1.05	100	131	301	374
SF	1.05	92	129	252	319
R	1.07	88	104	286	381
LSD 0.05	0.03	9	60	176	230
Before cropping	1.09	92	59	195	279

1/ M I = the depth that penetrometer penetrates into the soil surface by five blows.

change in either bulk density or mechanical impedance due to chemical inputs or tillage one year after cropping (Table 4). However, the trend was for deep tillage to have a slightly lower bulk density, a higher mechanical impedance, and a higher infiltration rate compared to the other tillage treatments. The bulk density for all treatments averaged 1.07 kg dm^3, and mechanical impedance about 95 mm.

Conclusions

From the practical standpoint, this soil cannot be reclaimed without chemical fertilizer and lime applications. No tillage practice will be effective unless accompanied by chemical inputs. As the rate of chemical input increased, so did yields and soil fertility, although rice did not respond to high fertility as strongly as did soybean.

Green manure was very important in increasing yields of all the crops examined. Mulching was effective primarily during periods of moderate drought. Deep tillage and strip forking were not beneficial for rice, but were slightly beneficial for soybean. In contrast, rototilling was good for rice but only slightly beneficial for soybean. (Mr. Makarim's PhD thesis reports this project in detail.)

Liming in Transmigration Areas

Michael K. Wade, N. C. State University
Eugene J. Kamprath, N. C. State University
Heryadi, Center for Soils Research
Al-jabri, Center for Soils Research
Edi Joniarta, Center for Soils Research
Fahmuddin Agus, Center for Soils Research

This report covers the results of several experiments that deal with various management aspects of soil acidity and liming in the Sitiung transmigration area of Sumatra, Indonesia. The objectives of these studies are 1) to determine the critical level of soil acidity parameters for optimum production of upland rice, soybeans, and mung beans; 2) to determine a method of predicting lime rates necessary to achieve a specified level of Al saturation; 3) to determine the annual lime application rate required to maintain a specified level of soil acidity; and 4) to monitor the residual effect of various rates of one-time lime applications on a rotation of annual food crops.

Table 1 presents a brief description of the experiments. The results of these experiments are not discussed individually, but are referred to when relevant to a given topic.

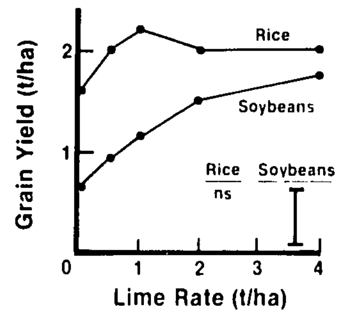


Figure 1. Rice and soybean response to applied lime.

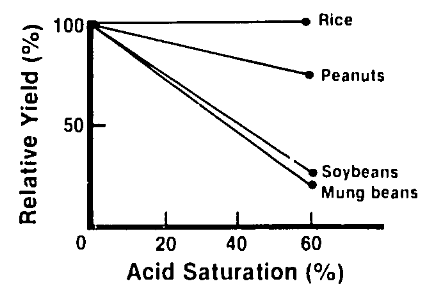


Figure 2. Relationship of acid saturation to yield of four food crops.

Crop Response to Lime

The soils in the Sitiung area are generally quite acid, often having pH less than 4.5 and exchangeable Al greater than 2 meq/100 ml soil, with an Al saturation greater than 60%. The lime response demonstrated in Figure 1 was expected under these conditions. Upland rice is a crop tolerant of soil acidity, and shows only marginal response to low rates of applied lime. Soybean is a crop susceptible to soil acidity, and yields increase several fold when lime is applied in adequate amounts.

In many areas of the world, Al saturation [(exch. Al/ECEC)*100] has proven to be a good estimator of effective (or growth-inhibiting) soil acidity. Figure 2 shows how the yields of four different food crops have correlated with acid saturation (discussed in more detail below). Rice yield was unaffected by the 60%

Table 1. List of experiments in the liming study.

Experiment	Treatment	Crops
I	a. Lime rates: 0, .38, .75, 1.5, 3.0 x exch. Al (0, 1/2, 1, 2, 4 t/ha) b. Residual and annual maintenance	rice-soybean
II	a. none, $Ca(OH)_2$, $CaCO_3$ b. Tillage: none, hoe, plow, rototill, deep	rice, peanut soybean, mung
III-V*	a. Rates: to suppiy 0, 1, 2, 3, 4, 6, 8 meg Ca/10C ml soil	corn, soybean
VI	a. Lime: none and 1.5 x exch. Al b. Tillage: none and hoe c. Burn: none, flash burn (b1), and pile and reburn logs after flash burn (b2)	soybean, peanut, rice

* Same treatment at three locations

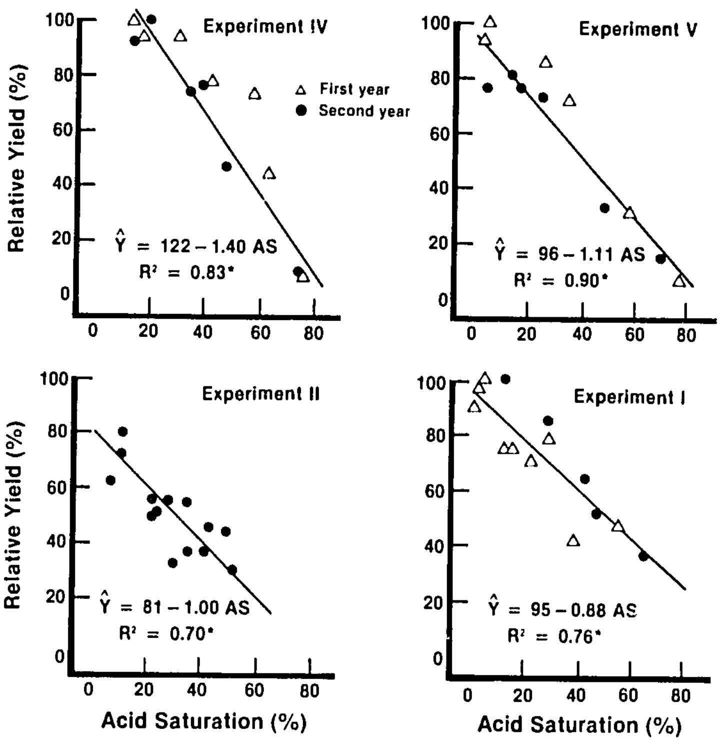


Figure 3. Relationship of acid saturation to soybean yields at four locations in Sitiung. x = first year; * = second year.

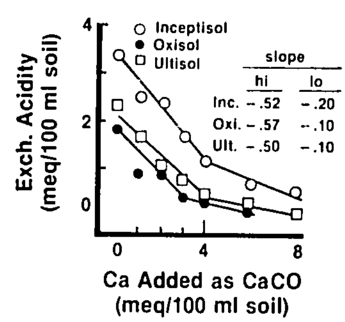


Figure 4. Exchangeable acidity as affected by Ca additions on three soils in Sitiung (III, IV, V).

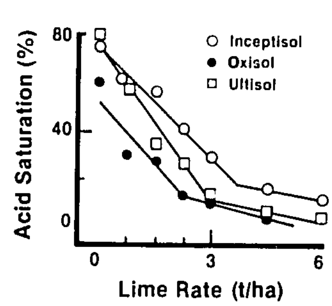


Figure 5. Effect of lime rate on acid saturation of three Sitiung soils.

acid saturation (AS) in this soil.

Data has been gathered for soybeans from four locations in Sitiung (Figure 3), all with quite similar results. All show a negative, linear regression of AS on yield. The slopes of the regression lines are also remarkably similar (ave. -1.1). These data indicate that each % AS will result in a yield decrease of about 1%. The consistency of this relationship across the four locations enhances the credibility of the data.

Chemistry of Lime Reactions

If acid saturation is a good indicator of inhibitory soil acidity, then these studies should tell something about the effectiveness of lime to reduce it. Figure 4 presents the effect of added Ca (as lime) on exchangeable acidity in three different soil types in the Sitiung region. The efficiency of the lime is the slope of the line. The ideal efficiency would be a slope of -1, i.e., each meq of Ca added would reduce Al + H by 1 meq. Here the slope is much less than 1, only slightly over 0.5 in the steeper portion. At low acidity levels, it takes much higher amounts of the lime to effect a given change in acidity. This change in the effectiveness of the lime occurs at about 20% AS (Figure 5), which means that the most effective use of lime is in the greater-than 20% AS range. Figure 4 shows that an average slope of -.53 means that 1.9 meq of Ca must be added to reduce 1 meq of acidity. If this factor is used in the Cochrane *et al.* equation, and units are converted to t/ha of lime, the equation for Sitiung becomes:

Lime Requirement (t/ha) = 1.4 [(exch. acidity (RAS*ECEC/100)]

where exch. acidity = N KCl extractable meg Al + H/100 ml soil,

RAS = required acid saturation (greater than or equal to 20%),

and assumes bulk density = 1.0 and plow layer = 15 cm.

Exchangeable acidity (Al + H) is measured in soil by extracting with N KCl and titrating to the phenolphthalein end-point. To separate the Al and H requires an addition of NaF and a back titration with HCl. It is common for highly weathered, low CEC soils to contain very little H. Thus, assuming H to be negligible, exchangeable acidity becomes exchangeable Al. However, after this separation was performed on dozens of Sitiung soils, H was found to be as high as 1.0 meq/100 ml soil, accounting for a fairly constant 20-25% of the total exchangeable acidity, and was highly correlated with Al (r = 0.81). When comparing regressions of Al and Al+H on yield, applied lime, pH, and ECEC, the coefficients of determination were always very similar. Thus, the extra laboratory steps required to separate the Al and H seem unwarranted. However, it is incorrect to call the results exchangeable Al, as H makes a considerable contribution to the total. Therefore, the relevant calculation for Sitiung is not Al saturation but exchangeable acidity (acid) saturation, which is [(Al+H)/ECEC)* 100].

Another aspect of the chemistry of liming is Ca and/or Mg movement, or leaching down the profile. Such movement into the subsoil should be very important for enhancing rooting depth and helping to increase drought tolerance in acid-susceptible crops. Table 2 shows evidence for modest cation movement after two years. There has been no change in exch. acidity or pH (data not shown) by this increase in Ca+Mg. The high rainfall and extremely porous soils of Sitiung should provide near maximum opportunity for Ca and Mg leaching. This movement will be monitored as the experiment continues.

Management of Lime Applications

After learning how lime changes the acid saturation of the soil, how the various food crops are affected by that acidity, and how lime requirements might be predicted for a given soil and crop, the next question is how to maintain a desired level of acidity (or acid saturation). Table 3 gives the acid saturation of the soil as affected by lime rates and time. To date two

Table 2. Exchangable Ca + Mg at three soil depths as affected by lime rate one and two years after application.

	Soil Depth					
	0-15 cm		15-30 cm		30-45 cm	
Lime Rate	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr
t/ha	meg Ca + Mg/100 ml soil					
0	1.1	1.2	0.7	0.8	0.6	0.6
0.5	1.5	1.5	0.7	0.9	0.6	0.8
1.0	1.9	2.1	0.8	1.2	0.6	0.8
2.0	2.6	2.6	0.8	1.0	0.7	0.8
4.0	4.0	4.2	1.1	1.1	0.8	0.8

Initial levels: o-15 cm, 1.0; 15-30 cm, 0.7; 30-45 cm, 0.6 meg Ca + Mg/100 ml soil.
Ca added in fertilizer: 85 kg Ca/ha = 0.3 meg Ca/100 ml soil (top 15 cm).

Table 3. Lime applied as initial and maintenance applications and resulting acid saturation.

	Lime Rates				
Trend	Initial	12 month Maintenance	24 month Maintenance	Total Maintenance	% of Initial
	t/ha				
1	0	0.17	0.06	0.23	—
2	0.5	0.28	0.06	.34	68
3	1.0	0.56	0.15	.71	71
4	2.0	0.52	0.52	1.04	52
5	4.0	1.40	1.40	2.80	70
		Acid Saturation Achieved			
Trend	Goal	4 months	12 months	24 months	24 months +Maintenance
	%				
1	60	66	66	62	54
2	40	42	42	48	36
3	20	20	40	36	22
4	10	6	22	25	12
5	0	0	5	5	4

annual "maintenance" applications of lime have been given in an attempt to maintain AS's of 60, 40, 20, 10, and 0%. The data indicate that these applications were effective. It has taken a fairly consistent proportional rate, i.e., two-thirds of the initial amount (over a two-year period), to maintain the desired levels of AS. Therefore, approximately one-third of the initial rate is required, per year, to maintain a given AS. It should be pointed out that this experiment has been conducted with burned lime [$Ca(OH)_2$] as the source, and not the commonly distributed ground limestone ($CaCO_3$). Burned lime is considerably more soluble than ground limestone and its residual effect might be less, i.e., a higher maintenance rate might be required for burned lime than for ground lime. If so, this trial would over-predict the necessary maintenance rates for the current liming program.

The maintenance rates for the first year were developed from a "calibration curve" based on lime added vs. initial AS achieved (four months after application). In the second year, rates were selected based on Figure 6, which is a graph of first-year maintenance rates vs. the resulting change in AS. There is a very distinct decrease in efficiency of the maintenance rates at the lower AS levels. Maintenance applications on the 0, 1/2, and 1 t/ha plots (which are at AS levels greater than 20%) produced a drop of 8% AS per 100 kg lime/ha. Maintenance applications on the 2 and 4 t/ha plots (which were at 10 and 0% AS) averaged reductions of only 2.5% and 0.75% AS, respectively, per 100 kg lime/ha. Not only are initial lime applications most effective at higher AS, but so are maintenance applications. Therefore, if lime is an expensive and scarce resource, these data indicate that the most effective use of that lime is in correcting and maintaining soils to no lower than 20% acid saturation. Data for several years are needed to properly evaluate the length of the residual effects and the frequency and rate of maintenance applications. Only preliminary conclusions can be drawn at this time.

Incubation Time

Another management question for lime applications is incubation time. Historically, scientists working in the temperate zone have recommended that lime be applied several weeks or even months in advance of planting. In tropical soils, where temperature and moisture are usually high and mineralogy consists of low-activity clays, such conventional wisdom may not hold. Figure 7 shows the average acid saturation of

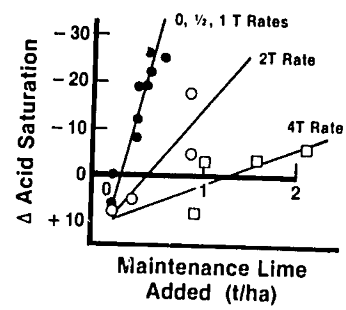


Figure 6. Change in acid saturation by maintenance lime applications at each initial lime rate (I).

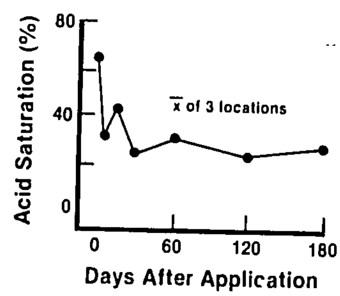


Figure 7. Acid saturation as affected by time after lime application.

three different soils over time after liming. With the exception of an inexplicable rise in AS at 15 days, the acidity level is virtually unchanged from three to 180 days after application. It seems clear that no incubation time is needed, and that farmers could apply lime and plant the same day with no detrimental effects (as has been done, in research plots at Sitiung). When commercially ground limestone is hoed-in at planting, most of the lime has reacted by the time seeds germinate.

Tillage and Response to Lime

Table 4 indicates that tillage management has little effect on crop response to lime. Except for rice, these yields are quite low, however, and responses may be different with higher yields. Soil samples taken with depth and over time show no particular trend in effectiveness of lime reaction among the various tillage methods. However, extreme soil variability within this trial makes meaningful data interpretation difficult. The deep-tillage method shows a tendency (though non-significant) toward higher yields. This treatment received a 2x rate of lime compared to the others because it was tilled to 2x the soil depth. Soil analysis indicates

Table 4. The effect of method of lime incorporation on crop yields of rice, peanut, soybean and mung bean.

Crop	Tillage: None	Hoe	Plow	Roto	Deep	
	t/ha					
Rice	3.11	3.05	3.45	3.22	2.93	ns
Peanuts	0.69	0.77	0.64	0.64	0.81	ns
Soybeans	0.66	0.67	0.64	0.84	0.98	ns
Mung beans	0.18	0.27	0.24	0.24	0.35	ns

incomplete mixing within the intended 30 cm of soil, which resulted in a lower acid saturation in the upper 15 cm. Apparently the higher rate of lime, and subsequent lower AS, is the reason for the tendency for higher yields rather than a superior effect of deep tillage.

Newly Cleared Soils

Clearing of forests for agricultural production has a profound effect on soil properties. It has often been observed that newly cleared acid soils do not respond to lime. This was the case in Sitiung as well. Soybean yields on a newly cleared Ultisol were good despite an acid saturation of 55% in the unlimed soil. Organic matter is known to form organo-Al complexes, and a recently cleared soil would have a considerable addition of forest litter as well as a probable buildup of humus during the forest fallow. This organic material may be complexing, and detoxifying, Al. Other work done in Sitiung has shown that green manure applications can also produce a temporary alleviation of Al toxicity (reported in detail in another section of this annual report).

Experiment VI was initiated in a newly cleared forest to assess how burning and tillage affect soil properties and crop yields, and the interaction of these practices with liming. Figure 8 shows a significant tillage x burn interaction. This interaction was similar with and without lime. The question was why, when the forest was not burned, was tillage necessary to achieve good yields? Both twice-burning (b2) and liming greatly reduced acid saturation (24% and 17%, respectively) from an initial 60%. But neither AS nor Ca + Mg correlated well with yields, an unexpected result for peanuts on a low Ca soil. As the soil analysis was evaluated by depth, a possible answer appeared. Figure 9 shows a strong correlation between peanut yield and exch. Ca + Mg at the 10-15 cm soil layer. Neither the total surface (0-15 cm) layer nor the 0-5 and 5-10 cm layers show such good correlation. Table 5 shows the 10-15 cm layer values for Ca + Mg as affected by the

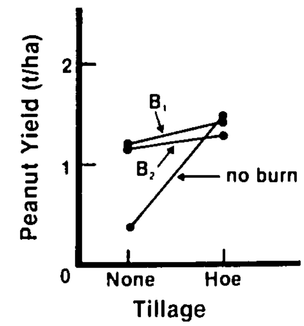


Figure 8. Effect of tillage and burning on peanut yield (VI).

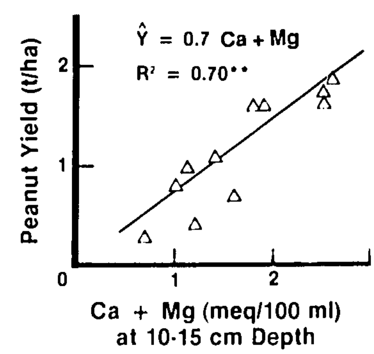


Figure 9. Regression of Ca + Mg at 10-15 cm soil depth on peanut yield (VI).

Table 5. Exchangeable Ca + Mg at the 10-15 cm depth as affected by liming, burning and tillage.

	No Burn	Flash Burn	Pile and Reburn
	meg Ca + Mg/100 ml soil		
		No Lime	
No Tillage	0.7	1.0	1.6
Tillage	1.1	1.4	2.5
		Lime	
No Tillage	1.2	1.8	1.4
Tillage	2.6	2.5	2.5

lime, burn and tillage treatments. Generally all three factors enhanced Ca+Mg at the 10-15 cm layer. Tillage would obviously help the distribution, and burning would put Ca and Mg in a relatively soluble, hydroxyl form and therefore enhance leaching. Unfortunately there is no good estimate of the amount of Ca and Mg added from the ash. The positive response to the distribution of nutrients may partially be due to the crop, as peanuts have a particular demand for Ca. Also, this crop was grown in the dry season, when bases at greater depth would increase rooting volume and therefore help the plant withstand drought.

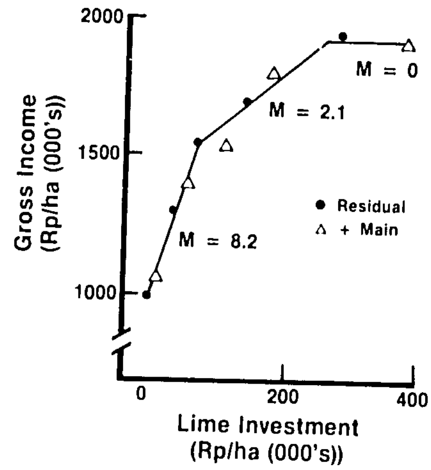


Figure 10. Effect of lime investment on gross income of a rice-soybean rotation (I).

Economic Considerations

The ultimate evaluation of the success of liming as an agricultural practice is its economic viability. Figure 10 shows the gross income from two years of an annual rotation of rice and soybeans, as affected by the amount of money spent on lime. The relationship breaks into three linear segments. The slopes of these segments are the rates of return (Rp. gained/Rp. spent). Clearly, the greatest economic return on lime investment is for lower amounts spent. Up to Rp. 70,000 spent (for either initial or maintenance liming) gives greater than an eight-fold return. Spending over Rp. 250,000/ha was no longer profitable. As long as there is considerable residual effect of the lime and/or only small maintenance doses are required, then the economic returns will increase over time. The data in Figure 10 are from only two years of an annual rice-soybean rotation.

Table 6 gives the amount of lime required to reduce acid saturation to 20% and to 0% for four locations in the Sitiung area. The table also gives the calculated rate of return of lime at those two levels, for a single crop of soybeans. There is considerable savings in the amount of lime required and considerable increase in the return to investment when 20% AS is the goal. For each of these examples, it is certain that more than one crop will respond to a given application of lime, and thus the rate of return will increase with each residual crop. It is also a fairly safe assumption that considerable additional income will be generated over the next year or more, with little or no additional money spent on lime. On the other hand, it must be remembered that these data were generated from crops under the management of researchers. Farm-level management will likely be less, with the result of lower yields and lower returns on investment.

Conclusions

While these studies are not yet complete, some preliminary conclusions may be reached regarding liming at Sitiung:

Table 6. Lime required to achieve 20% and 0% acid saturation and the return on lime investment.

Location	Lime Required to		Rate of Return to Lime	
	20% AS	0% AS	@ 20% AS	@ 0% AS
	t/ha		dollars per dollar	
Ia	4.4	7.6	0.8	0.8
IIe	1.4	4.0	3.2	1.5
IIIc	2.5	4.5	1.7	1.3
IVb	3.2	6.3	1.4	1.0

Assumes: 1. maximum yield = 1.5 t/ha
2. yield at 20% AS = 80% max (1.2 t/ha)
3. unlimed yield = 30% of max (0.45 t/ha)
4. lime costs Rp 70/kg and soybeans are worth Rp 400/kg

1) Soybean showed a negative, linear response to AS, with each % AS resulting in approximately a 1% reduction in yield.

2) Initial lime applications were most efficient in improving crop yields at AS levels of 20% or greater. Maintenance applications were also more efficient at higher AS levels.

3) A formula for lime requirements at Sitiung should include a calculation of acid saturation [(exch. Al + H)/ECEC], instead of Al saturation.

4) For the first two years of this study, approximately one-third of the initial rate of burned-lime application was required, per year, to maintain a given AS.

5) Acidity level was virtually unchanged from three to 180 days after lime application, indicating that no incubation time is necessary at Sitiung.

6) The interaction of tillage and burning of newly cleared forest had a positive effect on soybean yields. This interaction was similar with and without lime, and may be due to the incorporation of ash containing Ca + Mg.

7) The greatest economic return on lime investment is for lower amounts spent. Up to Rp. 70,000 spent (for either initial or maintenance liming) gives greater than an eight-fold return. Spending over Rp. 250,000/ha was no longer profitable.

Implications

Data from these experiments indicate that the efficiency of liming to reduce toxic acidity, the response of crops to applied lime, and the rate of return on investment are all greatest at low rates of lime and modest levels of acid saturation. Early indications are that modest rates of lime applied annually will suffice, if desired levels are on the order of 20% AS or greater.

However, determining the most efficient and economical rates of lime applications will require monitoring these experiments for several more years.

Phosphorus Management In Transmigration Areas

Michael K. Wade, N. C. State University
Djoko Santoso, Center for Soils Research
Al-jabri, Center for Soils Research
I. Putu Gedjer, Center for Soils Research

Phosphorus fertilizer experiments have been initiated in the Sitiung transmigration area of West Sumatra, Indonesia, on two soil types with very distinct P reactions. The soils, an Ultisol and an Inceptisol, are both very acid (pH less than 4.5) and low in native available P (less than 5 ppm by modified Olsen). However, their P fixation as indicated by the relationship between extractable P and added P fertilizer is quite different (Figure 1), as the Inceptisol requires much more P fertilizer to achieve a given extractable P level.

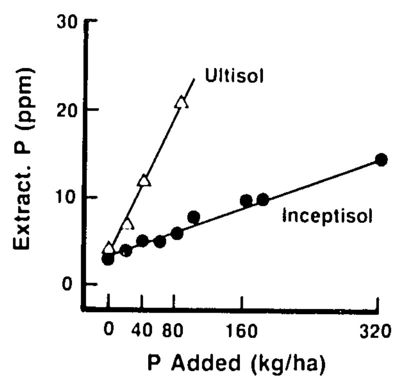


Figure 1. Effect of P fertilizer on extractable P for two soils.

The two experiments are not identical but do have some common objectives. These include: 1) to determine optimum rates of TSP fertilizer (triple superphosphate, 20% P) on a newly cleared soil (clay loam Ultisol) and a cultivated soil (Inceptisol); 2) to determine cost-benefit ratio of various methods of applying TSP fertilizer; 3) to study long-term effects of various P management schemes (i.e., various rates and methods of application) on crop production and soil P levels; and 4) to determine critical P soil test values for corn, soybean, rice, and peanut.

High-Input Experiment

The experiment on the Inceptisol is high-input management, with high rates of lime, N, K, Mg, and S for all plots. Treatments are a) initial rates (broadcast and incorporated) of 0, 20, 40, 80, 160, and 320 kg P/ha; and b) per-crop (including the first) P rates of 0, 20 kg banded, and 20 kg broadcast/ha. The cropping sequence is corn-soybean-peanut.

The first crop, corn, responded significantly to P fertilizer (Figure 2), well described by a three-segment, linear-plateau model. There were no differences between the banded and broadcast per-crop applications; therefore, a single regression of total P (regardless of method of application) described the response. However, the second crop, soybean, showed a very distinct response to the per-crop applications (Figure 3). Those treatments with the per-crop broadcast maintenance showed no effect from the initial rates. However, the residual of those rates gave a very sharp response, up to the 160 kg P/ha rate, while the banded maintenance gave a less sloping but linear response, also up to the 160 kg rate. The third crop, peanut, was planted at the end of the rainy season with no inputs other than seed. The expectation was that water would be limiting and that residual lime and nutrients

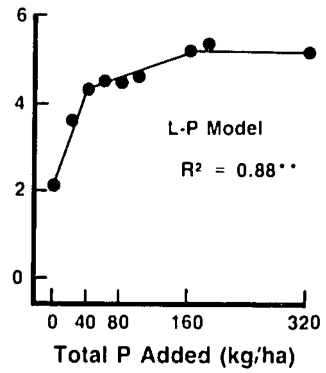


Figure 2. Effect of P fertilizer on corn yields.

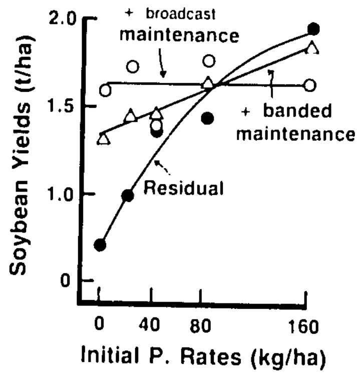


Figure 3. Effect of maintenance and residual P on soybean yields.

would be adequate for this dry-season crop, which would typically be planted with a take-what-you-can-get philosophy. There was very little rain in June (during flowering and pod set) which resulted in relatively low yields and there was no response to residual P. The plots that had never been fertilized with P averaged 1.04 t/ha, while those that received various amounts of P for the corn and soybean crops averaged 1.07 t/ha.

Soil Test Calibration, Inceptisol

Data on the relationship of extractable P to corn and soybean yields from the Inceptisol soil indicate that a critical level of 9 ppm very nicely divides the responsive and non-responsive P levels. As stated above, the peanut did not respond to the residual fertilizer P despite the zero P plots having only 3 ppm extractable P. This is surprising even at low yield levels.

Low-Input Experiment

The basic premise of the low-input experiment on the Ultisol is that recently cleared land in the Sitiung area is primarily P deficient, and that only P fertilizer is needed to grow acid-tolerant crops. Thus, the intended rotation is rice-peanut, although late planting and poor germination resulted in no rice the first year. Also, a mung bean crop was planted in the dry season following the peanut in an attempt to get a second crop that first season. Treatments were a) rates of 0, 20, 40, and 80 kg P/ha, banded or broadcast; b) methods of application (at the 20 kg P/ha rate): band, broadcast, band between row, dibble beside seed hole, place in seed hole; and c) high input at one level of P (80 kg/ha): 2 t lime/ha, 50 kg K/ha, 16 kg Mg/ha, and 23 kg S/ha. Except in the latter treatments (c), management is low input, with no lime or fertilizers except 45 kg N/ha on rice and 325 kg $Ca(OH)_2$/ha as top-dress on peanut.

Figure 4 shows that peanut (the first and fourth crop) responded dramatically to added P, and that the high-input treatment indeed had no additional effect on yield. Also, the method of applying the fertilizer clearly had no effect.

The choice of mung bean as the second crop was incongruous with the original plan, as mung bean is not tolerant to either acidity or low fertility. Whereas peanut had shown uniformly good growth, mung bean growth was extremely variable within the plots (the subsequent rice crop was reasonably uniform). The most variable mung bean plots were divided into "good" and "bad" sections and harvested and sampl-

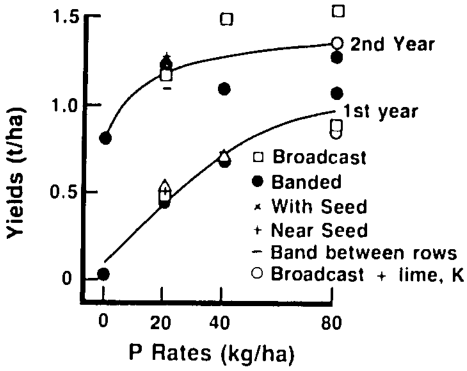


Figure 4. Peanut yields as affected by P rates and method of application.

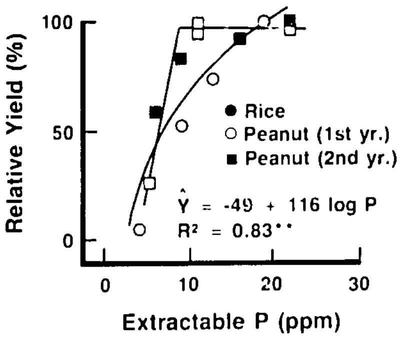


Figure 5. Relationship of extractable P to rice and peanut yields.

ed accordingly. The "good" sections were found to have consistently high base status while the "bad" sections had a much lower base status. A multiple linear regression using both Ca + Mg and extractable P gave a high coefficient of determination, providing a reasonable explanation for the variability. The high-input treatment, which had no positive effect on rice or peanut, increased mung bean yields by 50% over the P only treatments.

The third crop, rice, was grown on the residual of the two P applications (all rates had been reapplied to the mung bean). Dry matter production was tremendous (approximately 10 t/ha on the plots receiving P), but grain yields were poor due to disease, despite the fact that a local variety was grown. However, a considerable response to P was evident. The lowest rate (20 kg/ha) was sufficient to reach plateau yields, and this unimproved rice variety did not respond positively to higher rates.

Soil Test Calibration, Ultisol

Figure 5 shows the relationship of rice and peanut yields to extractable P from the Ultisol. The rice has basically a two-point response, very low yields at zero P (5 ppm) and high, plateau yields for all the P fertilized treatments. There are no data for what should be the response portion of the model and thus a critical level cannot be identified, except that it is equal to or less than 11 ppm. The peanut had a nearly linear response to increasing levels of extractable P, such that no plateau yield was established. Again, no critical level can be determined except to say that it is apparently greater than 20 ppm. This result is quite the opposite of the peanut on the Inceptisol, which showed no response to P on a soil with only 3 ppm extractable P. That discrepancy is unexplained at present.

Differences among responses of crops to soil P in these experiments underscore the fact that both soil type and management can be expected to influence critical levels. In order to confidently identify critical levels for fertilizer recommendations, we need a large set of data on various soils and management levels for each of the major crops.

Methods of Application

Results from both of these experiments indicate that crop yields were not influenced by methods of applying P fertilizer. In the high-input trial, banding or broadcasting the per-crop application of P produced no difference in corn yields. In the low-input experiment trial, peanut showed nearly identical results for banding and broadcasting at all rates, and there was no difference among the five methods of application tested at the 20 kg/ha rate (Figure 4). Neither rice nor mung bean (as residual and direct P application, respectively) showed any significant differences among the methods of application. There was an effect on soybean of the high-input experiment; the broadcast maintenance was superior at the lower P rates (Figure 3). It is hypothesized that at these low soil P levels, banding limited root exploration and thus increased moisture stress during dry periods. This soybean crop suffered a 17-day period of no rain early in the vegetative-growth stage. Brief periods of moisture stress are common even during the rainy season, and may be yield-limiting. Therefore, these results indicate that the labor-intensive method of banding P, currently recommended by the Food Crop Institute, is not necessary and may even be detrimental under certain conditions. It must be noted that by "broadcast" we mean applying the fertilizer prior to tillage, such that it is incorporated or mixed with the soil to some degree and not simply top-dressed.

Economic Considerations

Perhaps the most meaningful way to compare the cumulative or overall effect of P fertilizer on the management system is by monetary returns. Figure 6 shows the effect of applied P fertilizer on net monthly income. The data are presented on a monthly basis in order to compare the two experiments, as the high-input experiment has run for 12 months and low-input experiment for 18 months. A three-segment, linear-plateau model, very similar to the corn yield response, fits the data very well. Total P applied, regardless of timing (initial or maintenance) and method of application (banding or broadcasting), gave the best regression. This model predicts the most beneficial amount to apply is 40 kg P/ha, although substantial increases in income occur up to rates of 165 kg P/ha. Especially noteworthy are the very similar values for the two management systems.

The true impact of residual P and maintenance applications of P fertilizer cannot be properly evaluated in the short term. Continued monitoring and data collection for several years will be necessary to establish the most effective and economically efficient management of P fertilizer on these soils.

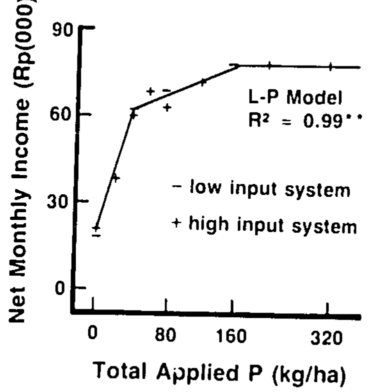


Figure 6. Effect of total P fertilizer, applied to crop, on net monthly income.

Effect of Green Manure Applications On Soil Fertility and Crops

Michael K. Wade, N. C. State University
Ir. Heryadi, Center for Soils Research
Dan W. Gill, N. C. State University

This report covers two experiments conducted in the Sitiung II transmigration area of West Sumatra, Indonesia. Both were conducted with a rice-soybean rotation, and deal with the effect of green leaf manure (glm) on soil fertility and the interaction of glm with inorganic fertilizers and lime. They were established to further investigate a remarkable response of crops to glm found by Karim Makarim in the same area.

Green Manure and Fertilizer P

The objective of this experiment was to study the effect of green-manure application on lime and P fertilizer requirements for rice and soybean. Treatments were four rates of lime (0, 1, 2, and 3 t/ha), three rates of P (10, 25 and 50 kg/ha/crop), and 20 t/ha of fresh calapogonium at the 10 kg P/ha rate on all levels of lime. The glm was applied at the beginning of the rainy season, just prior to rice planting.

Rice Response

Visible symptoms of Al toxicity and/or Ca deficiency in young upland rice were clearly suppressed by the glm applications, and growth and development were better as a result. Because blast severely reduced grain yield, dry matter production data are presented to demonstrate the responses. Figure 1 shows a marked lime response of the rice, when P fertilizer was ade-

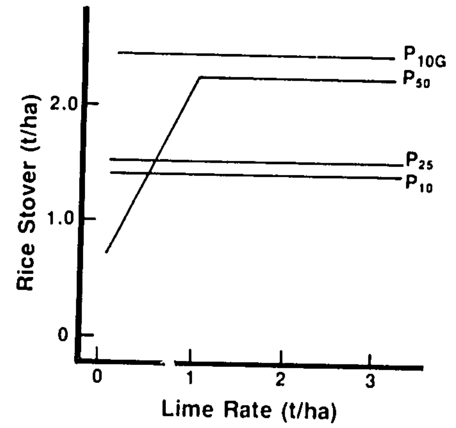


Figure 1. Effect of lime and green manure on P response of rice.

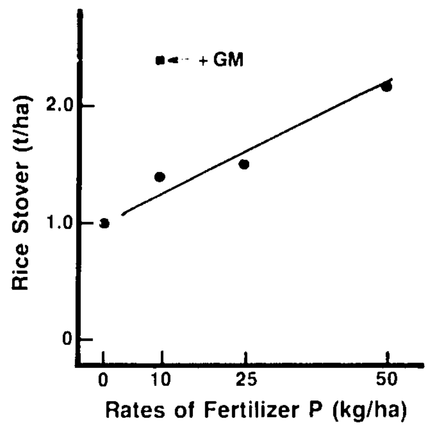


Figure 2. Effect of P fertilizer and green manure on lime response of rice.

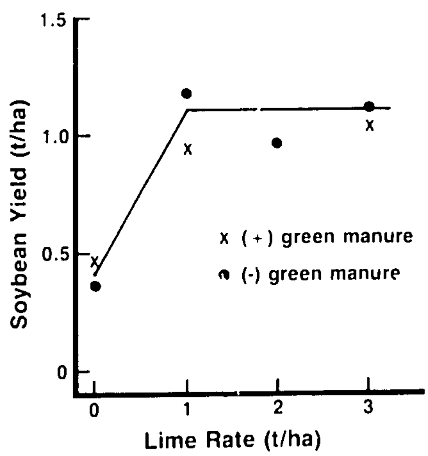


Figure 3. Effect of lime on soybean yield (with and without green manure).

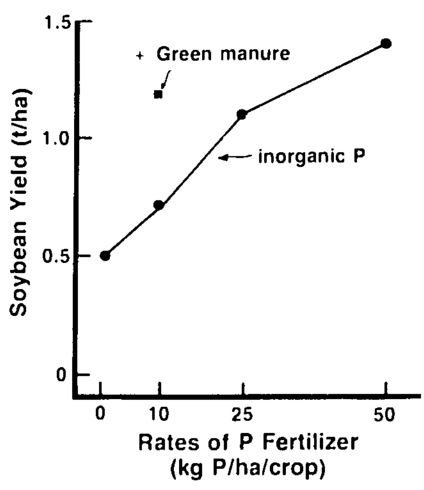


Figure 4. Effect of inorganic P fertilizer and green manure on soybean yield.

quate (50 kg rate). Apparently the 10 and 25 P rates were insufficient to overcome P deficiency and thus gave no response to lime. However, the 10 P rate, when combined with glm, produced higher yields than the limed 50 P and did not show a response to lime. Glm thus not only alleviated soil acidity but also seemed to have improved P availability as well. Figure 2 shows this more clearly, as yields of the non-glm 10 P were quite low (either with or without lime). However, when glm was applied along with 10 kg P/ha, yields were similar to those with 50 kg inorganic P/ha and lime.

Soybean Response

The next crop, soybeans, received the same levels of P, but no more lime or glm. As might be expected, the effects of the glm appeared to be short-lived. Soybean yields responded sharply to lime, and there was no evidence that glm alleviated soil acidity (Figure 3). There was no significant lime x P or glm interaction for the soybeans. Figure 4 indicates that glm continued to enhance P availability, but this time the 10 P rate + glm was equivalent to the 25 P rate, whereas for the rice it was approximately equal to the 50 P rate. Tissue analysis indicates that complete mineralization of the green manure would provide approximately 10 kg P/ha. Thus, the response to the glm is greater than can be explained by added nutrients, and therefore, must be due to enhanced availability of P.

Soil Analysis

Despite the fact that glm had a substantial effect on rice growth by apparently detoxifying soil Al and enhancing P availability, it had no significant effect on either extractable P (mod. Olsen) or acid saturation (N KCl) (Table 1). The growth response is obvious but standard soil analyses did not detect a corresponding change in chemical properties.

Table 1. Effect of green leaf manure (glm) and P fertilizer and lime on extractable P (mod. Olsen) and acid saturation.

P Rates	Ext. P	Lime Rates	Acid Saturation	
			no glm	+ glm
kg/ha	ppm	t/ha	%	
0	5	0	78	72
10	6	1	55	53
25	6	2	42	40
50	13	3	30	36
10+glm	8	-	--	--

Green Manure and Fertilizer K

This experiment was initated to investigate the effect of residue management and glm on K fertilization requirements. It is a "high-input" experiment with rates of basal lime, N, P, Mg, S and micronutrients (Cu, Mn, Zn). Treatments were rates of fertilizer K (0, 10, 20, 40, 80, 120 and 240 kg K/ha), and methods of residue management (residue removed, residue returned, and residue returned plus 10 t/ha of fresh green manure, a mixture of calapogonium and kudzu, at the 0 and 80 kg K/ha rates only). In this experiment, the glm was applied before each crop.

Crop Response

Table 2 gives the yields of rice and soybeans at two levels of K for each of the management treatments. Since there were no previous residues for the first crop, management treatments were only no glm and plus glm. As in the phosphorus experiment, straw yields are used to express the growth response as grain was completely destroyed by blast. Both rice and soybeans responded very strongly to glm. In the treatments receiving no fertilizer K, glm increased rice straw and soybean yields three- or four-fold over results from crops receiving no glm. Soybeans also responded to the return of rice straw. Crop growth response to glm, visibly evident in the field, was impressive.

Tissue analysis of the glm and the rice straw revealed that substantial K was being applied via these organic materials. Figures 5 and 6 show regressions of K fertilizer on rice straw yields and soybean grain yields, respectively. They also show that when the glm and/or straw treatments are plotted using total K applied (KCl + organic K) on the X-axis then those points fall very close to the inorganic K fertilizer regression lines. Thus,

Table 2. Effects of residue management on rice and soybean yields at two levels of K fertilizer.

Residue Management	Fertilizer K (t/ha)	
	0	80
	rice straw (t/ha)	
no glm	1.17	5.84
+ glm	4.57	6.59
	soybean grain (t/ha)	
straw removed	0.59	1.67
straw returned	1.32	2.48
straw + glm	2.20	2.37

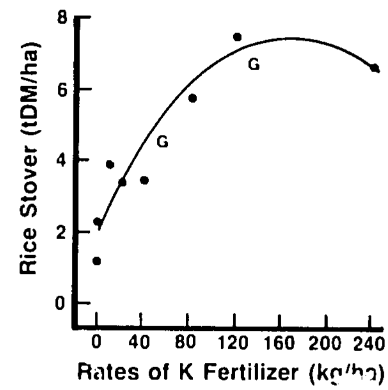


Figure 5. Effect of K rates on rice stover yields (DM).

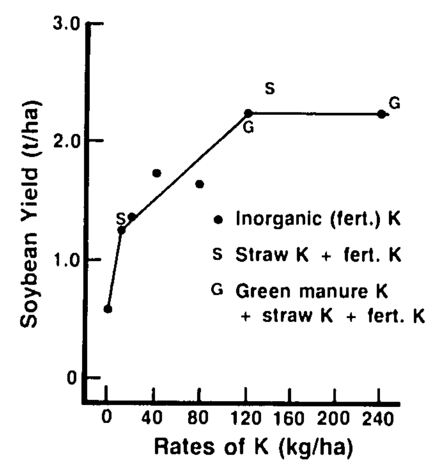


Figure 6. Effect of K rates (organic or inorganic).

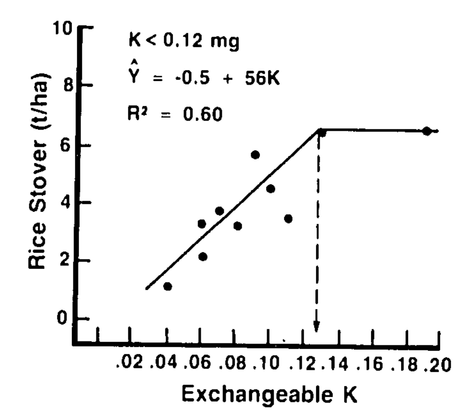


Figure 7. Relationship of soil test K (meq/100 ml soil) and rice yield.

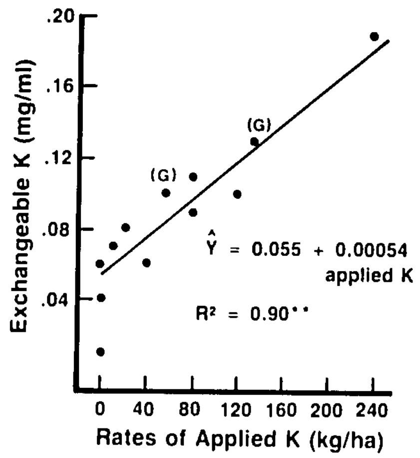


Figure 8. Effect of applied K on exchangeable soil K.

the apparent response to residues and glm can be explained largely by the amount of K supplied, in whatever form, to this obviously very K-deficient soil.

Soil Analysis

Figure 7 shows a fairly good linear plateau regression of the effect of exchangeable K's effect on rice straw yields, with a critical level of 0.12 meq K/100 ml soil. Also, rates of total K applied correlated very well with exchangeable soil K (Figure 8), indicating that source of K (organic or inorganic) was equally effective.

Implications

After one year of these continuing experiments, initial results with crop residues and green manuring strongly indicate that organic-material management on these soils may be crucial, both at low- and high-input levels. The green leaf manure appears to offer a complex of nutritional benefits, either by direct release in mineralization or enhancement of availability. The mechanisms for increasing nutrient availability (or Al detoxification) are not clear at this time, and certainly warrant more investigation. Another critical issue is whether or not glm can be incorporated into cropping or farming systems in a manner that is acceptable, reliable, and economical for farmers. Research to address that problem has been initiated under a different project.

Potassium Management Of Upland Crops

Dan W. Gill, N.C. State University
Sri Adiningsih, Center for Soils Research
Antonius Kasno, Center for Soils Research

Soils in the central Sumatran transmigration region are known to be highly Al toxic and low in bases, especially K. Thus a study of crop response to fertilizer K at three lime rates was made at two locations in the Sitiung area using two crop rotations. Both experiments are complete factorials with lime rates establishing 70, 40 and 10% Al saturation in the soil (0.375, 1.5 and 5 t/ha, respectively) and applying 0, 20, 40, 80, 120 and 240 kg K/ha as KCl.

Corn-Peanut Rotation

On a typic haplorthox at Sitiung I with about 75-80% Al saturation and 0.10 meq K/100 cc soil (common levels in this region), a corn-peanut rotation was grown. As could be expected, corn responded significantly to both lime and K (Figure 1). Responses to K were quite strong at both high and low lime rates, but were minimal at the 1.5 t/ha rate. It is felt that variability in original soil K levels among plots may help explain the absence of response at the medium lime rate. Soil K data is not yet available for this experiment.

The peanuts that followed gave a significant response to lime, but they did not respond to K at the low lime rate and only to 20 kg K/ha at the two higher lime rates (Figure 2). Lime rates were adjusted upward for the two higher rates in order to achieve the desired

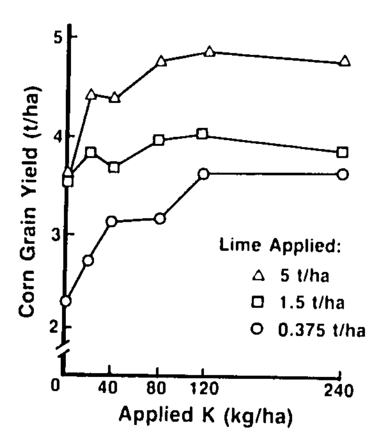


Figure 1. Corn grain response to applied K at three lime rates.

Al levels, and all K rates were reapplied to the peanut crop. Few conclusions can be drawn at this time, because analysis of plant and soil samples is still pending. However, it appears that for this rotation to grow well in this region, substantial amounts of lime will be needed. It seems likely that relatively high K rates are needed for good corn production, but low rates of K are sufficient for peanuts.

Rice-Soybean Rotation

A rice-soybean rotation, perhaps the most popular rotation among farmers in the Sitiung area, was grown on a haplorthox with soil chemistry similar to that of the soil in the first experiment. The rice did not respond to lime rates, demonstrating its tolerance to high levels of soil Al (Figure 3); however, applied K rates were very effective at increasing rice yields. Maximum yields were obtained by addition of 120 kg K/ha or more. The soybeans that followed the rice were highly affected by lime rates, since this crop is relatively Al sensitive (Figure 4). At the 0.375 tons lime/ha rate, with high Al levels limiting soybean growth, no response to K was observed; at the 2.25 t/ha rate, yields were increased by application of 20 kg K/ha or more. With most of the soil Al neutralized (at the 5 t lime/ha rate), however, a yield response was obtained up to the 80 kg K/ha treatment.

Although the new atomic absorption spectrophotometer has been shipped to Indonesia, it has yet to arrive on site and thus most soil samples taken during the past year have not been analyzed. The few samples which have been run indicate that a large percentage of applied K is rapidly leaching out of the profile. It seems that although these soils are relatively high in clay, building up soil K may be as much of a problem here as it is in the sandier soils of the Amazon basin of Peru. More concrete conclusions await the analysis of both soil and plant samples, as well as another year's data collection.

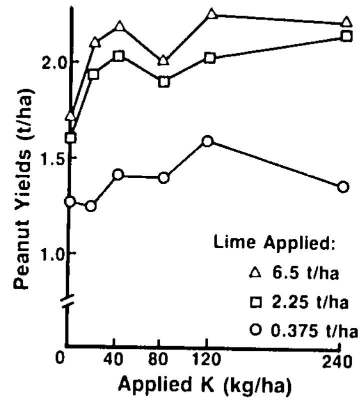


Figure 2. Peanut grain response to applied K at three lime rates.

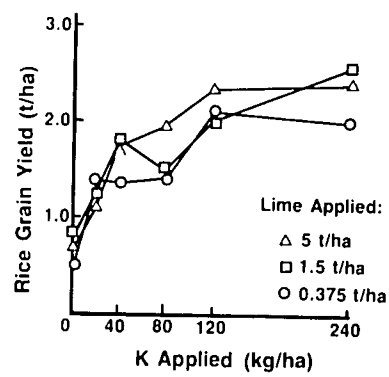


Figure 3. Rice grain yield response to applied K at three lime rates.

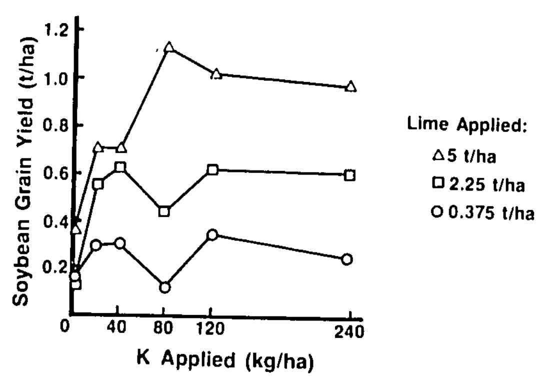


Figure 4. Effect of applied K at three lime levels on soybean yields.

Sulfur Fertilization

Michael K. Wade, N.C. State University
Eugene J. Kamprath, N.C. State University
Ir. Heryadi, Center for Soil Research

This work was initiated at Sitiung II and IV, on two sites, one recently cleared, and the other cultivated for five years. The objectives were to determine, for each site, the total sulfur and sulfate content of the soils, and the response of grain crops and legumes to sulfur fertilization. Two crops, corn and mungbean, were

New-Project Update

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

grown on each site under various rates of S. However, both crops were damaged by unseasonably severe droughts, and consequently there are few meaningful data to report. Measurements of grain and stover yields showed no response to S fertilization, nor were deficiency symptoms noted in the check plots. These experiments will be continued, possibly in conjunction with a planned micronutrient survey, in order to evaluate the role of S fertilization and the effect of time on the availability of S in these soils.

Contributions to North Carolina And U.S. Agriculture

Pedro A. Sanchez, N.C. State University

The basic link between TropSoils research and North Carolina is the striking similarity between soils in North Carolina and those at the research sites in the tropics. The main soils at Yurimaguas are classified in the same family in Soil Taxonomy as the dominant soil of the North Carolina Coastal Plain, Norfolk, except for soil temperature regime. Many soils of the North Carolina Piedmont are similar in age to Oxisols and Ultisols of Brazil and Indonesia. Present North Carolina agricultural practices evolved from the shifting cultivation used 150 years ago.

Because climate and socioeconomic conditions are different, however, agricultural practices cannot be directly extrapolated from one location to the other. Consequently, the main domestic contribution of TropSoils is that it helps develop and broaden the university's capabilities, and suggests new directions for in-state research. Because key senior faculty are involved in both TropSoils and domestic research, it is very difficult to pinpoint contributions that can be attributed solely to TropSoils, as most are the product of long-term interaction, travel and many discussions. However, the following contributions were definitely stimulated by tropical research.

1. A simple, semi-automated, soil-test apparatus, developed by the International Soil Fertility Evaluation and Improvement Project (ISFEIP) throughout Latin America, has been adopted by the North Carolina Department of Agriculture for routine soil-testing analyses of more than 250,000 samples per year. The method combines several determinations with a single extraction, thus saving valuable time in making fertilizer recommendations to farmers.

2. The Linear Response and Plateau Model for fertilizer response curves, developed by members of the ISEFIP project, changed the approach to fertilizer recommendations because of its emphasis on maximizing yield response per unit of fertilizer, as opposed to the classic marginal analysis and quadratic response curves, which assume unlimited resources. The model is applied not only by many North Carolina researchers, but worldwide.

3. The development of Fertility Capability Classification (FCC), a technical system to identify soil constraints to crop production by interpreting Soil Taxonomy, is being included in new soil surveys in North

Carolina and other states. This technical system simplifies the interpretation of soil mapping units by allowing units to be grouped under the same FCC class. For example, the 145 mapping units present in the soil survey of Wake County, North Carolina were reduced to 15 FCC units for fertility interpretations.

4. TropSoils soil-characterization projects have provided a vast array of soil profile data from tropical America, Asia, and Africa, serving to improve U. S. Soil Taxonomy. The leadership of Dr. S. W. Buol in the International Commission on Low Activity Clay Soils (ICOMLAC) helped to ensure that the changing classification of tropical Ultisols would remain compatible with the classification of Ultisols in the U.S. N.C. State University's participation in the International Commission on Oxisols (ICOMOX) and wetland soils (ICOMAQ) is strengthening the credibility of U. S. Soil Taxonomy as a worldwide system.

5. The recognition of downward movement of calcium and magnesium in acid soils as a means for long-term amelioration of acid subsoils by TropSoils researchers in Brazil and Peru led to the deterination that the same process occurs in Ultisols of North Carolina. This provides a better understanding of long-term maintenance of soil fertility.

6. TropSoils research on the screening of crop varieties for tolerance to soil acidity, conducted in Peru and Brazil, together with similar developments by CIAT in Colombia, led to the realization that the same can be done for crops in North Carolina, particularly for areas where subsoil acidity is a problem. State research projects were then conducted with sweet potatoes, beans, and peanuts. Some have involved NCSU plant breeders, who are now screening peanut varieties for soil-acidity tolerance and other desirable traits. This effort involves cultivars from Yurimaguas and the southern U. S., and field testing at Yurimaguas and North Carolina. The release of acid-tolerant cultivars in North Carolina is likely to increase their tolerance to drought because of their ability to develop roots in acid subsoils that have residual moisture.

7. Intercropping research conducted in Latin America raised the question of its applicability to North Carolina and the U. S. in general. Research on two North Carolina Coastal Plain sites demonstrated that strip intercropping of corn and soybean, or corn and snapbean, would increase overall yields by 15% under North Carolina conditions. The next step is to modify combines for harvesting strip-intercropping systems. Intercropping research also developed the concept of Area-Time Equivalency Ratio (ATER) which provides a more rigorous and realistic comparison of sequential vs. intercropping systems than the commonly used Land Equivalency Ratio (LER).

8. The development of a low-input soil-management philosophy for acid soils (published in *Advances in Agronomy*, 1981) has sparked interest in a combination of management practices that permit the use of alternative agriculture in North Carolina. Low-input studies have been used in an effort to help small farmers of North Carolina, who number about 50,000 and are mostly middle-aged and black. Projects are under way to test and transfer this technology to small farmers in both the Amazon and in North Carolina.

9. Faculty with TropSoils experience are frequently asked by North Carolina farmers and agribusiness people about opportunities abroad. First-hand knowledge of the tropics has enabled NCSU to provide quick, appropriate advice to this constituency.

10. Faculty with TropSoils experience are doing a more thorough job in teaching undergraduate and graduate courses, which broadens the understanding of our North Carolina and American students. Some of this information also reaches farmers on a regular basis, through programs of the North Carolina Agricultural Extension Service.

11. Faculty with TropSoils experience have been requested by several U. S. Agencies to assist in formulating national policy recommendations. Recent examples include participation in studies sponsored by the National Academy of Sciences, the Office of Technology Assessment of the U. S. Congress, USAID and the Department of Energy, on issues related to world food production, fertilizers, soil constraints, tropical deforestation, the global CO_2 question and low-input systems.

Publications, North Carolina State University

Al-jabri and M. K. Wade. 1985. Lime Reaction Rate and Effectiveness. Field Research Brief No. 10, Center for Soils Research, Bogor, Indonesia.

Alegre, J. C., D. K. Cassel, D. E. Bandy and P. A. Sanchez. 1985. Effect of land-clearing on soil properties of an Ultisol and subsequent crop production in Yurimaguas, Peru. In: R. Lal, P. A. Sanchez and R. W. Cummings, eds. Land-clearing and Development in the Tropics. Amsterdam: Bakelma Publishers.

Alvarado, A. and S.W. Buol. 1985. Field estimation of phosphate retention by Andepts. *Soil Sci Soc. Am. J.* 49: 911-914.

Ayarza, M.A. and P.A. Sanchez. 1985. Effect of sulfur in solution on dry matter and tannin content of *Desmodium ovalifolium*. NCSU Phytotron 1984 Report pp 38-42.

Ayarza, M.A. y R. Dextre. 1985. Manejo de Pastos. CIPA XVI Estación Experimental de Yurimaguas. Serie de Separatas No. 12. INIPA, Yurimaguas, Peru, 23 pp.

Bandy, D.E. and P.A. Sanchez. 1986. Post-clearing soil management alternatives for sustained production in the Amazon, pp 347-362. In: R. Lal, P.A. Sanchez and R.W. Cummings Jr. Land Clearing and Development in the Tropics. Amsterdam: Balkema Publishers.

Bastos, J.B. and T.J. Smyth. 1985. Adubação com micronutrientes para milho e caupi em Latossolo Amarelo argiloso do Amazonas. Pesquisa em Andamento No. 62. Manaus, EMBRAPA-UEPAE. 4 pp.

Den Ouden, G.G. 1985. Mycorrhiza. Report of B.S.C. National College for Agriculture, Tropical Section, Deventer, Netherlands, and Soil Science Department, N.C. State University. 120 pp.

Fahmuddin Agus, M. K. Wade and Jusuf Prawirasumantri. 1985. Effects of post-clearing methods on soil properties and crop production. Field Research Brief No. 18. Center for Soils Research, Bogor, Indonesia.

Gill, D. W., A. Kasno, and S. Adiningsih. 1985. Response of upland rice and soil K levels to K fertilization and green manure applications at Sitiung V. Field Research Brief No. 8, Center for Soils Research, Bogor, Indonesia.

Lins, I.D.G., F.R. Cox and J.J. Nicholaides II, 1985. Optimizing phosphorus fertilization rates for soybeans grown on Oxisols and associated Entisols. *Soil Sci. Soc. Am. J.* 49:1457-1460.

M. P. Gichuru. 1986. The management of phosphorus, calcium and magnesium in low-input cropping systems in the humid tropics. Ph.D. Thesis, North Carolina State University, Raleigh, 182 pp.

Makarim, A. K. 1985. Effects of land reclamation management practices on crop production and physical and chemical properties on a tropical soil. Ph.D. thesis, North Carolina State University, Raleigh, 163 pp.

McCollum, R.E. 1985. Dinámica de los nutrientes en el suelo en sistemas de cultivas múltiples con relación al uso eficiente de fertilizantes. CIPA XVI-Estación Experimental de Yurimaguas. Senédi Separatas No. 10. INIPA, Yurimagnas, Peru. 41 pp.

Newman, L. J. 1985. Ultisol dominated landscapes in the Amazon Basin of southeastern Peru. Master's thesis, N.C. State University, Raleigh. 107 pp.

Nicholaides, J.J., D.E. Bandy, P.A. Sanchez, J.R. Benites, J.H. Villachica, A.J. Coutu and C. Valverde. 1985. Agricultural alternatives in the Amazon Basin. Bioscience 35(5):279-285.

Pérez, J. M. 1984. Determinación de fenotipos de *Gulielma gasipaes* Bailey (Pijuayo) en la Zona de Yurimaguas, Loreto. Tesis Ing. Forestal, Universidad Nacional de la Amazonia Peruana, Iquitos, Peru. 84 pp.

Poutanen, M. 1985. Agroforestry in tropical land use with special reference to the Peruvian Amazon. University of Helsinki, Institute of Development Studies. Report 9/1985. B., 111 pp. Helsinki, Finland.

Reátegui, K., M.A. Ara, and R. Schaus. 1985. Evaluación bajo pastoreo de asociaciones de gramineas y leguminosas forrajeras en Yurimaguas, Peru. Bol. Pasturas Tropicales (CIAT). 7(3):11-14.

Sanchez, P. A. 1985. Fertilizers make continous cropping possible in the Amazon. *Better Crops International I* (July 1985) 12-16.

Sanchez, P. A. and S. W. Buol. 1985. Agronomic taxor.omy for wetland soils. pp 207-208. In: Characterization, Classification, and Utilization of Wetland Soils. IRRI, Los Baños, Philippines.

Sanchez, P. A., C. A. Palm, C. B. Davey, L. T. Szott and C. E. Russell. 1985. Tree crops as soil improvers in the humid tropics? pp. 331-362. In: M. G. C. Cannell and J. E. Jackson, eds. *Attributes of Trees as Crop Plants.* Institute of Terrestrial Ecology, Huntingdon, UK.

Smyth, T.J. 1985. Métodos de applicaçao de fosforo e naiaveis criticos de P disponiveis para milho e caupi em Latossolo Amarelo muito argiloso. Relatório de Projeto de Pesquisa. Manaus, EMBRAPA-UEPAE. 12 pp.

Smyth, T.J. 1985. Definiçao e correçao cronologica de deficiencias nutricionais para culturas anuais em Latossolo Amarelo muito argiloso. Relatório de Projeto de Pesquisa. Manaus, EMBRAPA-UEPAE. 18 pp.

Smyth, T. J. and J. B. Bastos. 1984. Adubação potássica para milho e caupi em Látossolo Amerelo alico do Estado do Amazonas. In: EMBRAPA-CPATU Documentos, 31. pp. 191-2. Nov. 12-17, 1984. Belaam, Brazil.

Smyth, T.J. and J.B. Bastos. 1985. Adubação fosfatada para milho e caupi em Latossolo Amerelo alico do trópico úmido. *Pesquisa Agroecuaria Brasileira* (in review).

Smyth, T.J. 1985. Avaliação de fontes de adubação organica nas produtividades de milho e caupi, em Latossolo Amarelo argiloso. Relatório de Projeto de Pesquisa. Manaus, EMBRAPA-UEPAE. 13 pp.

Smyth, T.J. 1985. Resposta do guaranazeiro a aplicação de nitrogenio, fosforo, potassio e magnesio em Latossolo Amarelo muito argiloso. Relatório de Projeto de Pesquisa. Manaus, EMBRAPA-UEPAE. 9 pp.

Swift, M.J. and P.A. Sanchez. 1984. Biological management of tropical soil fertility for sustained productivity. Nature and Resources 20(4):1-9. (Also in Spanish and French).

Wade, M. K. and Heryadi. 1985. Effect of green manuring on food crop response to lime and P fertilization. Field Research Brief No. 2, Center for Soils Research, Bogor, Indonesia.

Wade, M. K. and D. Santoso. 1985. Phosphorous rates and methods of application. Field Research Brief No. 14, Center for Soils Research, Bogor, Indonesia.

Wade, M. K., E. J. Kamprath and D. Santoso. 1985. Residual and maintenance rate for lime. Field Research Brief No. 15, Center for Soils Research, Bogor, Indonesia.

Wade, M. K. and Al-jabri. 1985. P fertilization and maintenance. Field Research Brief No. 9, Center for Soils Research, Bogor, Indonesia.

Wade, M. K. and D. Santoso. 1985. Phosphorous rates and methods of application. Field Research Brief No. 3, Center for Soils Research, Bogor, Indonesia.

Wade, M. K. and Al-jabri. 1985. P fertilization and maintenance. Field Research Brief No. 1, Center for Soils Research, Bogor, Indonesia.

Humid Tropics

University of Hawaii

The primary goal of the TropSoils/Indonesia program is to uncover principles of soil management that will enable resource-poor farmers to 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 and crop-simulation models.

The project's research area is the 100,000 ha Sitiung transmigration site in West Sumatra, Indonesia, where 6,000 transmigrant families and 1500 indigenous families live. 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 rainforest 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 ha of recently cleared land, and a year's supply of food, fuel, seed, and fertilizer awaited each family upon its arrival. Since then, five additional areas in Sitiung (Sitiung II — VI) 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 less desirable lands of the dissected peneplain.

While most of the work described in this report has been conducted to find solutions to soil-elated problems confronting Indonesian farmers, the research has also been designed to produce results transferable to other locations. The use of crop-simulation models and systems-based research, developed in collaboration with scientists of diverse backgrounds and expertise, helps ensure that the results of these studies will apply in a wide range of environments, in the U.S. and in the humid tropics worldwide.

Contents

Site Characterization: Soil Variability

Soil variability over short distances is common throughout the tropics, and especially on newly cleared land in the Sitiung transmigration area of Sumatra, Indonesia. This variability complicates agricultural experiments and the management of farmers' fields, and occurs over distances too short for consideration by traditional soil-survey methods. The studies reported here apply the theory of regionalized variables, which was developed by mining engineers to extract the maximum amount of information from a minimum amount of sampling data. The sample data were used to generate a semi-variogram, which displays the spatial dependence among neighboring samples. Information from the semi-variogram can be used to estimate values of soil properties in unsampled locations, so that problem areas can be identified.

Soil Variability in Forest Land Mechanically Cleared

Russell S. Yost, University of Hawaii
Bruce Trangmar, University of Hawaii
Goro Uehara, University of Hawaii
Michael Wade, North Carolina State University

The objectives of these studies were 1) to construct semi-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 determined 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 means of managing such variability in field research and in farmers' gardens and dry-land fields.

Patterns of Soil Variability

Work toward the first three objectives has comprised two parts: 1) mapping and display of macroscale or regional variation in soil chemical and physical properties that would provide some indication of the representativeness of the experimental sites; and 2) mapping and determining the cause of the considerable microscale soil variability that has severely hindered field experimentation. These two activities primarily differ in scale. In the first case an area of about 100,000 ha was considered (anisotropic kriging) while for the second case an area of about 800 m² (co-kriging) was considered.

Anisotropic Kriging

Spatial and temporal interactions of the soil-forming factors and processes determine the distribution of soil properties in a landscape. These spatial processes are sometimes more effective in some directions than others (i.e. they are not isotropic), yet current methods of interpolation assume isotropy. The purpose of this study was to determine the importance of considering directional effects in making regional estimates of soil properties and in maps developed from such estimates.

Results

This study related anisotropic spatial dependence of particle size fractions, pH and 25% HCl-extractable

Table 1. Soil chemical properties of the various terrain units within a 28m x 28m experiment.

Soil Porperty	Burn Sites (n = 26)	Surrounding Soil (n = 87)	Exposed Subsoil (n = 24)	Range in Values
ph	5.0a*	4.4b	4.1c	3.4 — 6.3
Organic C (%)	3.9a	3.4a	2.9a	0.2 — 7.2
Total N (%)	0.27a	0.24a	0.22a	0.07— 0.49
$NaHCO_3$)-P (mg/kg)	13a	9b	7c	2.0 —29.2
Exchangeable Cations (cmol(p+)kg)				
Ca	3.9a	1.6b	0.6c	0.0 —11.2
Mg	1.4a	0.6b	0.2c	0.0 — 3.2
K	0.5a	0.3b	0.2c	0.1 — 1.4
A1	1.3b	2.4a	2.8a	0.0 — 6.3
Sum (ECEC)	6.9a	4.8b	3.9c	2.8 —15.3
Al Saturation (%)	26c	54b	73a	0.0 —94
Cu mg/kg	2a	2a	2a	1 — 6
Zn mg/kg	3a	2b	1c	1 —11

a* Means within a row followed by the same letter are not significantly different (P=0.05) according to Student's test. T tests were performed on log transformed values of all properties except pH, Mg, Al and Al saturation. Arithmetic means reported for pH, Mg, Al and Al saturation, while means reported for log transformed properties are those reexpressed in terms of the original data using equations of Haan (1977)

P to directional differences in the main soil-forming factors in Sitiung, West Sumatra, Indonesia.

Previous studies of regional variation in Sitiung showed that sand content of soils was higher and silt content lower on the peneplain compared to the Quaternary terraces and floodplains. There was no clear pattern of differences in clay content among geomorphic units. Soil pH and levels of HCl-P decreased from younger to older surfaces as the intensity of soil weathering increased. Changes in soil properties across geomorphic boundaries were generally gradational and continuous.

Fitting the anisotropic model semi-variance increased with distance, indicating a decrease in spatial dependence with increasing distance. In isotropic conditions this relationship was independent of direction. With anisotropic variation the direction must be included in the equation relating semi-variance with distance. The description of anisotropy is given by the following equation:

gamma (h) = C(theta(i)) + w(theta(i))h (1)

where gamma(h) is the semi-variance in distance h, C(theta(i)) is the nugget variance of the semi-variogram in direction theta(i), and w(theta(i)) is the slope in direction theta(i).

The four directional semi-variograms of each property had similar nugget variances, but slopes that varied with direction. This indicated the presence of geometric anisotropy for each property.

Geometric anisotropy gives an ellipsoidal neighborhood of spatial dependence elongated in the sector of minimum variation and compressed in the sector of maximum variation. The directional semi-variogram with the steepest slope (shortest range of spatial dependence) marks the sector of maximum variation while that of the least slope (longest range) indicates the sector of minimum variation.

The linear geometric anisotropic model fitted to the pooled semi-variances of four directions of topsoil sand is shown in Figure 2. Each experimental semi-variance value was plotted with a symbol indicating the 45 degree of the two-dimensional semi-variogram in which it lies. The solid lines are those of the maximum and minimum slope defining the envelope of the fitted anisotropic model.

Detrimental Effects

The range of spatial dependence in any direction, theta, was assumed to be the distance (h) at which gamma equalled the sill value or general variance. The estimated range of sand was shortest (5.9 km) for the semi-variogram calculated in the sector of maximum variation (NE-SW) and longest (20.8 km) in the sector of minimum variation (NW-SE).

Semi-variograms for the E-W and N-S sectors had intermediate ranges (13.6 km, 6.6 km, respectively). In contrast, the range would have defined a circular spatial dependence neighborhood of 10.0 km if topsoil sand had been assumed to vary isotropically.

The slopes estimated by w(theta) for the pooled semi-variance of topsoil sand and HCl-P in the four principal directions are listed in Table 2 for comparison with slopes (m(theta)) estimated directly for the individual directional semi-variograms. The agreement is generally good.

The parameter estimates of eq. (1) fitted to the pooled semi-variance of the particle size fractions are listed in Table 3 and for pH and HCl-P in Table 4. The anisotropic model generally provided a good fit to each property as indicated by the significant R2 values. The model slightly underestimated slopes of clay, pH, and subsoil HCl-P in directions of minimum variation. Only for subsoil silt did the model provide a marginal fit.

Anisotropic semi-variogram modeling enables the identification of changes in spatial dependence with direction which, in turn, reflects soil-forming processes. The estimated direction of maximum variation (phi) of all properties lies in a sector 7 to 28 degrees east of north. The direction of minimum variation occurs at right-angles in a sector 97 to 118 degrees (ESE-NNW).

Anisotropy of the textural component is largely caused by directional effects of volcanic tuff fallout and

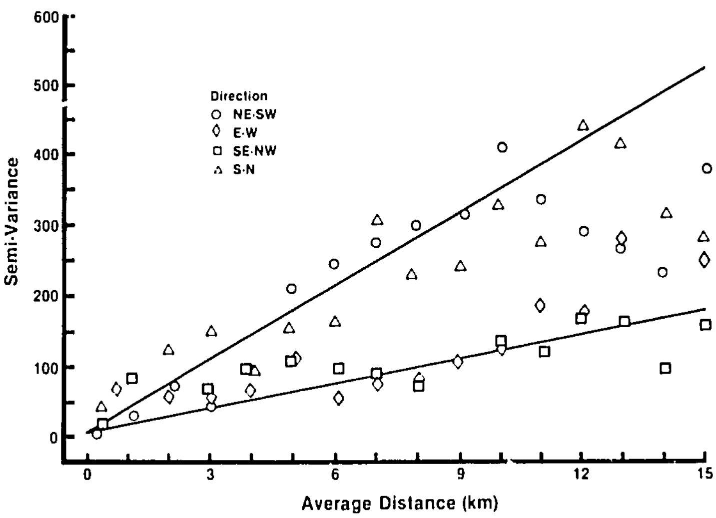


Figure 1. Linear geometric anisotropic model for semi-variances of topsoil sand for four directions.

deposition of alluvium by the major rivers. The SSW to NNE direction corresponds to the main axis of tuff deposition from the acidic volcanoes of the Braisan mountains to the southwest of the study region. Sand content is highest close to the tuff source along the southwest margin of the region and decreases to the north and northeast. Conversely, silt and clay contents of soils are generally lowest in the southeast, but increase to the northwest.

The sector of minimum variation (97 to 118 degrees) occurred at right angles to the direction of tuff fallout and also coincides with the main axis of the Batanghari River. The gentle gradient and low sediment load of the Batanghari River apparently has resulted in small downstream variation in particle size of suspended sediment. Alluvial materials of the low Quaternary terraces and floodplains deposited in this direction are relatively uniform in sand, silt and clay contents. Lateral variation of textural components over short distances in flood deposits away from the Batanghari River may also add to the anisotropy.

Effects on Soil Texture

The E-W and SE-NW direction semi-variograms for sand, silt and clay were generally more continuous and more highly structured than those in the NE-SW and N-S directions. Semi-variograms in the latter two directions showed a periodic or "hole effect" pattern of variation at lags of 10 and 11 km. This was probably

Table 2. Slopes of semi-variograms of topsoil sand and HC1-P estimated for each direction separately, M_i[a]), and from pooled semi-variances after fitting a geometric anisotropic model, $w(theta_i)$[b].

Direction, theta (degrees E of N)	Slope m_i	$w(theta_i)$
	Sand(%)	
45	38.4	35.0
90	16.6	15.3
135	15.3	11.8
180	30.5	31.5
	(HCl-P (mg. kg-1)))	
45	0.099	0.082
90	0.041	0.036
135	0.022	0.036
180	0.094	0.082

a. m* = slope of the linear model.

b. $w(theta_i)$ = Acos²(theta-phi) + Bsin²(theta-phi) where theta is the direction in which the semi-variance is estimated; phi is the direction of maximum slope A; and B is the slope of the semi-variogram at 90º) to phi.

Table 3. Parameter estimates of equation fitted to pooled semi-variance of particle-size fractions.

Parameter	Property: Sand (%)	Silt (%)	Clay (%)
Mean	16	26	58
Variance, s^2	212.8	213.5	201.4
Nugget Variance, Co	6.4	31.0	64.9
% of sill	3	15	32
Max. Gradient	37.5	58.2	37.9
Min. Gradient	9.3	19.3	8.7
Anisotrophy Ratio	4.0	3.0	4.4
Direction of Maximum Gradient, phi	27.6	7.3	29.3
R^2 of Model	0.89	0.81	0.69
Degrees of Freedom	58	19	26

a. Semivariance = Co + Acos²(theta-phi) + Bsin²(theta-phi)•h

b. $R^2 = (SS_C - SS_R/SS_C$. All R^2 values were significant at $P < 0.01$, except for subsoil silt which was significant at $P < 0.05$.

Table 4. Parameter estimates of the geometric anisoptropic equation fitted to pooled semi-variance of pH and HCl-P (0—15 cm depth).

Parameter	Property: pH	HCl—P
Mean	4.5	107
Variance, s^2	0.19	0.59
Nugget Variance, Co	0.05	0.25
% pf Sill	26	42
Max. Gradient	0.05	0.10
Min. Gradient	0.02	0.03
Anisotropy Ratio	2.4	3.5
Direction of Maximum Gradient, phi	11.3	22.9
R^2 of Model	0.73	0.56
Degrees of Freedom	15	28

a. Semivariance = Co + Acos²(theta-phi) + Bsin²(theta-phi)•h where theta is the direction in which the semi-variance is estimated; phi is the direction of maximum slope A; and B is the slope of the semi-variogram at 90° to phi.

b. Semivariance for HC1-P determined on log trfansformed values

c. $R^2 = SS_C - SS_R/SS_C$
All R^2 values were significant at $P < 0.01$.

caused by low values of sand on the Quaternary terraces and Batanghari floodplain in the north and Jujuhan floodplain in the south with higher values on the peneplain in between. Complementary amounts of finer materials in these areas also explain similar periodic semi-variograms of silt and clay at this distance in the NE-SW and N-S directions. The NE-SW and N-S semi-variograms for topsoil (Figure 2) and subsoil sand exceeded the general variance, s, indicating the presence of a weak trend in these directions.

Linear geometric anisotropic models were fitted to pooled directional semi-variances for each of these properties. Directions of maximum variation coincided with the main southwest to northeast axis of volcanic tuff fallout, deposition of alluvium and the general sequence of soil weathering in the region. Ranges of spatial dependence for each property were shortest (2.6 km for pH) in the direction parallel to this axis and longest (20.8 km for sand content) at right angles to it. Anisotropy ratios ranged from 1.5 for subsoil sand to 5.2 for subsoil HCl-P. Topsoil textural components and pH were more variable than in subsoils, having larger sample variances and larger anisotropy ratios. Punctual kriging of topsoil sand content using the linear geometric anisotropic model resulted in low estimation variances in densely sampled areas where weighting of neighbor samples by direction as well as distance took most effect.

Structural analysis of soil variation using geostatistics can aid understanding of the spatial distribution of soil properties and identifying the spatial effects of soil-forming factors and processes on soil genesis. In this study, geostatistical analysis of textural components, pH and HCl-extractable P indicated that anisotropy of these properties in Sitiung, West Sumatra was directly related to directional deposition of volcanic tuff materials and alluvium, and to the regional sequence of soil weathering.

Co-kriging of Chemical Variables.

In soil science certain variables are much more easily measured than others. In some cases there may be data available for certain variables but not for other variables that were subsequently determined to be necessary or critical to the major soil constraints in the area. The method of co-kriging permits making estimates of one infrequently measured variable, based on spatial correlation with another variable that is more easily or less costly measured.

Co-kriging extends the principle of optimal estimation using regionalized variable theory from that of a single property to situations where there are two or more co-regionalized ones. Co-kriging is most efficiently used where one variable may not have been sampled sufficiently (due to high cost, experimental difficulties, etc.) to provide estimates of acceptable precision.

Estimation precision can be improved by utilizing the spatial correlation between the undersampled primary variable and the other more frequently sampled covariables.

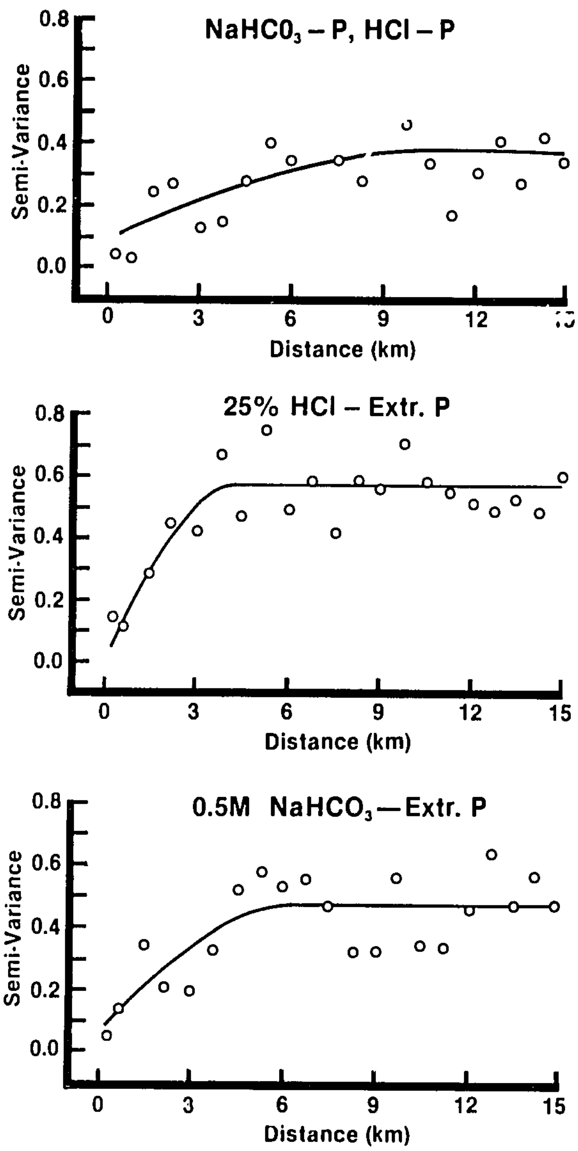


Figure 2. Isotropic cross-variogram (upper graph) and auto semi-variograms (lower two graphs) for log transformed values (mg/L) of 25% HCl -extractable P and 0.5M $NaHCO_3$ extractable P, 0 to 15 cm depth.

Results

In Indonesia P extracted with 25% HCl is commonly used as an indication of soil weathering status in unfertilized areas. Phosphorus extracted with 0.5M $NaHCO_3$ is often regarded as a measure of plant-available P in soils, making it more useful for agronomic interpretation of soils than HCl-P. During soil surveys in Sitiung, West Sumatra, Indonesia, 0.5M $NaHCO_3$-P was undersampled relative to HCl-P. Therefore 0.5M $NaHCO_3$-P was selected as the primary variable and HCl-P was selected as the covariable. The respective semi-variograms and cross-variogram are shown in Figure 2.

The map of co-kriged values for $NaHCO_3$-P showed a similar regional pattern but more local detail than that achieved by kriging from $NaHCO_3$-P samples alone. Co-kriging reduced estimation variances by up to 40% in areas where sampling density of $NaHCO_3$-P was lowest. Co-kriging variances exceeded those of kriging by up to 10% in areas where sampling density of $NaHCO_3$-P was high. In such cases, the covariate HCl-P had little effect on the interpolated value but still added a component to the estimation variance. Co-kriging could not be used to interpolate values for extreme locations where there were no $NaHCO_3$-P sampled within the radius of the kriging neighborhood.

A prerequisite for interpolation using co-kriging is the presence of a well-structured cross semi-variogram with low nugget variance. The apparent difficulties of obtaining such relationships indicates that co-kriging may be restricted to interpolation of very well-structured variables.

Being a widely used measure of plant-available P, $NaHCO_3$-P is of more interest for agronomic interpretation of soil P status than the more densely sampled measure of HCl-P. The co-regionalization of the two P measurements was exploited using co-kriging to interpolate topsoil $NaHCO_3$-P at 268 unsampled locations on a 2 km by 2 km grid across the study area. Fifty-two samples of $NaHCO_3$-P and 107 samples of HCl-P were used in the co-kriging operation.

Areas of Low Available P

The isarithmic map of co-kriged $NaHCO_3$-P shows that topsoils in 84% of the study area have less than 15 mg/kg $NaHCO_3$-P, a commonly used critical value of adequate P nutrition in many crops grown on acid, upland tropical soils. The sample areas with greater than 15 mg/kg coincide with young alluvial soils and areas recently fertilized prior to sampling. Soils in the east of the region appear very P deficient having less than 5 mg/kg $NaHCO_3$-P.

Isarithmic map of NaHC03-P obtained by auto punctual kriging from 52 samples was similar to that achieved by co-kriging, but local detail gained by utilizing the 107 covariate samples of HCl-P was absent.

The percent reduction in estimation variance achieved by co-kriging (Gamma) relative to that of auto krig-

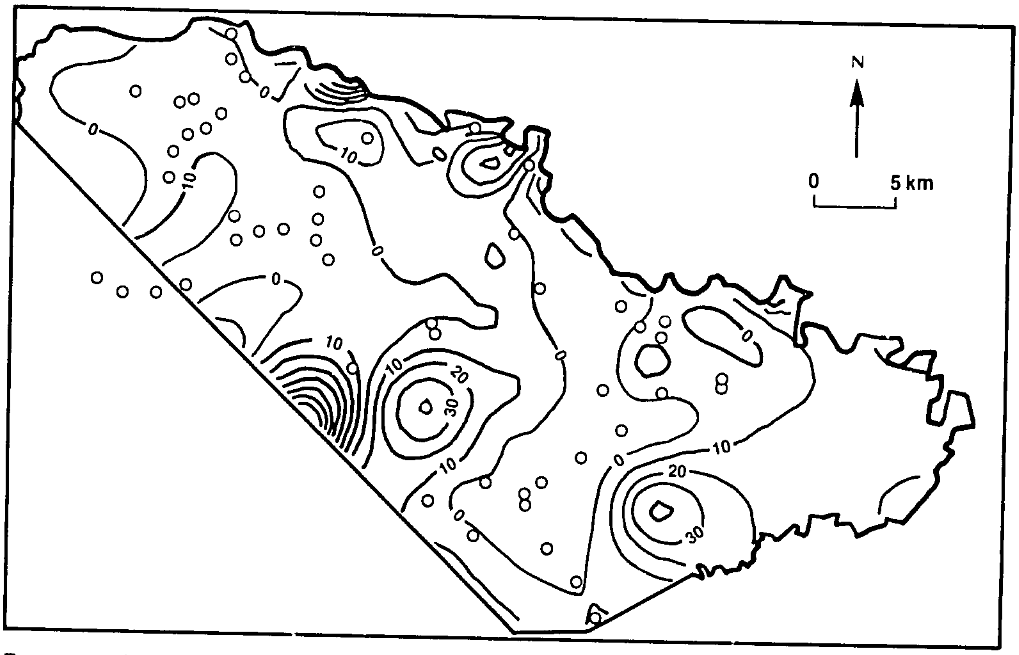


Figure 3. Percent reduction in estimation variance by co-kriging topsoil 0.5M $NaHCO_3$-extractable P relative to kriging. Circles indicate sample locations of $NaHCO_3$-P.

ing was determined as (1-SCK/SK) x 100 and is shown in Figure 3. (SCK = estimated variance associated with co-kriging; SK = estimated variance associated with kriging.) Positive values indicate the percent improvement in estimation precision while negative values indicate the decrease in precision obtained by co-kriging.

Co-kriging improved estimation precision by up to 40% for locations where there were few samples of $NaHCO_3$-P but relatively more HCl-P samples. Smaller estimation variances were obtained by co-kriging in such areas because the spatial correlation with another better sampled variable was taken into account. The percent reduction in estimation variance due to co-kriging was generally less than 10% and occurred for about 60% of the 260 kriged locations.

Estimation variances were not reduced by co-kriging in areas where $NaHCO_3$-P samples were concentrated. These locations are bounded by the 0 to -10% contour lines in Figure 3. Each kriging location in these areas had several neighboring samples so $NaHCO_3$-P received most of the weighting in solving the co-kriging equations. Under these conditions, the covariable (HCl-P) added another variance component to the estimation without causing much or any improvement to the overall estimation precision. As a result SCK exceeded SK. The relative increase in SCK over SK was generally less than 10% but occurred over about 40% of the region. The large negative values along the southwest margin of the region mark one location for which there was only one sample of each P measurement, causing instability of the co-kriging matrices and unreliable interpolation.

Data Requirements for Co-Kriging

The co-kriging system requires at least one sample point of both primary $NaHCO_3$-P and covariable HCl-P within the estimation neighborhood. The range of spatial dependence (6.3 km) of the $NaHCO_3$-P auto semi-variogram defined the search radius for samples of $NaHCO_3$-P and HCl-P to obtain the auto and cross semi-variances used in the weighting procedure of the co-kriging system. This radius resulted in between one and 13 neighbor samples of $NaHCO_3$-P for 234 of the 268 kriging locations. Co-kriging could not be performed at the remaining 34 locations because there were no $NaHCO_3$-P samples within 6.3 km of the kriging location. Twenty-seven of these 34 locations occurred in the eastern end of the region. The remaining seven locations occurred along the southwest margin and in the central area. Estimates of $NaHCO_3$-P at these locations could be just as reliably estimated using simpler techniques such as the sample mean, or by kriging values for HCl-P and then obtaining $NaHCO_3$-P values by regression analysis. A radius of

Table 5. Spatial dependence of soil properties highly correlated with rice plant height and dry matter yield.

Soil Property	Range of Spatial Dependence	Correlation: Plant Height At 60 Days	Stover Dry Weight	Grain Dry Weight
	m			
pH	4.1	0.51	0.44	0.38
Exchangeable Cations:				
Ca	No Pattern	0.56	0.55	0.49
Mg	4.3	0.52	0.45	0.40
K	No Pattern	0.41	0.38	0.46
Al	4.0	-0.55	-0.47	-0.41
Al Saturation %	3.9	-0.56	-0.51	-0.41
Zn (mg/kg)	<0.5	0.42	0.34	0.33
Plant Measures:				
Plant Height at 60 Days	19.9	—	—	—
Stover Dry Weight	15.3	—	—	—
Grain Dry Weight	18.5	—	—	—

All r values were significant at $P < 0.01$ unless otherwise indicated. ns = nonsignificant at $P = 0.05$.

6.3 km gave between one and 30 samples of HCl-P for all kriging locations.

These results demonstrate the sensitivity of co-kriging to the relative spatial distribution of primary and covariable sample locations. The irregular, nongeometric sampling scheme of this study is clearly nonoptimal from a co-kriging standpoint. Others have found that co-kriging consistently reduced estimation variances where primary and covariable properties were sampled in geometric patterns. Their results and the irregular improvement in estimation variance for this study indicate that a geometric scheme with samples of the primary variable regularly interspersed with covariable samples may be the optimum to gain maximum benefit from co-kriging. Clusters of the primary variable do not occur in such a scheme. As a result, the variance-reducing effects that accrue from using the better sampled covariable are not hindered in the interpolation. Design of such schemes can be improved by prior knowledge of the two variables' spatial covariance, which can be determined from reconnaissance data. Such data may be most economically obtained from samples collected over a range of spacings along transects parallel to, and also at right angles to, the apparent direction of maximum variation.

Variability and Crop Yields

A fourth objective of these studies, as stated previously, was to discover ways of managing soil variability in fields, gardens and research plots. The primary activities were to map soil microvariability and to determine factors causing yield reduction of rice, cassava, and peanut.

The identification of the causes of microscale (2 m or less) variability and options for dealing with it are fundamental to the entire research effort in the TropSoils/Indonesia project. Previous field research has led to inclusive results because of such variability.

The approach adopted to examine this variability was based in part on concepts of geostatistics and in part on concepts of the traditional uniformity experiment. A parcel of previously cleared land which is representative of the high soil variability was selected for a continuing study of the nature and sources of such variability.

A series of crops were planted across the unfertilized and untilled field. Plant growth and nutrient composition were monitored to identify the sources of variability. This design, in effect, utilizes the crop as the experimental material and the soil's potential to support plant growth becomes the experimental treatments. The soil was also sampled intensively in order to identify the chemical and physical variation.

Results

As indicated in the Tables 1, 5, 6 and 7 and in various regression relationships, extractable acidity (Al + H) and exchangeable cations accounted for most of the soil-chemical related variance in growth and yield components of the first rice crop. Lower levels of Al saturation and higher concentrations of exchangeable cations in burned sites coincided with larger plants, higher stover and grain yields compared to those grown on exposed subsoil areas. The ranges of spatial dependence (3 to 4 m) for soil acidity and exchange characteristics coincided with about one-half the distance between burned sites. Spatial dependence of plant height and yield components was also influenced by unidentified longer range sources of variation. Block kriged (for 1 m^2) rice grain yields ranged from 11 to 355 g/m^2 with estimation standard deviations ranging from 9 to 24 g/m, depending on the distance of interpolated cell from the sample locations.

Effects of Variability on Error

The effect of microvariability on precision of a field experiment was examined by laying out four replicates of seven potential treatments in a randomized complete block design across the site. Individual plot size was 4 m by 7 m. Sample values of grain yield and Al saturation from 1 m square cells in each plot were averaged to obtain means for each of the 28 plots. This

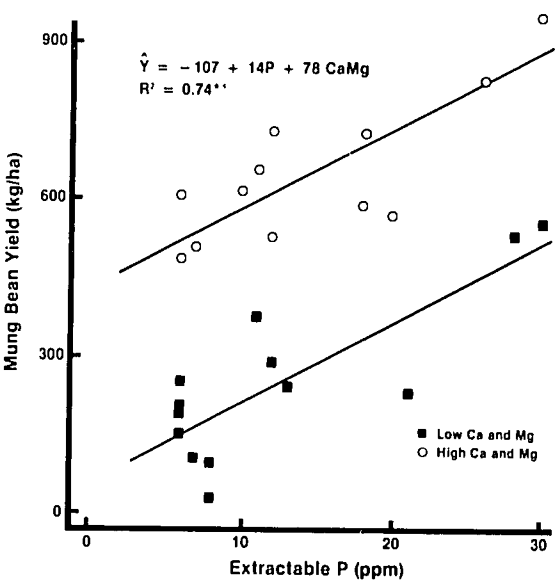


Figure 4. Mung bean yields as affected by extractable P at low and high levels of Ca and Mg.

is analogous to the common practice of bulking samples for analysis on a whole plot basis. A large experimental error (CV of 37%) resulted in nonsignificant differences among treatment means of yield estimates which ranged from 1.00 to 2.08 mg/ha with a Waller-Duncan LSD of 1.08 Mg/ha. Statistical analysis on a whole-plot basis masked the large within-plot variability of grain yield which ranged from 0.11 to 3.55 Mg/ha when considered on a 1 m square basis. Such variability was not shown by analysis of treatment means because the variation was averaged with each plot and because of the large error term which was partly due to significant variation among replicates. Similarly, the large variability of Al saturation (CV of 58%) within plots was masked by averaging on a whole plot basis.

As a further illustration of wi'hin plot variability, a P experiment was conducted in Sitiung V. The preliminary results of yields with mung bean showed so much scatter that the interpretation of response due to P was inconclusive. When microplots were subsampled for both crop yield and soil analysis, two general groups were identified, those with low Ca + Mg levels and those with high Ca + Mg levels. As shown in Figure 4, the response to P then was quite clear and significant. Mung bean yield increased linearly throughout the range of applied P.

Had there been no soil sample data upon which to segregate the low and high levels of Ca + Mg the conclusion of the analysis would certainly have been that no response was obtained to applied P. Observations such as this have become frequent in the field research efforts in the Sitiung region. This suggests therefore a strong need to sample both the crop and the soil when conducting field experiments in such highly variable soils.

Table 6. Effects of soil variability on yield of upland rice, peanut, and cassava among terrain units.

Plant Property	Burn Sites (n = 26)	Surrounding Soil (n = 87)	Exposed Subsoil (n = 24)
Rice			
Plant Height (60 days), cm	92.5a	78.5b	71.2b
Stover Weight, g/m^2	328 a	234 b	193 b
Grain Dry Weight, g/m^2	227 a	166 b	146 b
Peanuts (Crop 1)			
Plant Dry weight, g/m^2	150 a	101 a	74.3b
Nut Weight, g/m^2	59.3a	33.9b	21.0b
Number of Pods $/m^2$	123 a	78.8b	56.9b
Number of Empty Pods/m^2	14.9a	15.0a	14.0a
Cassava (Crop 1)			
Tuber Weight	2476	2459	2067
Stem Weight	3013 a	2165 b	1945 b
Leaf Weight	243	225	215

a. Means within a row followed by the same letter are not significantly different (P = 0.05) according to Student's t test.

Table 7. Correlations of soil chemical properties of the various terrain units within a 28m x 28m experiment on crop growth.

Soil Property	Plant Height At 60 Days (cm)	Stover Dry Weight (g/m^2)	Grain Dry Weight (g/m^2)
pH	0.51	0.44	0.38
Organic C (%)	0.07ns	0.02ns	0.02ns
Total N (%)	0.09ns	0.11ns	0.14ns
$NaHCO_3$-P (mg/kg)	0.06ns	0.11ns	0.11ns
Exchangeable Cations $cmol(p^+)kg^{-1}$			
Ca	0.56	0.55	0.49
Mg	0.52	0.45	0.40
K	0.41	0.38	0.46
Al	0.55	0.47	0.41
Al saturation (%)	0.56	0.51	0.41
Cu mg/kg	0.07ns	0.09ns	0.12ns
Zn mg/kg	0.42	0.34	0.33

a. All r values are significant at $P < 0.01$ unless otherwise indicated. ns = nonsignificant at P = 0.05.

Soil Management and People

If new soil-management practices are to succeed, they must not only rectify mismatches between crops and soils, they must also be suited to the farmer, and matched to his or her resources. One of the difficulties with developing appropriate practices, and transferring them, is that people's preferences for crops vary, as do farm resources and the skills and backgrounds of the farmers.

The studies reported in this section have examined the knowledge, habits and perceptions of transmigrant and indigenous farmers, compiling a base of socioeconomic information about such things as family decision-making, time allocation, nutrition, crop preference, diets and income. Work aimed at improving soil-management practices in farmers' upland fields and home gardens has employed a direct collaboration with farmers. Some studies have been designed using farmers' suggestions, and conducted on farmers' fields.

In the course of these studies, researchers have been gleaning from their association with farmers the kinds of first-hand knowledge and "local wisdom" that will improve the transfer and applicability of research results. Such information, along with a close collaboration among faculty from universities in Indonesia, North Carolina and Hawaii, has contributed to a better understanding of how farmers respond to agricultural innovation.

Indigenous Knowledge Systems Related to Soil Management

Carol J. Pierce Colfer, University of Hawaii
Herman Agus, Center for Soil Research
Dan Gill, N. C. State University
Barbara Newton, University of Hawaii

Indigenous knowledge of soils is an important factor in the development and application of effective soil-management practices. This is especially true in areas like the transmigration sites of West Sumatra, Indonesia, where there are several ethnic groups. Because ethnic groups differ in the way they perceive soil-related problems, this project was planned to identify and map, according to ethnic group, indigenous concepts related to soil. The "Galileo" method was chosen as an efficient and reliable way to characterize people's views related to soil in a quantitative manner.

The study began with the tape-recording of open-ended interviews with ten individuals from each of the three main groups in the area (Sundanese, Javanese, and Minangkabau). Every effort was made to influence the respondents as little as possible as they responded to the question, "What is the relationship between soil and people?" The interviews were conducted in the respondents' native language.

In each ethnic group respondents were selected in such a way that the sexes were equally represented. Additional considerations included age, income, educational level, and, in the case of the Minang, clan affiliation. The interviews were analyzed to ascertain the recurrent concepts within each ethnic group. The Minang interviews have been translated into English for use by the American team members.

For two of the three ethnic groups, a survey instrument was constructed based on important, recurring concepts identified during analysis. This instrument pairs each concept with every other. The instrument was expanded to reflect the concepts that were important for one group and not for another. Twenty-one concepts were deemed sufficient to document and measure inter-ethnic differences in perceptions of soil as it relates to people.

Respondents were asked to "measure" the distance between the concepts, using a cognitive measuring stick. In this case the measuring stick was the distance between black and white, set at 100 units. Thus a respondent was asked, for example, "If black and white are 100 units apart, how far apart are soil and water?" "soil and tree crops?", "soil and rice?" The distances between concepts are averaged across a given population to provide a "cognitive map" of the domain of soil-people relations.

This instrument has been administered to 100 Javanese and 100 Minang respondents. Half the respondents were male and half female; an attempt was made in the selection of respondents to represent the diversity that exists in each of the locations (Koto Padang and Sitiung I Blok B). Interviews were conducted by two trained native speakers of Javanese and Minang, respectively.

The data have not yet been analyzed.

Initial Results

The most fundamental and useful results from the analysis will take the form of a triangular means matrix which shows the average distances between each concept and every other concept. Thus we will be able to compare variation in people's perceptions based on ethnicity and based on sex. The Galileo program uses these data as well to create eigenvectors, from which three-dimensional plots can be constructed to make these "cognitive maps" more appealing visually for policy-makers and people from other disciplines. There is also an "automatic message generator," included in the Galileo program, which may, among other things, help with soil-related extension efforts.

Most immediately, the interviews provided the 21 most frequently mentioned concepts related to soil and people. These were: soil, smallholder plantation/garden, upland field, wet rice field, home garden, rubber, fruits, rice, field crops, vegetables, water, fertilizer, pests, yields, cultivation, good, enough, I, male, female, government. The identification of these concepts alone is of interest, providing a firmer sense of people's normal assumptions related to soil.

The tendency for the Minang to discuss tree crops was in striking contrast to the transmigrants' propensity for discussing field crops and vegetables. Similarly, the concept of smallholder plantation/garden (kebun) was commonly mentioned among the Minang, whereas upland fields (ladang) were a mainstay for the transmigrants. The Minang, like the research team, have found themselves constrained by unpredictable rainfall, insects, plant diseases and poor soils when they have tried to grow field crops. Their solution seems to be to grow tree crops and wet rice.

The Minang experience with extension efforts is of interest. The research team learned that when the Minang planted hybrid rice varieties introduced by the government at the recommended spacing, the young rice stalks frequently collapsed whenever anyone walked through the field. Some bitterness was expressed about the fact that the government supplied nearby transmigrants with an irrigation system (and other projects, such as TropSoils), without adequate regard for the indigenous people.

The transmigrants similarly recounted woeful tales of their experience with field crops in Sitiung; but their previous experience was with these crops, and until June, 1985 the government required that transmigrant fields be used exclusively for food crops.

Intrahousehold Decision-Making

Carol J. Pierce Colfer, University of Hawaii
Evi Martha, Andalas University, Padang
Mira Elfina, Andalas University, Padang
Fahmuddin Agus, Center for Soil Research
Vickie Sigman, University of Hawaii
Stacy Evensen, University of Hawaii

Because applying new soil-management technology requires an understanding of how people will use that technology, it is important to know how decision-making is conducted in transmigrants' households. The objective of this study, conducted in Sitiung V Blok C, and Koto Padang, West Sumatra, was to ascertain the patterns of intrahousehold decision-making among Sitiung farmers, particularly as it pertains to soil and crop management.

Methods

The study of intrahousehold decision-making, though recognized as important, is in its infancy. No good methods have, in our estimation, been developed. To date, the research team has used two approaches. The first was to closely monitor the income and expenditures/consumption of four families in Sitiung V for a period of two and a half months. These families, who were also cooperating in on-farm trials, were interviewed every three days, with a structured interview relating to specific expenses and consumption. During the interview, an attempt was made to discuss their intrahousehold decision-making in an informal way, to better understand the process.

Progress has been constrained by the fact that the research assistants conducting the interviews, while diligent, lacked adequate formal training.

Data from the structured portion of the interviews were acceptable, but the open-ended component was not adequate. Andalas University supplied two undergraduate students who lived and worked in Koto Padang, a Minang community within the Sitiung area, from mid-June to the end of August, 1985. They were trained in participant-observation methods, and they developed questionnaires, focusing on intrahousehold decision-making, after they had been in the community for one month. One student selected a random sample of 30 households, stratified by the three neighborhoods in Koto Pandang. Her work focused on women's status, but she also interviewed 18 husbands (six in each neighborhood) on topics relating to the division of labor and decision-making.

Preliminary Results

In the first attempt (January-March, 1985), which included two Javanese and two Sundanese families in Sitiung V, the team found a full spread of decision-making within the family. The wife in one of the Javanese families was clearly the major decision-maker. Her husband was fearful of interacting with outsiders and she seemed fully in charge. The husband in one of the Sundanese families was quite dominant, basically deciding everything, including details of food consumption. The other two families appeared to manifest a joint decision-making pattern.

One point of interest is that the meagreness of resources in these families appears to reduce the decision-making potential. Money and even time frequently simply go for some obvious need related to subsistence or health, without anyone particularly choosing or deciding what to do with that resource.

The report from Koto Padang has yet to be translated into English. However, some of its most interesting findings follow (subject to revision on closer inspection of the data):

1. Seventy-five percent of the women interviewed reported being involved in some kind of income-generating activity (farmer, unskilled laborer, or petty merchant)
2. The reported involvement of Minang women in each of the nine steps in local wet rice production, from ground preparation through carrying the yields home, surpasses men's, except for spraying and carrying the rice home from the fields. Women's involvement in home gardening far surpasses men's in the planting and weeding activities, and slightly surpasses it in harvesting.
3. Men, on the other hand are more active in smallholder plantation activities, both in connection with the ADP rubber replanting project, and in private holdings with other tree crops.
4. Women expressed general ignorance about new

seeds, fertilizer and pesticide management (though in other interviews with men, the same ignorance has frequently been expressed). Unfortunately, only women were queried on the topic in this survey.

5. When queried on decision-making regarding seeds, fertilizer and pesticides, responses were fairly evenly distributed among the following family actors: wife (5), husband (4), couple (4), parents (5), and "do what others do" (4).

6. A group of questions on intra-family and inter-family decisions reveals a pattern of generally joint decisions, with slight male dominance (within the general Indonesian context of not forcing others).

Implications

One important reason for conducting this research stems from global concerns over the role of women in agriculture. While the fact that women are active farmers is now widely accepted, many maintain that women's labor is irrelevant, since the decision-making power remains with men. One purpose of this research is to establish whether this is in fact the case in West Sumatra. Our preliminary findings, reported above, suggest that women from both locations used in this study do have an active voice in agricultural decision-making. Results from decision-making studies will also be useful in applying technology such as the agroforestry trials planned in cooperation with transmigrants and the Minang, and in the creation of the farming-systems expert system discussed elsewhere in this report.

Collaborative Research With Farmers On Upland Fields

Carol J. Pierce Colfer, University of Hawaii
Mike Wade, N. C. State University
Carl Evensen, University of Hawaii
I Putu Gedjer Widjaja-Adhi, Center for Soil Research
Fahmuddin Agus, Center for Soil Research
Dan Gill, N. C. State University

Farmers arriving at transmigration sites must adjust to unfamiliar soils, climate and living conditions. Collaborative research with 14 transmigrants and five indigenous farmers in their upland fields has been conducted in order to gain insight into their concerns and needs, while developing appropriate and usable technology. The goals of this project are 1) to gain access to the knowledge and experience of the farmers in a practical, hands-on fashion, 2) to provide a testing ground for agricultural technologies that appear appropriate for the Sitiung area, and 3) to determine in an iterative manner the most important limiting factors affecting these farmers' production.

Progress in 1985

In response to the farmers' complaint that the control plots did not produce well, and the fact that the plan to plant mucuna as a green manure crop was not successful, the team harvested calapagonium from a nearby rubber plantation and distributed it to be used as green manure (10 T fresh/ha) on the control plots. The other treatments received only inorganic fertilizer. The government treatment was limed according to the government's liming program (3½ T/ha)

Table 1. Average rice grain yields from farmers' upland fields.

Treatment	Grain Yield (kg per 200 m_2 plot)
Control (green manure)	25
Gov't Recommendation	20
Rock Phosphate	24
Lime + NPK	27
	ns

and continued to receive 100 kg TSP and urea per ha. The rock-phosphate treatment was unchanged, also receiving the standard 100 kg TSP and urea per ha, in addition to the base application of 800 kg rock phosphate/ha, which was applied at the beginning of the trial. The lime treatment got a maintenance lime application of 0.5 T/ha as well as 200 kg TSP, 100 kg urea and 50 kg KCl/ha.

Table 1 shows the overall average yields of upland rice in farmers' fields. There are no significant differences among these yields and thus no real response to the lime and fertilizers. However, the control, with its application of green-leaf manure (GLM), performed remarkably well and produced interesting results.

Not all farmers handled their GLM in the same manner. Four farmers buried the material in furrows (plowed under); five spread the material and hoed it in, thereby mixing it with the soil but with partial exposure; four merely mulched the soil with the GLM; and two farmers failed to use it at all. When the GLM was not used the control yielded only 65% of the fertilized plots. Mulching or mixing of the GLM helped some, but the buried GLM was dramatically better.

Table 2 shows yields of peanut, the second crop in the season. Both of the limed treatments (second and fourth) gave the best results, which may be expected due to peanuts' specific requirement for Ca during pod fill. However, as in the rice crop, organic-matter management was critical. This time utilization of the rice straw had a strong impact on the peanut response to the fertility levels. Most farmers (7) burned the straw on the plots, while three removed the straw, and two incorporated it. When straw was removed, burned or incorporated, the control plots yielded 40, 71, and 110% respectively of the lime plots.

Table 2. Average peanut grain yields from farmers' fields.

Treatment	Grain Yield (kg per 200 m_2 plot)
Control (green manure)	11.0
Gov't Recommendation	15.5
Rock Phosphate	14.0
Lime + NPK	16.2
LSD .05 = 1.9	

The rambutan fruit trees, planted as a part of the collaborative research, were measured for height and diameter one year after transplanting. There has been no treatment effect on the initial growth of these young trees, as tree development seems to be more or less independent of fertility treatment and farmer practice.

Implications

The value of appropriately managed organic materials, either as GLM or crop residue, is apparent. These initial results strongly indicate the possibility of alleviating lime and fertilizer requirements by proper management of plant material. The need for more research as to how and why these relatively modest inputs can produce food-crop yields is obvious. Also, methodology or systems to produce this positive effect that would be feasible and practiced by farmers must be developed.

Time-Allocation Study

Carol J. Pierce Colfer, University of Hawaii
Russell Yost, University of Hawaii

Because transmigrant families generally invest their energies in the activities most critical to their welfare and survival, innovative farming practices are likely to be adopted only if the family's work habits and schedules can accomodate them. Information from time-allocation studies can be useful in predicting whether soil-management programs will meet farmers' needs. The objectives of this study, conducted in Sitiung I Blok A and Sitiung V Blok C, were 1) to quantify changes in the allocation of time in Sitiung, over the course of the project, and 2) to help in evaluating the impact of project activities on the lives of farmers in the immediate vicinity of TropSoils research.

The study used a randomized schedule of visits to settlers' homes over a year. Data were analyzed according to division of labor by sex; division of labor between agricultural and other income-producing activities; division of labor among the various agricultural activities possible; seasonal variation in labor allocation; leisure time available; time spent on providing feed for animals; and variation among the different locations within Sitiung. Activities in 1985 focused on analysis and presentation of the data.

Farming, Labor and Leisure

Figures 1-3 show seasonal variation in Sitiung I and V, with regard to allocation of time to agriculture, paid or contract labor (including home industry), and

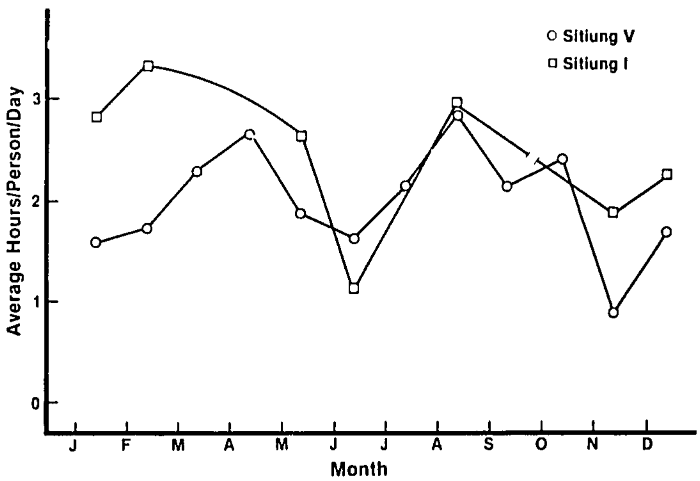


Figure 1. Seasonal variation in Sitiung I and V with regard to allocation of time for agriculture.

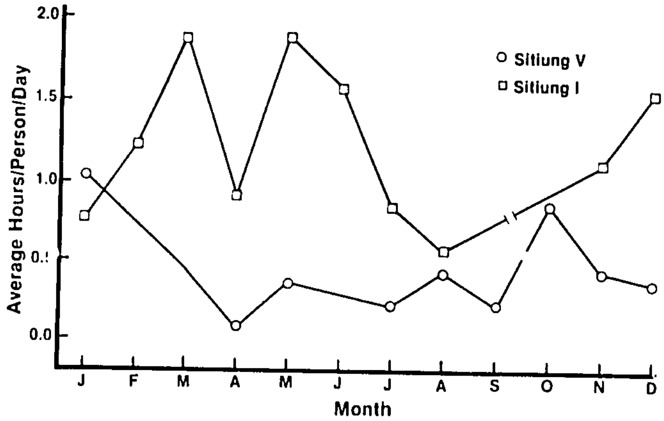


Figure 2. Seasonal variation in Sitiung I and V with regard to allocation of time for paid or contract labor.

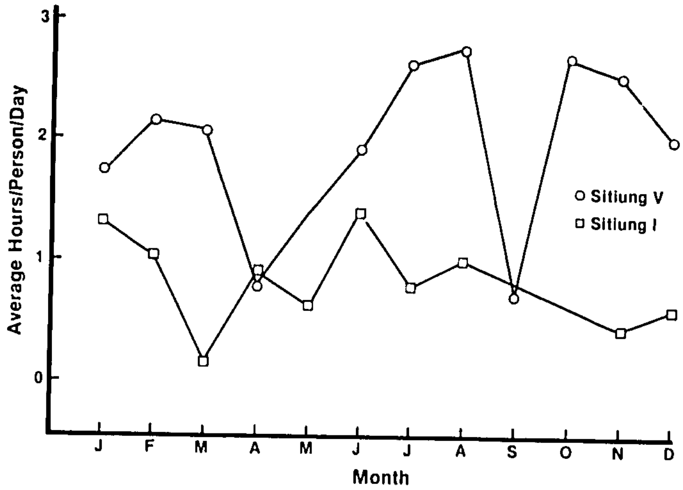


Figure 3. Seasonal variation in Sitiung I and V with regard to allocation of time for leisure.

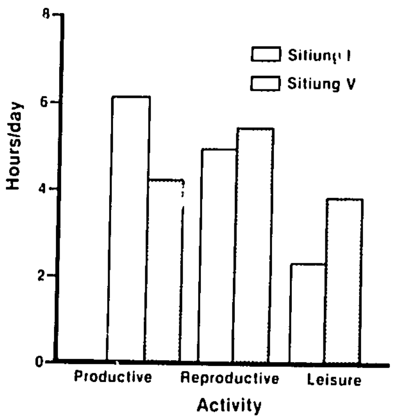


Figure 4. Divisions of adult labor among activities.

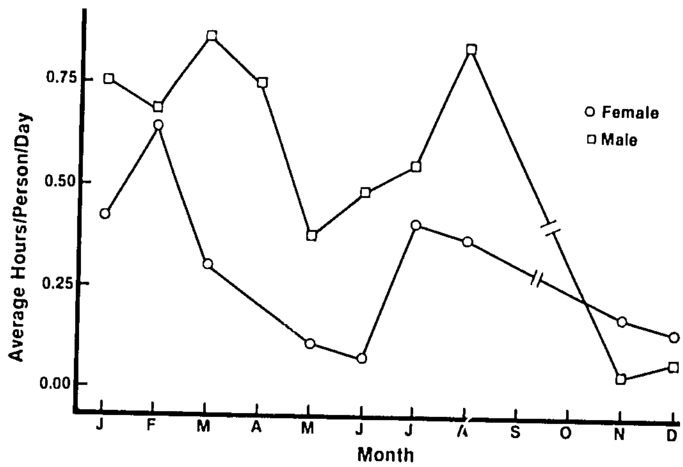


Figure 5. Seasonal variation in allocation of labor to upland fields (ladang) of Sitiung I.

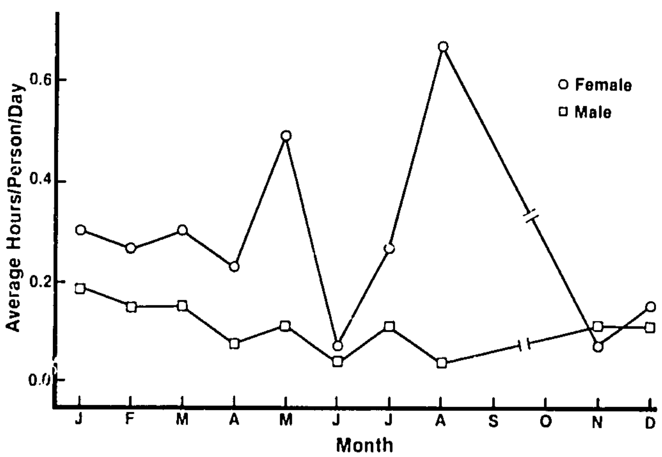


Figure 6. Seasonal variation in allocation of labor to home gardens in Sitiung I.

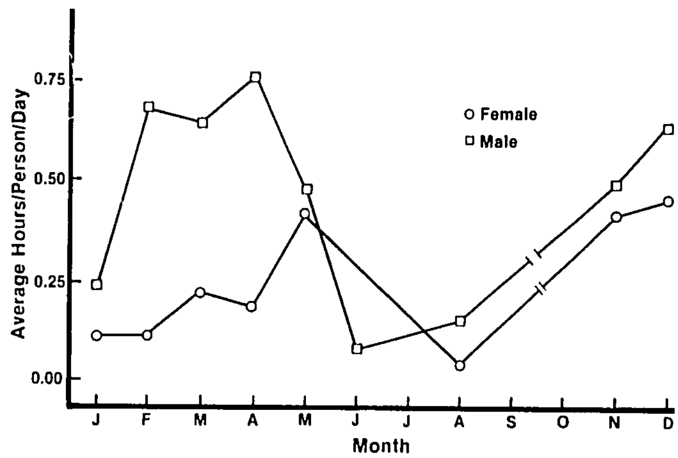


Figure 7. Seasonal variation in allocation of labor to wet rice fields (sawah) of Sitiung I.

leisure. The most striking pattern was the greater amount of leisure time in Sitiung V, compared to that in Sitiung I. The time-allocation study was begun during the first year of settlement of Sitiung V, and the data suggest that opportunities for productive activity increase with the length of settlement. However, there were significant differences between the two settlements. Sitiung V farmers may have worked less because they were demoralized by the adjustment to a new home, and by the necessity of clearing logs from their fields, or because of the subsidy provided, necessary though that subsidy is. The greater productivity in Sitiung I may have been influenced by the availability of sawah (wet rice fields), the necessity to be fully self-supporting, animal ownership and the expectable payoff, in yields, for agricultural activity.

Not surprisingly agricultural activities roughly follow seasonal variation, with heavy periods at the onset of the rains and at rice harvest. In Sitiung V, a peak later in the year (April) undoubtedly relates to marginal harvests, and subsequent planting of legumes for a second crop.

From the standpoint of off-farm work, there is again a rough complementarity with the agricultural seasons, the main point being the low level of non-agricultural activity at the onset of the rains, sometime between August and October. However, the high levels of both off-farm and on-farm labor during March and May in Sitiung I suggest that people respond with increased work when there are multiple opportunities, rather than substituting one kind of work for another. In Sitiung V, a similar situation occured in October.

The relatively high levels of productive activity and leisure in October suggest that the remaining major category of activity (what we are calling, broadly, "reproductive" activity) may have suffered neglect.

Production, Reproduction, and Leisure

Besides off-farm labor, household activities necessary for human survival can constitute a significant drain on human resources which might otherwise be available for productive activity. People are not available for productive work if they do not eat, bathe, dress, repair things, and ensure that children survive to join the work force. Figure 4 shows the division of adult labor among activities that result in the creation of value ("productive activities"), those devoted to the maintenance of the work force ("reproductive activities"), and the remainder ("leisure").

The fact that reproductive activity requires more time than productive activity in Sitiung V (in contrast to the Sitiung I situation) is partially related to a higher proportion of children under 15 in Sitiung V. The fact that markets are more readily available to Sitiung I may also be a major factor.

Labor in Fields and Gardens

Figures 5-7 show seasonal variation in the allocation of labor to the upland fields, home gardens, and wet rice fields, by sex, in Sitiung I. One of the most interesting findings reflected here is the relatively high proportion of labor devoted to the home garden, which was one-fourth of the labor devoted to other fields combined. Upland fields (ladang) reflect more seasonal variation in labor than do wet rice fields (sawah), because the sawah schedule is determined by the government's irrigation project.

In Sitiung V there are no wet rice fields. Figures

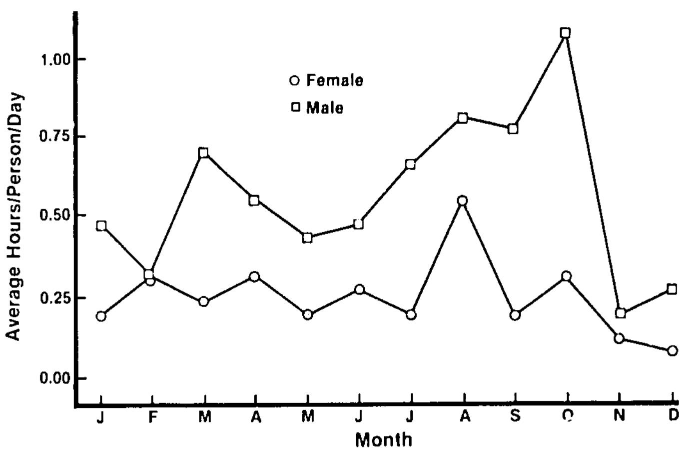


Figure 8. Seasonal variation in allocation of labor to upland fields (ladang) of Sitiung V.

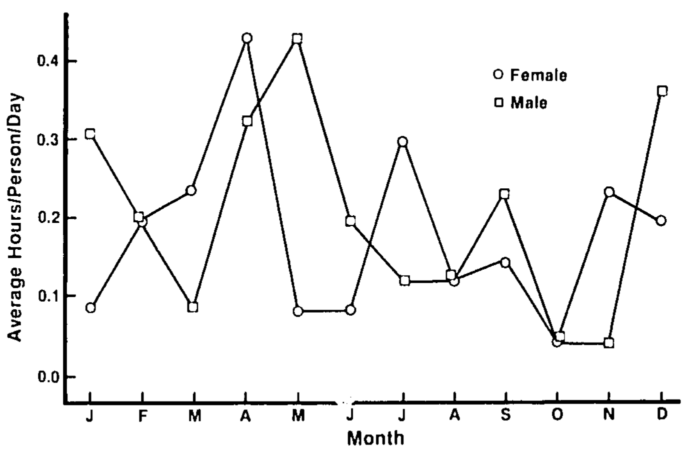


Figure 9. Seasonal variation in allocation of time for home gardens in Sitiung V.

8 and 9 clearly show the complementarity of busy times in home gardens and upland fields. Rice is the major upland-field crop, and it must be planted at the time the rains come. In the early years of a settlement, the home garden appears to be cultivated intensively throughout the year, for subsistence. Men and women are more equally involved in home gardening activities in Sitiung V than in Sitiung I.

Implications

Frequencies of all activities in the 5,635 observations of individuals remain a valuable resource data set, available as the program develops new research questions relating to people's behavior and its impact on soil-management practices. For example, the substantial amount of labor devoted to home gardening, particularly by women, has influenced the research team to pursue more research in home-gardens.

Nutrition/Income Survey

Carol J. Pierce Colfer, University of Hawaii
Barbara Chapman, University of Hawaii
Bartholomeus Weid, IPB Nutrition Department
Harry Apriadji, IPB Nutrition Department
Liek Irianti, IPB Nutrition Department

A purpose of this study was to establish the nutritional status and income levels of people in the Sitiung area. This information was to be compared with similar data collected at the conclusion of the TropSoils project, as well as with those from other Indonesian locations. The analysis will provide the team with a means of selecting appropriate food crops and technologies for use in the TropSoils program.

The analyses reported here are based on a survey undertaken in April, 1984 in Sitiung I, II, and V. The objectives of work during 1985 were 1) to provide further descriptive analyses of the survey, focusing on crop diversity, production, and income, 2) to provide the team with a summary of literature on nutritional status on Java, for purposes of comparison, and 3) to do a multivariate analysis of the factors related to better diets among these settlers.

Discussion

A variety of descriptive data are available in a report by Chapman (1984). One of the most important findings was the low level of agricultural productivity of Sitiung's farms. The percentage of farmers producing crops worth less than $100 for whole-farm operations (about 1.25 ha each) ranged from 70% for rice to 100% for cassava and banana. Of 77 families in the three locations, 36 had total farm incomes (from agricultural produce, including the value of produce consumed by the family) of less than $100; another 36 had agricultural incomes between $101 and $500; and only five had incomes over $500.

The diversity of crops, important from a nutritional standpoint, is most evident in the home garden, though on-site experience suggests that the diversity in home gardens is considerably greater than that reflected in the survey.

The availability of cash is an important concern for those interested in enhancing agricultural productivity by increasing inputs. Annual cash incomes ranged from under $100 to over $2000. Thirty families had under $100 in annual cash income, 29 had between $100 and $500, and 18 had cash incomes of over $500. Although perhaps higher than cash incomes would be in Java, these figures are still too low for people to allocate funds to fertilizers, pesticides, and other agricultural inputs.

Java Compared to Sitiung

Chapman's previous research had been in Gunung Kidul, an area in Central Java, not far from Wonogiri, the home area of inhabitants of Sitiung I and II. Drawing on her own experience as well as the published literature, she identifies the following probable nutritional difficulties in the settlers' sending communities: calorie/protein malnutrition, Vitamin A deficiencies, anemia, and goiter. She points out that since many of the people come from an unusually poor part of Java, and transmigrants tend to be from among the poorer segments of any particular local community, the probability of their having experienced these nutritional difficulties is high.

In Sitiung, the dietary pattern is not very different from patterns found earlier in Java by Chapman and others. Meals are starch- and vegetable-centered, with most of the protein derived from rice and the bean-/peanut family. Meat, eggs, fish and milk products are rare. The overall conclusion though is that settlers are probably considerably better off nutritionally than they were in Java. However, roughly 50% of the households in Sitiung appear to be getting less than their nutritional needs in calories, protein and Vitamin A.

Chapman postulated that seven household

characteristics should have an influence on nutritional status, as measured by the three indices, per capita calories, protein and Vitamin A. These seven household characteristics were ethnicity; length of residence; education, total income; and diversity indices of agricultural production, vegetable and fruit production, and consumption. However, these characteristics only accounted for 28% of the variation in per capita calories, 31% of the per capita protein, and 19% of the per capita Vitamin A, using a multivariate analysis.

The diversity index of consumption had the highest explanatory value in regard to calorie and protein intake. The education level attained by the most educated member of the household contributed strongly to the role of these nutrients. Ethnicity was important in per capita protein (the Minangkabau eat more meat).

A significant conclusion, also found in other studies in Indonesia, is that household income is singularly unimportant in explaining a good diet in Sitiung. For Vitamin A, the strongest factor was the diversity index of vegetables and fruits, followed by length of residence in Sitiung and educational attainment.

Recommendations

Some specific recommendations emerging from this study include the following:

1) Research on home gardens should encourage the planting of a number of non-commercial plants high in Vitamin A and C (e.g., amaranth, edible-pod beans, and tubers of a deep color).

2) Dietary diversity should be increased through planting a greater variety of crops, since Sitiung families are primarily dependent on their own production for their diets, and thus cannot afford to take a narrowly commercial view of cropping strategies.

3) Diet and cropping patterns should be investigated in the settlers' areas of origin, in search of more species of plants that can be tried in Sitiung.

4) Increased incomes only result in modest improvements in diets. Income-generating activities that directly increase the variety of foods available, such as garden plantings of vegetables and fruits now unavailable, or household processing of agricultural products into salable snacks at the markets and school yards, are recommended. Both of these activities could predominantly involve women, since they are active entrepreneurs in these activities in Java.

Literature Cited

Chapman, Barbara. 1984. Diet and Production Survey of Sitiung, West Sumatra. Research Memos 2 and 3.

Collaborative Research With Farmers On Home Gardens

Stacy Evensen, University of Hawaii
Carol J. Pierce Colfer, University of Hawaii

Previous studies in Sitiung have shown that home gardens are important sources of food, and are allocated a significant portion of the typical household's labor. In light of these findings, work has been initiated to study various aspects of home-garden production, including the effects of waste material (compost) on soil properties and crops, forage crops for domestic animals, fish-pond management and nutrition. These were all initiated recently, and to date only the nutrition component has produced noteworthy results. The objectives of this component, conducted in Sitiung I, Sitiung V, and Koto Padang, were 1) to ascertain the variety of home gardening patterns that exist in Sitiung, and 2) to characterize Sitiung's home gardens in terms of type of crops grown, soil-management practices, annual yields and use of crops.

Methods

Two steps in this ongoing study have been completed to date. In the first, the research team conducted a modified "sondeo," in which researchers from different disciplines paired off, interviewing the members of 12 farm households in order to learn how best to plan research. Th team also mapped gardens to identify variation ar ng them.

In the second step, a series of casual observations in home gardens was followed by the development of a survey. The survey was administered to 30 farmers—13 each from Sitiung I and V (five each from the Sundanese and East Javanese communities, three from the Minang transmigrants) and four from Koto Padang (in order to observe possible differences among Minang farmers by location). The plan for this two-month study was to learn what crops are planted in home gardens, for what purposes, and with what inputs, soil-management practices, and constraints to production. It was also planned to draw simple maps of home gardens outlining such things as the number of trees planted, plot size of food crops, and the orientation to house, stable and fishponds.

Preliminary Results and Interpretations

The first round of data collection has only recently been completed, and the following must be taken as preliminary observations only.

1) Farmers manage their garden plots in a variety of ways. Some vigorously hoe the soil, incorporating fertilizer and manure; some simply sprinkle a light application of fertilizer on the surface; and some spread or incorporate a compost of burned or rotted kitchen waste, leaves and crop residue. Ash from stump-burning in Sitiung V was used extensively in the home garden, along with government-provided TSP and urea. In Sitiung I, where there are cows and goats, manure and ash are the main soil amendments, and TSP and urea are used minimally. Manure is spread around perennial trees and incorporated in garden plots.

2) In the dry season, no new planting occurs. Gardeners use this time for soil preparation, yard-cleaning and maintenance. Gardens remain bare except for perennial tree crops such as jackfruit, rambutan, guava, papaya, coconuts, bananas, cloves and stinkbean. However, there were small plantings of cassava, sweet potato, corn, mungbean, pigeon pea and cowpea in Sitiung I, and, to a lesser extent, in Sitiung V.

3) Constraints to production mentioned by the farmers in Sitiung I and V included pests ("hama"), worms ("ulat"), pigs, the unavailability of seeds, and, in Sitiung V, the lack of a convenient market for excess garden produce.

4) Informal observations of home gardens in Koto Padang indicate considerable variation between home gardens in Sitiung I and V. Perennial tree crops dominate the plantings in Koto Padang home gardens. Sugarcane and some spice plants (lemon grass, basil, laos, turmeric, ginger, etc.) are also frequently planted. Much less care is taken of these gardens compared to those in Sitiung I and V. The use of soil amendments appears to be minimal. The food crops grown in Koto Padang home gardens seem to be used for home consumption, bartering, and sale at local markets.

5) Farmers' attitudes emerged as an important variable in crop selection. Observations have led to the hypothesis that, for food crops, there is a hierarchy based on social, economic and production value, and, to a much lesser degree, nutritional value. In Sitiung rice is king, followed by perhaps peanuts and soybeans. For whatever reason, cowpea is farther down in the hierarchy. Attitudes of this sort will be investigated further as this research proceeds.

6) Most food grown in the home gardens in Sitiung V is for home consumption. If there is extra produce it is sold or traded with neighbors. Farmers in Sitiung I, where a clear distinction is made between garden and ladang (upland field) systems, appear less dependent on their home gardens for the family's food supply and have more available for sale. In Sitiung V, however, home gardens appear to be used as an extension of the ladang. Often the same soil-management practices and inputs are used. By using a large part of home garden space for ladang crops, families in Sitiung V may be eliminating access to fresh fruits and vegetables (most families shop at the market only once or twice a month, so purchasing these commodities is not practical). This may have considerable negative impact on family nutrition and warrants additional study.

It became clear during the interviewing of these 30 families that garden crops vary from season to season. In order to better characterize the home-garden system on an annual basis it was decided to intensively interview and observe selected farmers in Sitiung I and V for one year. Gardens in Koto Padang will be mapped at least four times, with less intensive monitoring, since perennials dominate in Minang home gardens, and therefore seasonal variation is likely to be less.

Farmers' Perceptions of Constraints To Agriculture

Carol J. Pierce Colfer, University of Hawaii
Herman Agus, Andalas University
Mike Wade, N. C. State University
Dan Gill, N. C. State University
Carl Evensen, University of Hawaii

In order to determine which factors farmers of both sexes considered to be of greatest importance in limiting their production, a series of general questions was developed by the TropSoils team. Ten in-depth, but minimally structured, interviews were conducted in Koto Padang and Sitiung I, II, and V (40 total).

A preliminary report has been prepared by Agus, outlining differences among the four locations surveyed, and summarizing the major constraints to production in the Sitiung area. The following is a brief summary of the results.

Costs and Production

Sitiung V farmers complained of the transportation costs involved in marketing their goods. The wages paid for agricultural labor are also significantly lower, Rp. 1,500 for men and Rp. 1,250 for women, than in Sitiung I and II and Koto Padang, where they were Rp. 2,000 for men and Rp. 1,500 for women. At the time of this writing, one U.S. dollar was equal to approximately 1120 rupiah.

As observed elsewhere, the Minang focused on perennials, both in Koto Padang and among the local transmigrants residing in Sitiung V. This year, the Sundanese in Sitiung V had switched to peanut; and the Javanese were planting soybean, in line with the government's national soybean-production scheme.

Preliminary data show farmers in Sitiung I using fertilizer on their upland fields (averaging 65 kg TSP, 80 kg urea, and 50 kg Kcl per ha). This is not consistent with other information, and will be investigated further. Calculations using data from Sitiung I show that rice on 1 ha of sawah (wet rice field) costs Rp. 258,420 to grow (including family labor paid at the going rate for field labor), with an average yield of 1.85 tons/ha, valued at Rp. 136,000.

Costs for 1 ha of soybeans averaged Rp. 228,570, with an average of 0.95 tons/ha return, valued at Rp. 255,000; this reflects a loss, if costs include wages for family labor. Peanut yielded an average of 0.48 tons/ha, valued at Rp. 456,000.

For Sitiung II, the cost of land preparation, whether for upland rice or soybeans, was about twice as expensive for those who did not have cattle as for those who did. Yields from soybean averaged 0.55 tons/ha (equaling Rp. 165,000), whereas land-preparation costs alone were Rp. 306,250, if hoeing was the method used.

In Sitiung V, land preparation for the major upland crops comes to approximately Rp. 157,500 per ha. Soybean production was 0.45 tons/ha (Rp. 146,250); upland rice was 0.6 tons/ha (Rp. 102,000); and peanut was 0.4 tons/ha (Rp. 400,000). Prices given are those at time of harvest, varying by location.

In Koto Padang, wet rice is grown in rainfed areas. Land preparation costs Rp. 302,500, and yields about 1.9 tons/ha (Rp 228,000). This rice, however, sells for only Rp 120/kg (in contrast to Rp 170 or 175 at other locations) because of the high proportion of unfilled husks. Inhabitants of Koto Padang are far more dependent on their rubber-tapping activities than on yields from field crops, as was already clear from other studies.

Primary Constraints

The principal factors which contribute to this limited production, according to this study, include:

1) The soil and climate are unfavorable.

2) Labor is scarce, particularly at the times of land preparation and harvest, and, even when laborers are available, low yields make it difficult to hire them.

3) There is little cash available for the purchase of agricultural inputs.

4) The level of modern agricultural knowledge among the farmers is low, while the appropriateness of modern agricultural extension information remains uncertain.

5) The high level of pests and diseases which affect crops increases the riskiness of agricultural pursuits in the area.

6) Marketing of produce is a significant problem in Sitiung II and V, increasing costs and reducing farmers' profits.

7) Governmental policy has until very recently been something of a problem, since food crops were prescribed on transmigrants' upland fields. The more appropriate perennials were forbidden, except in home gardens.

8) The lack of irrigation, except in Sitiung I, is seen as a major limiting factor of production.

Implications

Preliminary observations from this study present a rather dreary view of the profitability of agricultural endeavours in this area. The kinds of figures presented above would seem to make the common practice of seeking off-farm employment both necessary and intelligent.

Minang Tree-Farming Study

Mochtar Naim, Andalas University
Herman Agus, Andalas University
Fahmuddin Agus, Center for Soil Research
Carol J. Pierce Colfer, University of Hawaii

Soon after the TropSoils project began, it became apparent that a study of indigenous farming systems might help guide the development of soil-management technologies in the Sitiung area.

A study of tree farming by the Minangkabau was conducted at Koto Padang. Participant-observation techniques were used to suggest specific questions appropriate to the setting. A 10% sample of families was chosen (n = 31) for more structured interviews. These interviews focused on land- and labor-use patterns, time and costs of production, and management practices relating to tree crops. Available secondary sources were consulted, and further in-depth interviews were conducted with a number of informal leaders in the community. Interviews were conducted in Bahasa Minang, the language of Koto Padang residents.

Results and Interpretation

A report of the study (Naim and Agus, 1985) includes background information outlining characteristics that differentiate the Minanagkabau from transmigrants. One surprising finding was the minimal amount of management apparently involved in traditional tree-crop production. The Minangkabau devote the least land to upland-crop fields (2.5%), and the most to rubber holdings (35.1%). The report concludes that 1.5 ha of rubber is sufficient for the subsistence needs of a family of five. The other most important tree crops include coconut, coffee, and duku (a fruit).

The average wealth of the Minang community members is striking when compared to the transmigrants. A survey of 20 randomly selected transmigrant households in Sitiung I, four months before this survey, revealed an average annual income of Rp. 390,000, compared to Rp. 960,000 for the Minangkabau.

Just as with the transmigrants, the importance of off-farm employment is considerable. The largest single contributor to income, overall, is "transportation" activities, accounting for over one-fifth of average total monthly income. Contracting and rubber tapping for a nearby plantation are also major contributors to income deriving from off-farm sources.

Other important differences between Minangkabau and the transmigrants include the following:

1) Koto Padang has a greater variation in wealth than is evident among the transmigrants.

2) Land is held communally among the Minang by matrilineal clans (this means that any individual's access to land is largely determined by the powerful/influential men in his or her mother's clan).

3) The seven clans represented in Koto Padang have varying rights to land in the area. Those who came latest have the least land, and are more likely to specialize in animal husbandry and off-farm activities.

4) Home gardens among the Minang are used for growing fruit trees and flowers, in marked contrast to the transmigrants, who grow a substantial amount of their food in home gardens.

5) The Minangkabau of Koto Padang differ rather markedly in their way of life from other Minangkabau, who are more centrally located in the Minangkabau homeland (Central Highlands of West Sumatra). The Sitiung area is considered a frontier, and the most notable differences include a more important role of the father in the lives of his own children (in contrast to the "ideal" Minang pattern of men's being primarily involved in the lives of their sisters' children), and a far lower rate of outmigration compared to the ideal Minangkabau pattern.

Implications

The fact that the Minang tree crops continue to produce with so little human effort is a definite plus when contrasted to the situation with upland food crops. The report's conclusion that 1.5 ha of rubber is sufficient for the subsistence needs of a family of five is encouraging, if one is interested in incorporating tree crops more meaningfully into the transmigrants' farming system. The transmigrants have, or will soon have, 2 ha of land, and an average family size of about five members.

The fact that the Minangkabau are relatively well off suggests that people can do reasonably well in this environment, and that the indigenous population has something to teach us. The Minang experience with tree crops is being considered as the program plans its agroforestry experiments.

Productivity in Farmers' Fields

An effective system of agricultural production is adapted to local environmental and socioeconomic conditions, and achieves the best possible match of crop and soil. Crop requirements must be matched to soil characteristics, and some of these characteristics vary significantly, both with time and space. While these matches can sometimes be made by trial-and-error alone, this method is slow and laborious, and can delay the introduction of new varieties and soil-management techniques.

Because there are so many factors complicating the selection and management of crops in the humid tropics, much of the effort reported here has been devoted to the development of crop-simulation models that predict how a crop will perform, given a particular set of soil and environmental conditions. Such models can save time and effort by simulating trials that would require months or years to perform. Collaborative research in Hawaii and Sumatra has produced a corn model that performs equally well in either location. The model can simulate effects of water stress and nitrogen shortages, and one of the studies reported here has been designed to incorporate phosphorus and lime interactions. The model will be able to simulate water, nitrogen, phosphorus, and lime interactions not only for corn, but eventually for rice, soybean and peanut.

One constraint to the use of such models is the high variability of soils and climate. Deterministic crop models predict outcomes at a point in space. To deal with spatial variability in soils, geostatistical techniques have been refined and applied to the mapping of soils in Sumatra (see the report, "Soil Variability in Mechanically Cleared Forest Land"). With a minimum data set on daily solar radiation, rainfall and temperature, the crop model can deal with temporal weather variability.

Simulation models can also be of limited use unless the farmer becomes part of the equation. A decision-support system for farmers must make use of models that can simulate not only soil and weather effects on farm production, but also the large amount of local knowledge stored in the minds of farmers. This type of local knowledge can best be captured and represented in expert systems. An expert system on soil acidity, described here, has been designed to make liming recommendations for several important food crops produced on major soils of the humid tropics.

Matching Crop Requirements of Rice, Maize, Soybean, and Peanut to Soil Characteristics with Crop Simulation Models

Goro Uehara, University of Hawaii
Russell Yost, University of Hawaii
Upendra Singh, University of Hawaii

Crop models are an important ingredient in systems-based research. Properly formulated, these models can predict a crop's performance both in Hawaii and Indonesia, or almost anywhere else in the tropics. Such predictions can help accelerate the progress of agricultural research and development. The objectives of this study are 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 simulation models for these crops, using the minimum data set; and 3) to use the simulation models as screening devices for varietal testing.

To date, this project has tested crop models for maize and rice. A soybean model developed by the University of Florida has been selected, and has been modified to simulate growth and development of peanut, as well. Both versions of this model will be ready for testing and validation during the next cropping season. When they have been validated, all of the models are expected to be useful in screening crop varieties.

Minimum Data Sets

Soil data. The standard USDA, Soil Conservation Service soil-description and soil-characterization data file has been selected as the minimum soil data set needed for crop modeling. The critical soil data needed to operate the model are curve numbers calculated from the characterization data to simulate water runoff and run-on for the water-balance components; organic-matter and nitrogen content to operate the nitrogen-dynamics component; and the bulk density, organic carbon and particle)size analysis data to calculate available water capacity. These data are needed for each horizon in the root zone.

Weather data. Daily solar radiation, maximum and minimum air temperature, and rainfall are the minimum weather data needed to operate the models.

Crop data. The minimum data set for model testing requires more data and observations than the minimum set for model validation. The minimum data set for maize has two parts. The first part deals with observations of growth stages; the second deals with periodic measurement of plant components during the course of the experiment. The model is designed to predict phenologic events and biomass production over time. Water stress or nitrogen deficiency affects biomass production and final crop yield. The model operates on the law of the minimum so that responses to nitrogen applications vary with water supply and other factors.

Management data. Any management practice believed to affect crop performance must be noted. The model can deal with water supply through its water-balance sub-routine and nitrogen stress through its nitrogen-dynamics sub-routine. This means that, if the crops receive supplementary irrigation, the amount, manner and time of application must be recorded and used in the simulation. Similarly the green-manure application or nitrogen-fertilizer application must be recorded. The amount and source (C/N ratio for green manure and source for N fertilizer), depth and date of incorporation or application, must be recorded for use in the simulation.

The model does not account for deficiencies of P, K and lime, or for damage by insects and pathogens. These factors must be kept optimum at this stage of model development. P and lime should become part of this model in about two or three years, as results become available from studies reported elsewhere in this document.

Genetic data. The crop models are cultivar-specific. For example, genetic coefficients for maize include: thermal time (degree days) from emergence to end of juvenile phase; the sensitivity of tassel initiation to photoperiods greater than 12.5 hours; thermal time (degree days) from anthesis to physiological maturity; potential kernel number per ear; and potential grain fill rate. In this project, the genetic coefficients of local (Indonesian) cultivars will be obtained from field measurements.

Maize Model

A maize model developed by the Agricultural Research Service group in Temple, Texas has been modified for use in the tropics. A minimum data set was collected from an experiment installed in Oahu specifically to test the maize model. Two varieties of maize, a University of Hawaii hybrid, H 610, and a Pioneer hybrid, X-304C, were planted on clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox. Nitrogen levels were varied from 50 to 200 Kg/ha, and water supply ranged from full irrigation to supplemental irrigation.

Comparisons of observed and simulated leaf area indices and biomass production for the H-610 variety are shown in Figures 1 and 2. The calibrated model was tested against field results from similar soils on the Island of Molokai. The model calibrated on Oahu performed very well with data from Molokai.

The model was tested with experimental data from Sumatra and sites in Hawaii and again performed very well as illustrated in Figure 3. While grain yield will be of primary interest to most users, the model also predicts the date of silking and the date of physiological m :turity.

The model was altered in two significant ways to enable it to simulate maize performance under tropical

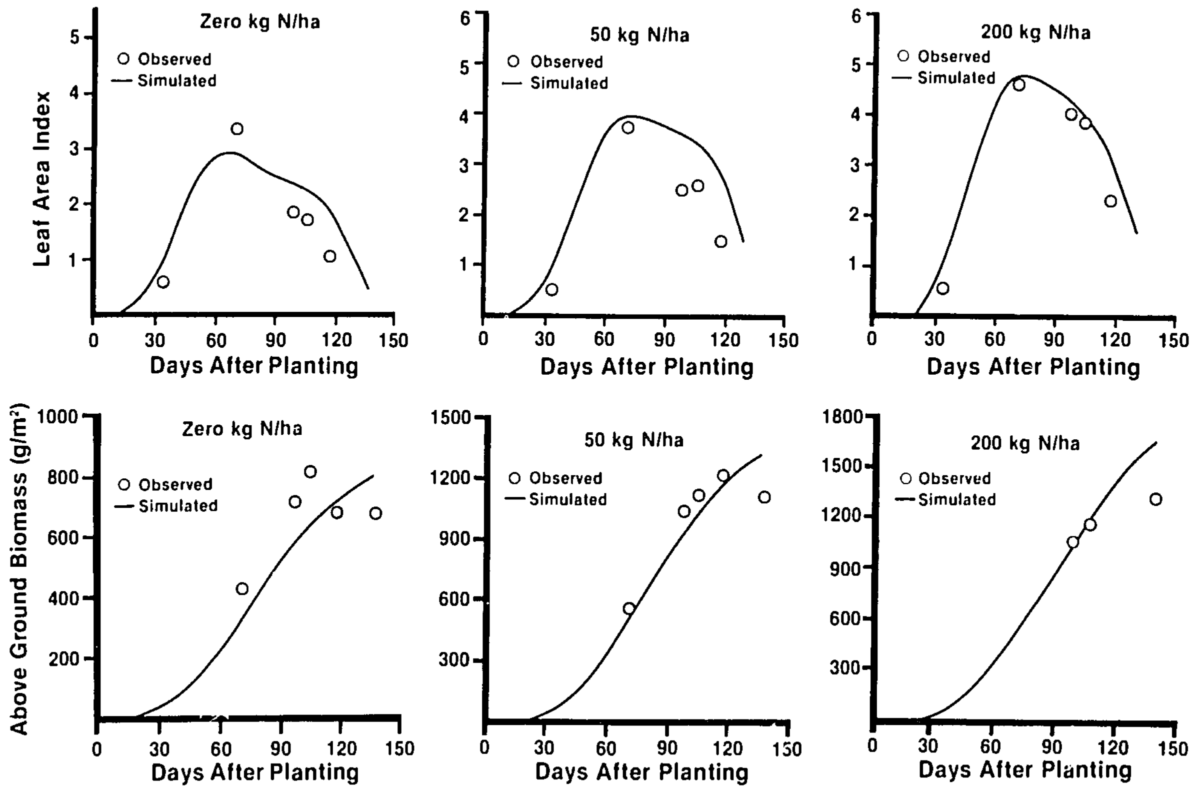


Figure 1. Comparison of observed and simulated leaf area index and aboveground biomass for maize cultivar H610, at three rates of N application.

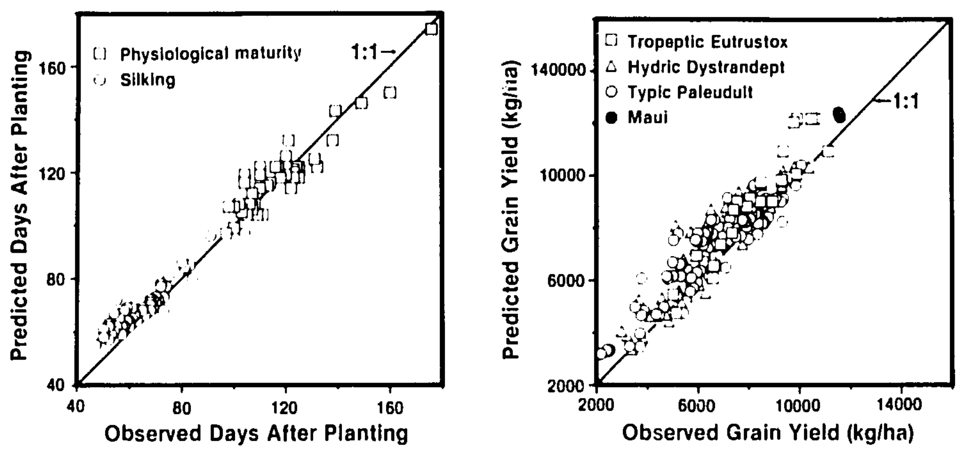


Figure 2. Comparison of observed and simulated phenological events and grain yields.

conditions. The first modification was to compute thermal time (degree days) from soil temperature rather than from air temperature. This change is particularly critical in the early stages of plant development, when much of the biomass is in or near the soil. In the temperate regions, this is not so important because crops are planted in spring, and temperature and day length increase simultaneously. In the tropics, crops can be grown at any time of the year.

The second modification was to adjust thermal time with solar radiation. This change accounts for differences in photosynthetically active radiation between summer and winter. In the tropics, maize can be grown during any season.

As shown in Table 1, the effect of climate on crop phenology is accurately predicted by the maize model. Another maize experiment has been harvested to assess the effect of phosphorous levels on crop phenology. The data clearly show that phosphorus deficiency delays tasselling, silking, and maturity. In the high nitrogen treatments, for example, the low phosphorus plots remained greener for about a week longer because maturity was delayed.

The maize model has been used to simulate the effect of subsoil acidity on crop performance. Using experimental data collected by the Indonesian Center for Soil Research, the corn model simulated corn performance at a two-month interval for rainfed conditions with and without subsoil acidity. The results in Table 2 show that rainfall is adequate to support high yields during the dry season. It appears that subsoil acidity constrains plant roots from exploiting subsoil moisture. The results suggest that screening for acid tolerant crops should be encouraged and that deep incorporation of lime can significantly reduce yield losses from periodic dry spells during the rainy season.

Rice Model

Five rice varieties have been planted under flooded and upland situations. The varieties were selected to cover a wide range of genotypes to assess the model's capacity to simulate cultivar differences under flood-

Table 1. Comparison of observed and simulated phenological events for X304C variety on the slopes of Haleakala, Maui, Hawaii.

Elevation (M)		Days after Planting			
		Emergence	End of Juvenile Stage	Silking	Physiological Maturity
77	Observed	6	23	62	120
	Simulated	5	25	67	119
340	Observed	7	28	73	138
	Simulated	5	28	73	132
800	Observed	9	42	104	176
	Simulated	7	38	97	174

Table 2. Simulated and measured corn yield on a clayey, kaolinitic, isohyperthermic Typic Paleudult in Sumatra, Indonesia.

Month and Year Planted	Grain Yield, kg/ha—Conditions Simulated				Grain Yield Measured
	Rainfed, Subsoil Acidity and no N application	Rainfed and Subsoil acidity	Rainfed	Optimum	
Dec 1980	5179	7624	10006	10308	10661
Jan 1981	4795	9024	9487	9495	
Mar 1981	2953	5638	7607	7614	
May 1981	864	891	6439	7989	
Jul 1981	740	744	5524	7745	6300
Sep 1981	4062	6339	7740	7781	
Nov 1981	138	577	7340	7348	
Dec 1981	2947	3981	8800	8948	8338

ed and upland soil conditions. The varieties were Kwang-Chang-Ai, which is short-statured and high-yielding, with a high photoperiod sensitivity; Bellemont, which is short-statured and semi-dwarf with low photoperiod sensitivity; and Starbonnet, IR-36 and Labelle, whose juvenile phases are long, intermediate and short, respectively.

The rice model is more complicated than the corn model because corn produces a single stalk whereas rice produces tillers. It is well known that soil fertility affects tillering and therefore grain yield. There is also strong evidence that low soil fertility delays the time of phenological events and therefore delays physiologic maturity.

The chronology of key phenological events for each variety grown in upland and flooded situations has been determined and will be compared against predicted results from the rice model. The model is also designed to predict biomass production over time, including grain yield.

Conclusions to Date

1. Minimum data sets have been identified for the maize and rice models. They include data on soils, the crop, weather, management and plant genetics.
2. A maize model, modified for tropical conditions, accurately predicted leaf-area index, biomass, kernel weights and numbers, grain yield and phenological events for maize grown on several sites in the humid tropics.
3. Results from a simulated and actual maize crops in Sumatra show that subsoil acidity rather than low rainfall is the major constraint to corn production during the dry season.

Effects of VA Mycorrhizae on Cowpea Response to P Fertilization and Lime In High Manganese Soil

Russell Yost, University of Hawaii
Edi Santoso, Center for Soil Research
Ruey-Shang Huang, University of Hawaii

In most acid soils, poor plant growth can not usually be blamed directly on low soil pH. Such factors as crop cultivar, soil phosphorus and manganese toxicity can all influence the plant's ability to develop roots and grow. In legume crops, studying the response of crops to lime and fertilizer applications is further complicated by VA mycorrhizal fungi. The effect of mycorrhizae on plant growth varies with soil conditions, as well as with the strain of mycorrhizae. An understanding of these interactions is important if mycorrhizal inoculants are to be used to improve the productivity of land cleared of tropical rainforests.

The work reported here was conducted at Poamoho, Hawaii. It examined the response of two cowpea cultivars to acidity differences covering a wide pH range (4.8 to 7.1), with and without phosphate, as well as with and without VA mycorrhizal fungi. Its objectives were 1) to evaluate the effects of VA mycorrhizae interactions with fertilizer amendments on cowpea growth, and 2) to examine the genetic variation in adaptability of species of mycorrhizae and cowpea to manganese in high-manganese soils.

Preliminary Experiment

Eight isolates of *Glomus mossae* were compared with one isolate of *Glomus aggregatium*, Schenk in fumigated Wahiawa soil (Tropeptic Eutrustox) amended with $CaCO_3$ to pH 4.8 and 5.7. At low soil pH (4.8) and high soil Mn (33 mg/L), all cowpea plants were stunted and exhibited typical Mn toxicity symptoms (crinkling, chlorosis and necrosis of leaves). Under these conditions there were no differences between mycorrhizal and nonmycorrhizal plants. Where soil pH had been increased to 5.7 and soil Mn was much lower (1.4 mg/L), however, mycorrhizal plants were significantly larger than nonmycorrhizal plants. Under the higher soil pH conditions differences in shoot dry weight were observed among the plants with different fungal isolates. One *Glomus aggregatium*, Schenk isolate was more effective than other *Glomus mosseae* isolates as measured by increased shoot growth (Figure 1). This isolate of *Glomus aggregatium*, Schenk was used in subsequent experiments.

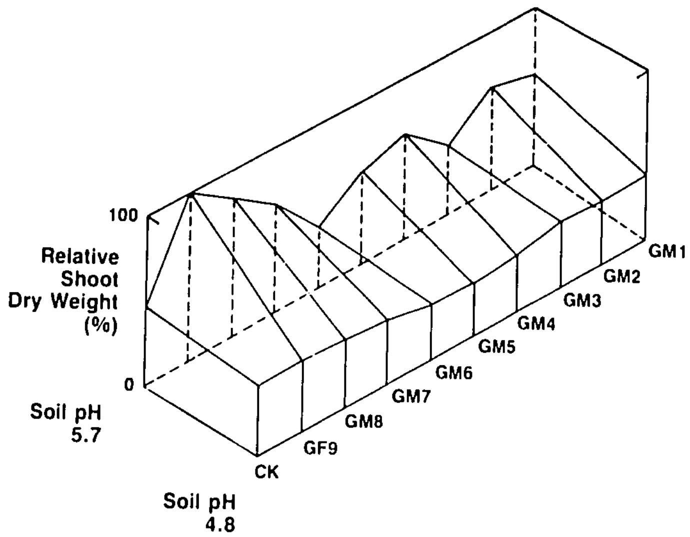


Figure 1. Comparison of pH effects on effectiveness of eight isolates of *Glomus mosseae* and one isolate of *Glomus fasciculatum* as measured by shoot growth of cowpea (*Vigna unguiculata*).

Main Experiment

Four factors were compared: mycorrhizae, soil pH, soil P, and cowpea varieties. The mycorrhizal treatments included mycorrhizal plants (inoculated with *Glomus aggregatium*, Schenk) and nonmycorrhizal plants. Soil pH was adjusted with $CaCO_3$ to water pH (1:1) of 4.8, 5.4, and 7.1. Soil P levels were modified with the addition of potassium phosphate to provide 9, 11, and 14 mg/kg sodium bicarbonate extractable P. Three plants of cowpea (*Vigna unguiculata*, cv. "TVu 91" and "TVu 3563") from the International Institute of Tropical Agriculture in Ibadan, Nigeria were planted in each pot. There were three replications of the treatments, in a split-plot arrangement. Mycorrhizae treatments were whole plots, in order to minimize cross-contamination. Cowpeas had previously been grown and harvested for three generations to ensure genetic uniformity. Third generation seeds were apparently pure, having the same color, size and seedling vigor.

Plants were grown 34 days in the greenhouse during June and July. Plastic pots were prepared with 2 kg of soil (Wahiawa series, Tropeptic Eustrustox) which had been fumigated with methyl bromide. Potassium, magnesium, molybdenum, boron, zinc and copper were added in amounts considered adequate for the crop.

Leaf area was measured by a LI-COR leaf area meter at harvest. Dry weights of shoots, roots and nodules were determined at harvest. Mycorrhizae infection was determined at harvest by the Phillips and Hayman (1971) method. Soil solution concentrations of Mn were estimated from 0.02 M $CaCl_2$ extraction of the soil for one hour.

Results, Main Experiment

Cowpea varieties differed markedly in leaf area and shoot Ca concentration (Table 1). Variety TVu 3563 had similar shoot Mn contents in mycorrhizal (2049) mg/kg) and nonmycorrhizal plants (2016 mg/kg) while variety TVu 91 had higher Mn contents in mycorrhizal plants (1749 mg/kg) than in nonmycorrhizal plants (1307 mg/kg). Response to mycorrhizae and soil P treatments were similar in the two varieties.

In nonmycorrhizal conditions, shoot dry weight of the two varieties was the same while shoot Ca, shoot Mn and leaf area were higher in cultivar TVu 3563. In mycorrhizal plants, however, shoot dry weight differed while shoot Mn was about the same.

Growth of nonmycorrhizal cowpea plants was only about 20% of that of mycorrhizal plants when soil manganese was not excessively high (Figure 2). In nonmycorrhizal plants even high levels of soil P failed to increase growth or P concentration in shoots (Table

Table 1. Variety difference in shoot dry weight, calcium and magnesium concentration and leaf area.

Mycorrhizal Treatment	Cowpea Variety	Shoot Dry Weight (g/pot)	Shoot Ca Concentration (%)	Shoot Mn Concentrat-ion (mg/kg)	Leaf Area (cm²/pot)
Mycorrhizal	TVu 3563	8.62 a	2.16 a	2049 a	1416 a
	TVu 91	5.75 b	2.74 b	1749 a	1094 b
Nonmycorrhizal	TVu 3563	1.93 a	1.98 a	2016 a	315 a
	TVu 91	1.45 a	1.37 b	1307 b	222 b

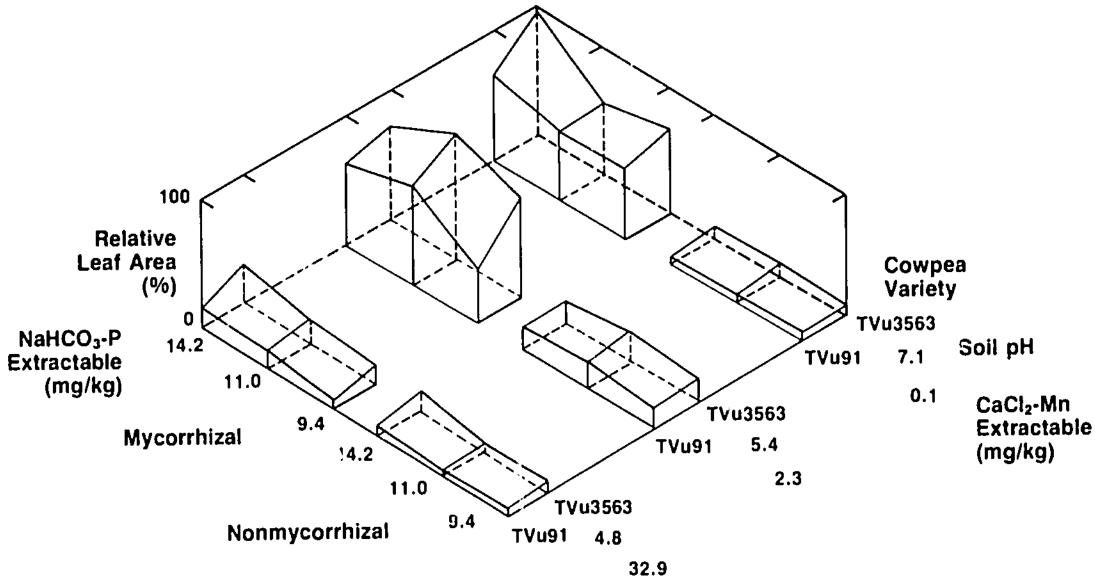


Figure 2. Leaf area response of two cowpea cultivars to mycorrhizal inoculation, soil P, and soil pH scaled to 100% where 100% = 2303 cm²/pot.

3). Increases in soil pH resulted in significant decreases in shoot P concentration, probably due to reduced P solubility at high pH. Other measurements such as nodule dry weight, leaf area, and shoot dry weight all decreased with the increase in soil pH from 5.4 to 7.1 and decreased with the decrease in soil pH from 5.4 to 4.8 (Table 2). Shoot Mn, however, decreased consistently from over 3000 mg/kg at pH 4.8 to 2000 to 1000 at pH 5.4, and then to less than 1000 at pH 7.1 (Figure 3). The two varieties differed significantly in leaf area, shoot Ca and Mn concentration (Table 1).

In contrast with nonmycorrhizal plants, shoot growth, leaf area, and nodule dry weight of mycorrhizal plants increased with higher soil P (Table 3). While shoot P did not change with increased P fertilization it was considerably higher in mycorrhizal (0.20%) than in nonmycorrhizal plants (0.12%). The presence of mycorrhizae also affected cowpea's response to soil pH. Shoot P and nodule dry weight increased as soil pH was increased, whereas the opposite occurred with nonmycorrhizal plants (Table 2). Other measurements (leaf area and shoot dry weight) increased as soil pH increased, and decreased from 5.4 to 7.1 which was similar to the trends with nonmycorrhizal plants. Mycorrhizal infection was highest at pH 5.4 (66.7%) and decreased both with higher soil pH (57.8% at pH 7.1) and lower pH (17.4% at pH 4.8).

Discussion

There are at least two reasons for poor plant growth in acid soils: toxic substances and deficiencies of plant nutrients. These experiments were designed to compare the effects of mycorrhizal fungi on both of these problems. The results only apply for the short-term

Table 2. Soil pH influence on cowpea shoot and nodule dry weight, shoot P and leaf area.

Mycorrhizal Treatment	Soil pH Treatment (g/pot)	Shoot Dry Weight	Nodule Dry Weight (mg/pot)	Shoot P Concentrat-ion (%)	Shoot Mn Concentration (mg/kg)	Leaf Area (cm²/pot)
	4.8	2.3 c	12 b	0.16 b	3463 a	386 c
Mycorrhizal	5.4	10.9 a	421 a	0.17 b	1608 b	1810 a
	7.1	8.4 b	467 a	0.28 a	628 c	1568 b
	4.8	1.3 b	0.3 b	0.13 a	3156 a	191 b
Nonmycorrhizal	5.4	2.7 a	15.7 a	0.12 b	1298 b	439 a
	7.1	1.1 b	0 b	0.11 c	530 c	175 b

Table 3. Soil P influence on cowpea shoot and nodule dry weight, shoot P and leaf area.

Mycorrhizal Treatment	0.5M $NaHCO_3$ Extractable P (mg/kg)	Shoot Dry Weight (g/pot)	Nodule Dry Weight (mg/pot)	Shoot P Concent-ration (%)	L-eaf Area (cm^2/pot)
	9.4	6.4 a	239 b	0.20 a	1116 a
Mycorrhizal	11.0	7.1 ab	254 b	0.20 a	1264 ab
	14.2	8.1 a	408 a	0.20 a	1385 a
	9.4	1.6 a	2 a	0.12 a	225 a
Nonmycorrhizal	11.0	1.8 a	6 a	0.12 a	290 a
	14.2	1.8 a	8 a	0.13 a	290 a

in fumigated, potted soil. In field conditions, native mycorrhizal populations would be expected, and effects of mycorrhizal inoculation would not likely be as pronounced.

In this acid highly manganiferous soil, manganese toxicity is one of the most serious growth limiting factors. Without lime application both cowpea varieties grew poorly in spite of mycorrhizal inoculation. Where the soil had been limed to 5.4, growth in leaf area of cultivar TVu 3563 (1948 cm^2/pot) was greater than that of cultivar TVu 91 (1324 cm^2/pot). At high soil pH cultivar TVu 3563 responded more dramatically to increased soil P than did cultivar TVu 91 (Figure 2). This suggests that cultivars may have differential tolerance to manganese, indicating some potential for further screening and selection. Nevertheless, in this experiment cultivar tolerance could not replace the need for lime.

Although mycorrhiza did not overcome manganese toxicity, they appear to have assisted in the absorption of nutrients such as P and Zn, and improved plant growth where other limiting factors were not present. While they can not be expected to replace mineral fertilizer in these soils, they may be used to improve its efficiency. Mycorrhizal fungi appear to be indispensible for cowpea growth, even where soil P is high. At high soil pH, growth of nonmycorrhizal plants was severely depressed. These plants showed symptoms of P and Zn deficiencies, while growth of mycorrhizal plants was not reduced to the same extent and the symptoms were not apparent. These results suggest that mycorrhizal plants would be less affected by overliming, which might occur with poorly distributed or poorly incorporated lime, than nonmycorrhizal plants, because of improved absorption of P and Zn through mycorrhizal hyphae.

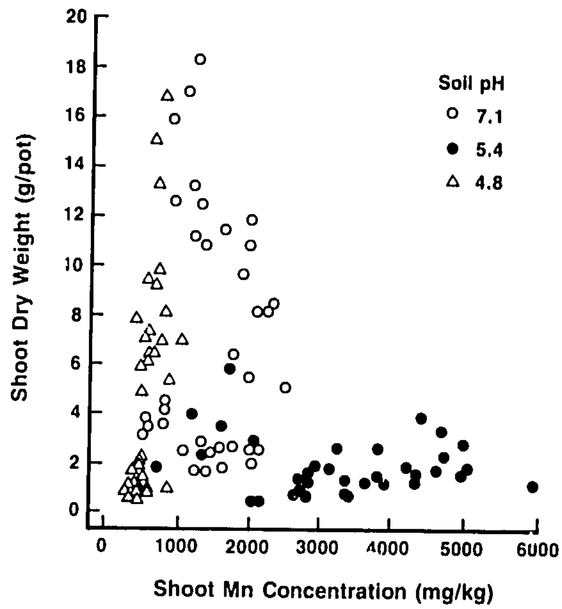


Figure 3. Cowpea shoot dry weight as related to shoot Mn concentration.

Modeling Phosphorus-Lime Interactions

Andrew Sharpley, Agricultural Research Service/USDA, Durant, Oklahoma
Goro Uehara, University of Hawaii
Upendra Singh, University of Hawaii

Phosphorus deficiency and aluminum toxicity are two common soil constraints encountered by farmers in the humid tropics. How a crop reacts to these two constraints depends on the genetic makeup of the plant, weather, water supply and the chemical, physical and biological conditions of the soil. Because P and lime interact with one another, and with other factors in the cropping environment, a systems approach is required to integrate relevant information into a model that predicts the effects of lime or P on crop performance when a host of constraints are operating simultaneously, as is almost always the case in a farmer's field.

The objectives of this study are 1) to quantify coefficients of a soil phosphorus-and-lime model, and couple this 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 P uptake and crop performance as indices for comparison; and 3) to develop and test a soil phosphorus-lime model that simulates changes in extractable phosphorus concentration and soil pH over time.

Determination of Model Coefficients

A soil and plant phosphorous (P) model has been developed for use in EPIC (Erosion-Productivity Impact Calculator) by the cooperating scientists. The P model was developed on soils from the continental U.S. and included only a few highly weathered soils. Consequently, the model cannot be used with confidence on these soils. The minimum data set required by the P model is labile P, organic P, and fertilizer P availability. As these parameters are not routinely measured by soil-testing laboratories, coefficients are needed to estimate the minimum data set from readily available soil physical and chemical properties for highly weathered soils.

Several highly weathered soils were chosen on the basis of soil taxonomy, pH, and aluminum saturation. As these soils will be used in the development of the P—lime model, Al saturation was used as a selection criteria. This model will simulate the effect of lime application on P cycling in highly weathered soils, where lime is often recommended to reduce Al toxicity to crops.

Samples of 32 highly weathered soils were obtained from the Soil Conservation Service, Lincoln Laboratory. The soils included five Alfisols, one Ferrisol, two Inceptisols, three Oxisols, three Spodosols, and 18 Ultisols from Burundi, Caroline Isl., Catie, Indonesia, Lesotho, Malasia, Panama, Papau New Guinea, Rwanda, and Sumatra. The 32 soils had an Al saturation greater than 30% with a mean value of 68%. Labile P (resin extractable), soil test P (Truog, Bray, Mehlich III, and Colwell) and organic P were determined on each soil. Fertilizer P availability was determined following incubation of soil and P for one and six months, and represents the fraction of fertilizer P which is labile after the incubation period.

Labile P (mg/kg) was linearly related to the amount P extracted by each soil P test (mg/kg) (Table 1). These relationships are similar to those obtained earlier for the continental U.S. soils. Soil organic P content (mg/kg) was linearly related to organic C (%) and total N content (%) (Table 1). Slope and intercept values of the relationship between total N and organic P for these highly weathered soils (1109 and 44.2, respectively) are similar to those for the continental U.S. soils determined previously (1130 and 44.4, respectively). Fertilizer P availability was related to clay content (Table 1).

Correlation coefficients were greater for availability measured after six-month incubations, compared to one-month incubations. As expected, fertilizer availability was significantly greater (at the 1% level) after one month (mean of 0.45) than after six months (mean of 0.28). Consequently, the minimum data set

Table 1. Relationship between labile (LP) and Troug (TP), Bray (BP), Mehlich III (MP), and Colwell P (CP); organic P (OP) and organic C (OC) and total N (TN); and fertilizer P availability (F) and clay content (CL).

Parameter	Equation	R^2
LP	= 0.20 TP + 5.62	0.71
	= 0.41 BP + 5.55	0.86
	= 0.64 MP + 5.72	0.84
	= 0.43 CP + 4.21	0.80
OP	= 1109 TN + 42.2	0.87
	= 62 OC + 63.4	0.82
F1 +	= -0.19 Log CL + 0.70	0.68
F6 +	= -0.30 Log CL + 0.68	0.85

\+ F1 and F6 represent fertilizer P availability after 1- and 6 month incubations, respectively.

of the soil P model can be obtained from readily available soil properties of highly weathered soils.

Testing the Phosphorus Model

The soil P model simulates P uptake and transformations in up to 10 soil layers of variable thickness, and is sensitive to soil chemical and physical properties, crop P requirements, tillage practice, fertilizer rate, soil temperature and soil water content. Although the model oversimplifies soil P transformations, model parameters can be obtained from limited soil data; the model is sensitive to soil properties, and has high overall accuracy.

The model was developed from data for soils in the temperate continental U.S. As soil P reactions will differ in highly weathered soils, the above coefficients were incorporated into the model for testing. In addition, fertilizer P availability determined as solution P after a six-day incubation was included.

Data from the Benchmark Soils Project was used to test the model. First, the simulation runs were made to calibrate the existing model so that it accurately simulated maize response to P. Seven experiments were used for calibration. Only the experiments with high N treatments (186 kg N/ha) were used for simulation. The phosphorus treatments ranged from 25 to 1200 kg P/ha.

The model was then run with labile P estimated from Truog P values. The relationship between soil solution P and labile P was used as a calibration factor for the model. The calibration factor was further modified so that the simulated results were reasonable for the seven sites tested. After calibrating the P model, runs were made from seven Benchmark Soils Project experiments on Hydric Dystrandept and Tropeptic Eutrustox. The same data was then rerun on the P model using fertilizer P availability determined by a six-month (Simulation 1) and six-day incubation (Simulation 2).

The calibrations were made so that most of the simulated results were within one standard deviation of the observed mean (Table 2). The model predictions in residual phosphorus experiments were as good as in experiments where P had been applied. In general,

Table 2. Comparison of observed and simulated grain yield on seven Benchmark Soils Management experiments.

Site/Block		Phosphorus Applied (Coded level)		
		-.85	Opt	+.85
HAL-B21[a]	Observed	7697 ± 525	8194 ± 264	8169 ± 815
	Simulaton 1	7100	8210*	8848*
	Simulation 2	7950*	8002*	8600*
KUK-A21[a]	Observed	6039 ± 917	6993 ± 607	7852 ± 1591
	Simulation 1	5780*	7004*	8692*
	Simulation 2	5284*	6190	7408*
KUK-C11[a]	Observed	7123 ± 539	8917 ± 100	8768 ± 433
	Simulation 1	6044	2991*	9179
	Simulation 2	6775*	9213	9213
KUK-C12[a]	Observed	8462 ± 697	9230 ± 550	9262 ± 509
	Simulation 1	8972*	10009	10009
	Simulation 2	9327	10031	10031
KUK-D11[a]	Observed	7003 ± 1132	7937 ± 835	8471 ± 354
	Simulation 1	7450*	9460	9700
	Simulation 2	7933	9340	9582
KUK-D20	Observed	6751 ± 1200	8212 ± 533	9828 ± 365
	Simulation 1	5200	794*	9802
	Simulation 2	7697*	8519*	9904
MOL-A10	Observed	8451 ± 477	9887 ± 478	10460 ± 650
	Simulation 1	7780	9723*	11034
	Simulation 2	8600*	9948*	11018*

[a] Phosphorus—residual experiments.
* Within ± one standard deviation of the observed mean yield.

simulated yields were greater than the observed yields, particularly at the highest P treatment. The main difference between simulations 1 and 2 occurs at the lowest rate of P . In six of seven experiments the modified P model predicted higher yields than the original model. This may be due to the lower accuracy of the P availability index at low levels of P in solution. Nevertheless, the predictions of both models were similar at high levels of P.

The simulation exercise showed that Troug soil test P may be related to labile P by regression equations and successfully utilized by the P model. Likewise, fertilizer P availability estimated by a six-day incubation may be used instead of the six-month incubation. In the present study, the six-day availability index was estimated using regression equations relating solution P to labile P. This step may be eliminated and the error in prediction reduced if the P model were modified to include soil solution P as an additional nutrient pool.

Soil Phosphorus-Lime Model

Work is in progress at the University of Hawaii to combine the soil-plant P model with the IBSNAT/CERES-MAIZE model. The response of maize to applied lime and the associated effects on P reactions will be accounted for through variation on Al saturation, which in turn will be controlled by lime applications. Exchangeable soil Mn will be used to evaluate potential Mn toxicities and the associated effects on potential top growth. Similarly, the effect of P deficiencies on phenology and length of plant growth stages will be included. A phosphorus-by-nitrogen field experiment just completed at the University of Hawaii will be used to test the response of the IBSNAT/CERES-MAIZE model to varying rates of N and P. Phosphorus-lime experiments will be installed also, in order to test the model response to lime and phosphorus.

Summary

A soil and plant phosphorus model was used to predict maize response to fertilizer P application. The model is able to account for organic and inorganic pools of soil P. Plant uptake of P is regulated by the labile P concentration which, in turn, is controlled by fertilizer, organic, and inorganic P pools.

A method to estimate labile P from standard soil P tests, organic P from organic C or total N, and fertilizer P availability from clay content, was developed for highly weathered tropical soils and tested. Once labile P is estimated, P uptake is regulated by plant demand, which is satisfied whenever labile P concentration is above a critical value. The model assumes that potential P uptake is a linear function of labile P concentratic oil water and temperature affect P uptake by their effect on biomass production and by regulating rate constants between various P pools.

When the model was tested with maize experiments conducted in Hawaii, over 50% of the predicted yields fell within one standard deviation of the observed yields. Field experiments designed specifically to test and validate an improved soil plant P model, incorporating the effect of lime application on soil P, will be installed in Indonesia.

Application of Expert Systems To the Transfer of Soil Management Technology

Russell Yost, University of Hawaii
Goro Uehara, University of Hawaii
Stephen Itoga, University of Hawaii
I. Putu G. Widjaja-Adhi, Center for Soil Research

There is a great need to implement existing information on management of tropical soils and to conduct follow-up research where needed. The first-generation problem is to adapt existing knowledge, to apply the right information to the right problem at the right time. "Expert systems" or "knowledge-based systems" offer promise as a means of capturing, in a microcomputer, not only the factual knowledge of experts but also a portion of their problem-solving skill. Using expert systems, people with limited training can access factual information and apply problem-solving skills developed from decades of experience.

Expert systems offer considerable potential to help people organize and transmit problem-solving, soil-management expertise. Soil management deals with a highly complex, soil-plant- climate-human system. Usually a large amount of information is necessary to understand and predict a particular phenomenon; it is not often possible to reduce this large amount of information to a single rule, theorem, or axiom. Other soil science information is clearly quantitative and can be represented mathematically. Still other types of information are best represented as rules of thumb, heuristic hunches, or as patterns from analogous situations. More precise representation of agronomic and soil-management information will require a better understanding of how we retain and use accumulated soil-science knowledge. Expert systems permit capturing not only many facts but also these various types of information, so that the information need not be relearned or duplicated by following generations.

Another characteristic of soil-management information is that it tends to be rather regional. Within regions there are typical problems and frequently various solutions, developed either by farmers, extension agents or research personnel. These solutions may apply well in one region, but not in another. This characteristic of soil-management information complicates the broad application of principles and the economizing of research effort. Nonetheless there are regional analogues of soil, climate, crop, and human factors throughout the tropics, and representing these factors efficiently, in the appropriate context, would measurably assist in the application of soil-management technology.

The objectives of the expert-systems studies reported here are 1) to design and construct expert systems in soil- and crop-management technology that 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 framework.

The ACID3 System

A prototype expert system has been developed to make lime recommendations in the humid tropics. The objectives were 1) to document current methods of determining lime requirements for highly weathered soils of the tropics; 2) to provide a way to transfer current TropSoils research within Indonesia for use by extension workers and people with limited agronomic training; and 3) to provide an exploratory, learning exercise for ourselves concerning the development of an expert system and the exploration of potential applications.

The ACID3 knowledge base is largely developed from existing information and research experience. Because the primary objective has been to address soil acidity problems in the transmigration area of Indonesia, work has been focused on extractable acidity (mostly exchangeable Al) as the primary cause of yield reduction due to soil acidity.

Knowledge-Base Concepts

Table 1 presents a summary of ECEC, extractable Al and possible lime rates for three crops, used in a preliminary test of the ACID3 system. The main concepts in the knowledge base are:

1. Growth-limiting effects are primarily due to exchangeable Al, although if all cations are present in very small quantities some lime is needed to provide Ca. It is assumed that Al toxicity is closely related with Al saturation such that Al saturation is a satisfactory measure of Al toxicity.

2. It is assumed that crop tolerance to Al can be adequately represented by Al saturation corresponding to 90 to 95% relative yield in field experiments. Crops vary considerably in their tolerance to exchangeable Al; extremes are represented by mung bean (very intolerant, tolerating no more than 0% Al saturation) and cassava (very tolerant, tolerating about 75% Al saturation).

3. Organic material seems to reduce lime requirements. The current approximation is that 10 ton/ha of organic material reduces the lime requirement by 1 ton/ha.

4. Lime requirements should be based on soil analyses in order to accurately reflect the soil conditions.

The calculation of a lime requirement is based on the need to neutralize sufficient Al to reduce aluminum saturation to the "critical level" established for the various crops, thereby adjusting soil properties to match crop requirements. Our modified form of the equation suggested by Cochrane et al., 1980, is:

Lime requirement (t/ha) = 1.4 (exch. acidity—(CAS*ECEC/100))

where:
- exchangeable acidity is that extracted with 1N KCl and includes extractable Al and H;
- CAS is the Critical Aluminum Saturation or the present Al saturation at which crop yield is no lower than 80-90% of maximum obtainable with adequate lime;
- ECEC is the "effective cation exchange capacity;"
- the value 1.4 represents the relation of the cmols of $CaCO_3$ required to neutralize 1 cmol of Al and H. This value is determined from field studies and is adjusted for both bulk density and depth of incorporation.

Table 1. General summary of ECEC, extractable Al, and possible lime rates for soybean (Orba), upland rice, and maize used in development of the ACID3 expert system.

	ECEC	Ex. Al	Soybean	Rice	Maize
	meq/100g		t/ha		
General					
mean	6.78	4.16	5.42	0.2	3.18
std dev	6.4	4.8	7.6	4.9	6.1
Aceh (n = 35)					
mean	7.27	4.11	5.04	0	2.64
std dev	5.7	3.9	6.1	4.3	5.0
N. Sumatera (n = 17)					
mean	4.59	2.92	3.90	0.4	2.38
std dev	3.2	2.5	3.9	2	3.0
Sumatera Barat (n = 14)					
d mean	6.37	4.20	5.74	0.8	3.64
std dev	1.7	1.5	2.8	2	2.5
Riau (n = 105)					
mean	10.8	7.07	9.63	1.3	6.07
std dev	8.9	7.0	12	9.	10
Jambi (n = 76)					
mean	5.38	3.59	4.94	0.8	3.20
std dev	2.5	2.1	3.4	2	3
Bengkulu (n = 10)					
mean	4.74	2.63	3.18	0	1.62
std dev	2.9	2.2	3.3	1.	2.4
Sumatera Selatan (n = 63)					
mean	3.71	2.17	2.74	0	1.52
std dev	1.7	1.6	2.6	1	2.1
Lampung (n = 93)					
mean	3.22	1.74	2.05	0	0.98
std dev	1.3	1.1	1.8	1	1.5
West Java (n = 35)					
mean	15.0	7.44	8.15	0	3.22
std dev	13	10	16	8	12
East Kalimantan (n = 26)					
mean	9.10	5.82	7.81	1	4.80
std dev	2.6	2.0	3.8	4	3.6
Kalimantan Barat (n = 20)					
mean	8.49	6.48	9.59	3.06	6.79
std dev	2.9	2.6	4.1	2.0	3.2
Kalimantan Selatan (n = 38)					
mean	6.42	4.01	5.29	0.35	3.17
std dev	2.0	2.0	3.4	2.2	2.9
Kalimantan Tengan (n = 37)					
mean	5.06	3.34	4.57	0.67	2.90
std dev	2.3	2.1	3.3	1.7	2.6
Sulawesi Tengah (n = 15)					
mean	4.05	2.28	2.78	0	1.45
std dev	1.5	1.4	2.5	2	2.1
Sulawesi Tenggara (n = 50)					
mean	4.75	2.25	2.34	0	0.77
std dev	1.5	1.0	1.8	2	1.8

In this case 1.9 cmol of Ca was required for each cmol of Al + H, the bulk density was assumed to be 1.0, and depth of incorporation was assumed to be 15 cm.

Preliminary data by Wade et al. suggest approximately 0.53 cmol KCl-extractable acidity is neutralized for each cmol of Ca added as $CaCO_3$. This corresponds to a relation of 1.9 cmol of $CaCO_3$ being required for each cmol of extractable acidity, a value in keeping with results reported elsewhere. This reference points out the need to consider the effectiveness of lime in neutralizing the extractable acidity. Such data should be obtained in field studies if possible because of the need to ensure that liming material and soil reactivity are tested in conditions that are representative of the situation or group of farmers to which the eventual recommendation is intended to apply.

Other data and results from the TropSoils work in Sitiung are incorporated, such as minimal requirements of P and K for soybean, rice, cowpea and peanut.

System Design

A directed graph of ACID3 is shown in Figure 1. The system is designed to apply to the Humid Tropics with soils of the Ultisol, Oxisol, and Inceptisol orders. In addition, the system has additional information pertinent to the Sitiung region, Indonesia. The general recommendations are based on other relationships such as a general reactivity of 2 cmol of $CaCO_3$ for each cmol of extractable acidity. Levels of critical aluminum saturation are, so far, the same for the general recommendation as for the specific location in Sitiung.

At present soil great group is incorporated for aquic- and fragi-subgroups. This has been expanded in an attempt to access a much larger data base such as that being developed by the Center for Soil Research of their extensive collection of soils data from various surveys and inventories, and the foreign soil data base of the Soil Conservation Service. Such data bases will be used to provide detailed soil data if the user provides the town or geographic location. The data base access by the expert system provides information on soil characteristics or specific problems that might be important for crop production or soil management in the area. A version of the system has been translated into the Indonesian language for more extensive testing.

As this project develops, a group of recognized authorities in soil acidity and liming will be assembled in order to capture their expertise, which will then be evaluated for implementation in the expert system.

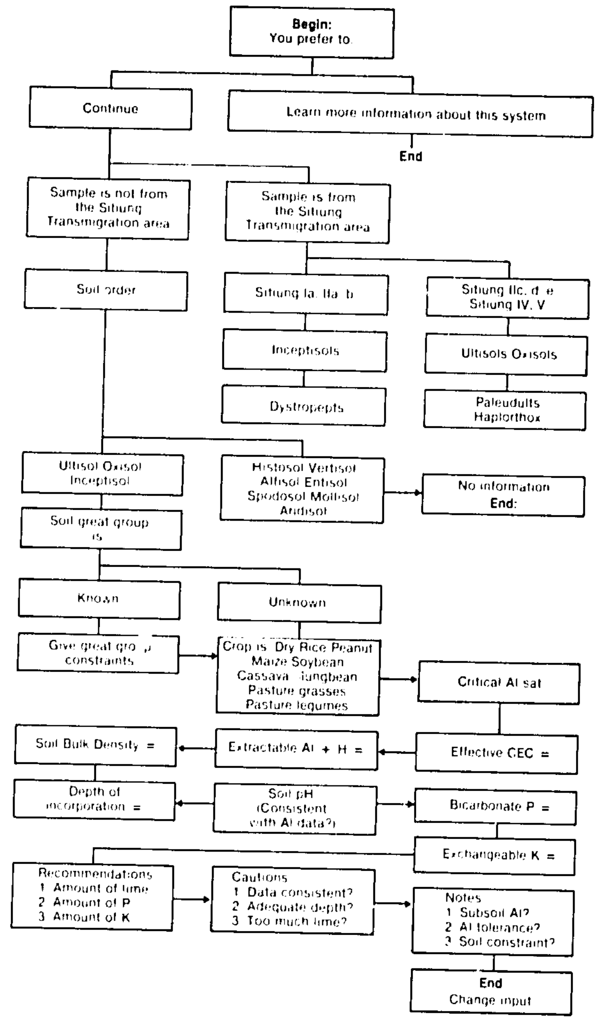


Figure 1. Directed graph of ACID3 expert system.

The expert system will be compared with practical experience wherever available.

Future developments include interfacing the expert system with water balance simulation models and detailed soil data bases.

Variance in input data will be propagated through the system to arrive at estimates of the reliability of the recommendations.

Farmer Information

Another expert system is being developed to organize farmer information in the expert-systems format. This system is intended to provide information to policymakers in the Indonesian government, TropSoils team members, and farming-systems workers.

Pasture Grasses and Legumes For the Humid Tropics

John F. Thompson, University of Hawaii
Carl Evensen, University of Hawaii
Russell Yost, University of Hawaii
Ronald Guyton, University of Hawaii
I Putu Gedjer Widjaja-Adhi, Center for Soil Research
Fahmuddin Agus, Center for Soil Research

In the Sitiung area, grasses and legumes have potential not only as forage crops but also as green manures and cover crops that may help reclaim degraded lands. The objectives of this continuing study are 1) to evaluate germplasm of pasture legumes and grasses under Sitiung edaphic and climatic conditions, 2) to determine most productive forages and to consider applications as green manures and cover crops as well as animal feeds, and 3) to participate in pasture-legume trials as part of the Centro Internacional de Agricultura Tropical (CIAT) network.

New-Project Update

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

The research was conducted in Sitiung I, on land cleared by bulldozing seven years before. Treatments are listed in Table 1. Twenty-two accessions were supplied by CIAT, and there were nine treatments using germplasm available locally. Lime was broadcast over all plots at a rate of 375 kg $CaCO_3$/ha (to give about 0.5 me Ca/100 g soil to a depth of 15 cm) except on several high-lime plots, which were limed at a rate of 5.4 t/ha (2 x me Al). Phosphorus was banded at 40 kg P/ha. The P (triple superphosphate) was applied in 20 cm wide strips and hoed in to a 20 cm depth. The seed was planted in rows 50 cm apart. Plot dimensions were 2 m x 5 m, with 1 m gaps between plots.

Data were collected according to CIAT's guidelines, and included 1) plant counts and height measurements during establishment; 2) plant counts and height during production; 3) dry-matter production at eight-week intervals, except during periods of minimum or maximum precipitation, when subplots were harvested at intervals of three, six, nine and 12 weeks. Also, some estimates were made of plant canopy coverage ("mulching percentage").

Summary

Several species of both grasses and legumes that are well adapted and highly productive have been identified, although their persistence and productivity over time remains to be determined. As this study progresses, the results are expected to be useful to related projects involving forage, green manures, land reclamation and home gardens. In addition farmers in the Sitiung area express strong interest in obtaining improved forage crops, and have agreed to cooperate in the research by supplying information about palatability and consumption by livestock.

LAND RECLAMATION: SOIL PHYSICS AND SOIL CONSERVATION

The clearing of rainforests often leads to soil degradation through the loss or rapid decomposition of organic matter, leaching of nutrients, soil compaction and erosion. Many fields in the Sitiung area have been cleared of rainforest by bulldozers. This method, unless carefully managed, can compound land-clearing's detrimental effects. Some bulldozed areas at the settlements are barren, and have been abandoned.

Studies reported here are part of an effort to find ways to promote and conserve soil physical properties favorable to crop production, to improve land-clearing methods, and to reclaim soils damaged by clearing. Central to this effort is the judicious management of organic matter, which is an important component in highly leached and weathered tropical soils. Soil organic matter---applied by farmers as manure, green manure, crop residues and mulch---is associated with increased cation exchange capacity and improved soil structure, and provides many important plant nutrients. Studies at Sitiung have shown that the use of green manures can reduce the need of costly fertilizer inputs for low-input farmers. Work with forages is expected to identify varieties that will conserve cleared soils, while providing better nutrition for livestock.

Several projects in this subject area are not reported because they have only recently begun. One of these is designed to quantify the rainfall erosion potential for major agro-environments at Sitiung, and to evaluate farming and soil-management practices for their effectiveness in controlling erosion and using rainwater efficiently.

Management of Organic Material In Indonesian Farming Systems

Carl Evensen, University of Hawaii
Russell Yost, University of Hawaii
Mike Wade, N. C. State University

The marked response of some crops to green manure in previous experiments has suggested that the proper management of organic matter might reduce the need for lime and fertilizer on Sitiung farms. The two studies described here are designed to quantify the influence of green manure on crop yields and fertilizer and lime requirements, to determine the adaptability of selected tree and herbaceous legumes for use on transmigrant farms, and to incorporate information from Sitiung transmigrants in the selection and design of legume-management systems.

Alley-Cropping Experiment

The objectives of this study are 1) to determine Al tolerance of three legume tree species under Sitiung conditions; 2) to determine their N, leaf, and wood production; 3) to measure the effects of green leaf manure (GLM) additions on the yields of rice and cowpea intercropped with the trees; 4) to measure effects of these organic-matter additions on soil chemical properties and their interactions with crop growth; and 5) to select appropriate legume tree species and liming levels for farmer testing.

The soil is a Typic Paleudult; clayey, kaolinitic, isohyperthermic. The site was cleared by manual felling then bulldozing but was never cropped, and was heavily eroded in parts. The experiment is laid out in a split plot design with four replications. The main plots were three tree species, *Albizia falcataria*, *Calliandra calothyrsus*, *Gliricidia sepium*, and a treeless control. Subplots were liming levels of no lime, low lime (375 kg $CaCO_3$/ha/year to provide 0.5 meq Ca/100g soil to 15 cm depth), and a liming rate to reduce Al saturation to 25% (2 t $CaCO_3$/ha in the first year).

During the establishment of alley-cropped trees, rice was planted, followed by cowpea. The lime was broadcast over the subplots along with a blanket application of P at a rate of 40 kg P/ha. To establish the tree hedges, TSP was applied in strips equivalent to 80 kg/ha of P. The trees were planted in hedgerows over the fertilized strips. Intra-row spacing between the trees is 12.5 cm for *Albizia* and *Calliandra*, and 25 cm for *Gliricidia*. Hedgerows are 4 m apart. Subplot size is 5.5 m x 12 m for the alley-cropped plots and 5.5m x 6m for the treeless control plots. 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.

Rice in Alley-Cropping

Upland rice ("Sentani") was planted at a 25 x 25 cm spacing, skipping one row of rice where there was a row of trees. Nitrogen was sidedressed at 25 kg N/ha at 42 days after planting. However, rice blast began to appear at about this time and became so severe that almost no grain was produced. The crop was harvested for total plant weight. The alley-cropped trees were quite small and were not expected to affect rice yields at this time, however a liming effect as well as extreme soil microvariability were observed. Zero-lime subplots were extremely stunted and chlorotic.

Cowpea in Alley-Cropping

A semi-determinate local variety of cowpea was planted at 20 cm intra-row x 40 cm inter-row spacing. No rows of cowpeas were skipped in subplots with trees (ie. rows of cowpea were planted 20 cm on either side of the tree rows). No additional fertilizer was applied, so that soil microvariability could be further characterized.

Germination was excellent, but within two weeks, plots without lime had extensive leaf chlorosis and necrosis and seedling mortality of 30 to 50%. At both low and high lime rates, plants were fairly healthy, although throughout the experiment, many plants exhibited leaf bronzing and purplish-brown mottling along the veins. This may indicate a K deficiency or Ca deficiency/Al toxicity, since it was much worse in the unlimed subplots. The alley-cropped tree species were much more vigorous by this time and, especially in the case of the *Albizia*, competed for light with the cowpeas. However, there was a prolonged drought from mid-June to late-July, which severely reduced pod set and yields. Thus, when cowpeas were harvested only total plant weights were measured.

Table 1. Upland rice response to liming.

Lime Rate kg/ha	Dry Matter Yield kg/ha	Plant Height cm
0	940	32
375	2005	50
2000	1667	46
LSD (0.05)	620	9

Crop Response

Total plant dry matter yields and plant heights in the upland rice crop showed a highly significant response to lime. There was no significant difference between the low and the high rates of lime (Table 1). There was also no rice growth response to the tree species, since the trees were too young to compete with the rice and had not yet been trimmed for green manure.

An analysis of variance for total dry-matter yields of cowpea indicated that tree species had a significant effect (0.05 level) and that liming rates had a highly significant effect (0.01 level) on cowpea yields. Table 2 shows that cowpea yields were significantly increased by lime application, although the low and high lime rates produced the same yields. This supports the earlier observation in the upland rice crop that 375 kg lime/ha is sufficient for Al tolerant crops on this soil. Table 2 also shows that the *Albizia* hedge significantly decreased cowpea yields (undoubtedly through shading, since the *Albizia* trees averaged 3-4 m in height by cowpea harvest). The other trees did not significantly differ from the treeless control in effects on the cowpea crop.

Discussion

Competition between the trees and intercropped food crops will not be so severe in subsequent crops because tree hedges will be cut to a 40-50 cm stubble every few months. It is expected that application of the GLM will more than compensate for tree/food-crop competition. Earlier planting should reduce blast infection and improve soil moisture conditions, which together should improve the dismal yields obtained in the first two crops.

Source and Management of Green Manures

The objectives of this study are: 1) to compare two legume cover crops for nutrient contribution to intercropped plants and organic matter maintenance in the soil; 2) to compare three methods of production and application of cover-crop organic material as measured by subsequent crop yields; 3) to determine the extent to which green manures reduce lime requirements; and 4) to determine the response curve of upland rice to inorganic N and to compare this response to that from the application of a legume green manure.

The soil and site are similar to those in the alley-cropping study. The experimental factors and treatments are shown in Table 3 and Table 4, respectively. There are three replications and plot dimensions of 4 m x 6 m.

Table 2. Total dry-matter yield of cowpeas (vines and pods) in response to liming and to alley-cropped trees.

Lime Rate kg/ha	Dry Matter Yield kg/ha	Tree Species	Dry Matter Yield kg/ha
0	73	No tree	256
375	215	Calliandra	189
2000	216	Gliricidia	175
		Albizia	49
LSD (0.05)	92	LSD (0.05)	118

A semi-determinate local variety of cowpea was planted as a uniformity trial to characterize soil variability before imposition of the treatments. P was applied as a blanket application on all plots at a rate of 40 kg P/ha. Germination was delayed for over a week by drought and was not uniform. Because of uneven plant growth, harvesting of pods was staggered over several weeks. Cowpea yields and soil analyses from each plot were used to determine between-plot variability. Within plot variability was visually rated on the basis of uniform growth and vigor of plants within each plot. Both between-plot and within-plot variability were used to select "uniform" plots to be included in each block of the subsequent experiment.

Table 3. Experimental factors.

Green manure species
1) Calopogonium mucunoides
2) Crotalaria usaramoensis
3) Centrosema pubescens

Methods of cover-crop application
1) in situ incorporation
2) cut-and-carry
3) residue roots and stubble used to produce cut-and-carry material

Levls of lime
1) L0 = no lime
2) L1 = 375 kg CaC03/ha
3) L2 = liming to 40% A1 saturation
4) L3 = liming to 20% A1 saturation

Levls of N
1) N0 = no N
2) N1 = 30 kg N/ha (split application)
3) N2 = 60 kg N/ha (split application)
4) N3 = 120 kg N/ha (split application)

Table 4. Experimental treatments in the green manure study

Treatment No.	Green Manure sp.	Application Method	Nitrogen, 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,L1
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)	—	NI,L2
19	check (no gm)	—	N2,L2
20	check (no gm)	—	N3,L2,

Crop Response

Crop yields and soil analysis data summarized before and after plot selection are shown in Table 5. For most of these variables, the range and variation of values was reduced by discarding 15 of the plots. The selected plots were still quite variable as measured by soil properties and yield potential; however, much of this variation was stratified into between-block variation. The soil is generally quite infertile and high in Al.

To test the effectiveness of plot selection and blocking, treatments were randomly assigned to the three blocks of "uniform" plots and an analysis of variance was calculated using the cowpea yields from the uniformity trial. Because the treatments had not been imposed, a significant treatment effect could only have been due to inherent soil variability. As shown in Table 6, treatment effects were non-significant, which indicates that there are no systematic trends in soil variability that will cause incorrect interpretation of treatment effects. The block effects were highly significant, suggesting that plot selection and blocking had been appropriate.

Table 6. Analysis of variance for uniformity trial.

Source	df	Grain Yield	Pod Yield	Vine Yield
Block	2	***	***	***
Treatment	19	ns (0.18)	ns (0.25)	ns (0.15)
Error	38			

*** Significant at 0.001 level (Probability value)

Table 5. Cowpea growth and soil test analyses summarized from the uniformity trial before and after plot selection.

	Yields, kg/ha			Soil Analyses		
	Grain	Pod	Vine	Al+H	Ca+Mg	Al Sat.
				---- meg/100g ----		%
75 original Plots:						
Mean	653	1170	665	2.27	0.69	74
St'd Dev.	269	488	390	0.30	0.23	6.0
Minimum	78	126	119	1.40	0.30	57
Maximum	1397	2568	2005	3.40	1.50	84
60 Selected Plots:						
Mean	654	1173	652	2.25	0.70	74
St'd Dev.	236	425	350	0.33	0.23	5.8
Mimimum	185	330	169	1.50	0.30	57
Maximum	1116	1891	1415	3.00	1.50	83

Contributions to Hawaii Agriculture

A major purpose of the Collaborative Research Support Program is to integrate its research with that of other federal and state programs in order to maximize contributions to agriculture in the United States and developing countries. To achieve this purpose, the University of Hawaii has made its TropSoils program an integral part of a larger effort that employs systems analysis and crop simulation to combine state, federal, and international projects into a program that produces outputs useful to local, national and international clients. The central concept of systems-based research is that the whole system must be understood in order to evaluate benefits derived from introducing new crops, products and practices into an existing farming system. Systems-based research compels scientists to seek out and understand key processds that regulate systems performance and enables users to predict and control outcomes of farm operations.

Crop Models and Expert Systems

An important ingredient of systems-based research is crop modeling. A crop model, properly formulated, can predict the performances of the crop in question in Hawaii, Sumatra, or within limits, anywhere in the tropics. A corn model obtained from another federally supported project has been tested and validated in Hawaii and Indonesia with good results (see report on "Matching Crop Requirements of Rice, Maize, Soybean, and Peanut to Soil Characteristics with Crop Simulation Models"). The crop model is able to deal with temporal weather variability, but requires that a minimum data set of daily solar radiation, rainfall, and temperature is recorded. A network of weather stations purchased from state and TropSoils funds has been installed in Hawaii and Sumatra to collect the minimum data set to test and validate crop models.

Crop modeling is one part of a decision-support system for farmers. A second is the use of expert systems developed to capture, in microcomputers, not only factual information but also the reasoning of scientists and the large amount of local knowledge stored in the minds of farmers. The decision-support system will be sufficiently general to accommodate conditions in Hawaii and Indonesia.

Farming Systems

A soil-climate project funded by the Hawaii Institute of Tropical Agriculture and Human Resources is applying, in Hawaii, principles and concepts of farming systems designed for TropSoils/Indonesia. The purpose of the project is to account for the high variability in crop productivity and quality along the slopes of Mt. Haleakala, a major vegetable-growing area of the state. The project hypothesis is that the variability is due to soil and climate variability. A network of weather stations has been installed in the area, and benchmark locations have been characterized for soils variability.

Before installing experiments to test this hypothesis, researchers met with farmers to obtain their perceptions of problems and priorities. The farmers are delighted that a research project designed by them to answer specific questions raised by them is in place. The farm foreman makes special effort to ensure that the field plots are properly monitored. The farmers are provided with summary reports of project status and many visit the experiments to observe how location, date of planting, and planting density affect size, shape, and color of cabbage. They are now asking that the project look at a second cultivar.

Researchers involved in this study learned that fertilizer application varied greatly among farms. This difference was clearly reflected in the soil test. The most variable nutrient was phosphorus, which ranged from 20 to 40 ppm by a modified Truog test. Researchers are now beginning to suspect that the critical soil test value for phosphorus may be temperature-dependent. Corn grown at three elevations seem to confirm the fact that corn grown in the highest elevation requires higher soil-test phosphorus.

As has been found in Indonesia, scientists and farmers alike benefit from the collaboration, and farmers' contribution to the research substantially ensures the applicability of its results.

VA Mycorrhizal Inocula

Research on VA Mycorrhizal inocula indicated that this group of organisms not only affects soil-plant phosphorus relations but the soil-plant-water relationship as well (see report on "Assessing Field Inoculation with Introduced and Indigenous Mycorrhizal Inocula by Crop Growth and Yield on Soil Cleared of Tropical Rain Forest"). Related work on a state-funded project showed that methyl bromide soil fumigation severely reduces yield in mycorrhizal plants, but can significantly increase yield in non-mycorrhizal plants such as cabbage.

Publications, University of Hawaii

Cochrane, T. T., J. A. Salinas and P. A. Sanchez. 1980. An equation for liming acid mineral soils to compensate crop aluminum tolerance. *Tropical Agriculture*. 57:133-140.

Evensen, C., H. Agus, and C.J.P. Colfer. A comparison of research and farmer perceptions of constraints to agricultural production. Presented at International Farming Systems Meeting, December 1985, Sukarami, West Sumatra, Indonesia.

Singh, U., G. Uehara and C.A. Jones. Simulating corn (*Zea mays* L.) performance in the tropics. Presented at 77th annual meeting of American Society of Agronomy, December. 1985, Chicago, Illinois.

Singh, U. A crop growth model for predicting corn (*Zea mays* L.) performance in the tropics. Ph.D. dissertation, University of Hawaii, 1985.

Trangmar, B.B., R.S. Yost and G. Uehara. 1986. Spatial dependence and interpolation of soil properties in West Sumatra, Indonesia. I. Anisotropic variation II. *Soil Science Society of America Journal. Vol 50.*

Trangmar, B.B., R.S. Yost and G. Uehara. 1985. Application of Geostatistics to Spatial Studies of Soil Properties. Vol. 38:45-94. Advances in Agronomy, Academic Press.

Trangmar, B.B. Spatial variability of soil properties in Sitiung, West Sumatra, Indonesia. Ph.D. dissertation, University of Hawaii, 1984.

Trangmar, B.B., R.S. Yost and G. Uehara. 1986. II. Co-regionalization and co-kriging. *Soil Science Society of America Journal*. 50:000. Vol. 50.

Uehara, G., B.B. Trangmar and R.S. Yost. 1985. Spatial variability of soil properties. In *Soil Spatial Variability*, D.R. Nielson and J. Bouma, eds. Proceedings of a workshop of the ISSA and SSSA, Las Vegas, Nev. December 1984. Pudoc, Wageningen.

Uehara, G. and R.S. Yost. Spatial and temporal agroecosystem variability. Symposia on Future Developments in Soil Science. Presented at 1986 meeting of the Soil Science Society of America. New Orleans, La. 1986.

Wade, M., F. Agus and C.J.P. Colfer. The incorporation of information from collaborator farmers into a research strategy: a till-no-till example from Sitiung. Presented at the International Farming Systems Meeting, December 1985, Sukarami, West Sumatra, Indonesia.

Yost, R. S., G. Uehara and S. Itoga. 1986. Applications of expert systems to soil management. Paper presented to the Society of Manufacturing Engineering at the Agri-Mation II Conference, Chicago, Illinois, March 1986.

Yost, R.S., S. Itoga, Z.C. Li and P. Kilham. Soil acidity management with expert systems. Proceedings of IB-SRAM seminar on soil acidity, land clearing and Vertisols. Oct. 13)20. 1986. Khon Kaen, Thailand.

Yost, R. S., G. Uehara, M. Wade, I P.G. Widjaja-Adhi and M. Sudjadi. 1986. *Expert systems in agriculture: determining lime requirements for soils of the humid tropics.* Research Bulletin No. 00, Hawaii Institute for Tropical Agriculture and Human Resources. Publications, Texas A&M University.

Acid Savannas
Cornell University

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 other savannas, as well.

Contents

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 emphasizes 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 manures as compared to using fertilizer nitrogen alone because, 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 within 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. One study in this group is not reported. The project, "Soil and Crop Management Systems for Acid Savanna Soils Using Green Manures and Crop Residues as Nitrogen Sources,' is designed to develop planting sequences and cropping systems that effectively use organic sources of nitrogen; to evaluate the role of these sources in nitrogen cycling and soil organic matter; and to determine the effects of legumes and crop residues on long-term soil productivity.

Nitrogen Availability From Legume Crop Residues And Green Manures To Succeeding Nonlegume Crops

W. Shaw Reid, Cornell University
Walter T. Bowen, Cornell University
Robert J. Carsky, Cornell University
Eric R. Stoner, Cornell University
Allert R. Suhet, CPAC

This field experiment was designed to compare the accumulation of inorganic nitrogen in clean fallow soil with the yield response and nitrogen uptake by maize after incorporating leguminous residues. It was conducted on a red-yellow latosol (Acrustox) at the Centro de Pesquisa Agropecuaria dos Cerrados (CPAC), Planaltina, Brazil. The objectives of the experiment were 1) to determine if inorganic N accumulated in bare fallow plots is proportional to N taken up by maize at the end of the growing season; 2) to compare the N mineralization patterns of a legume plowed under as green manure (high N concentration) with a legume harvested for grain and only residue (low N concentration) plowed under; 3) to determine the relative rates of aboveground N accumulation by maize on a soil amended by legume green manure versus unamended soil; and 4) to observe the residual effect of incorporated legume plant materials on a second maize crop.

A legume green manure, *Mucuna aterrima* (Piper & Tracy) Merr., and soybean, *Glycine max* L. Merr. 'Cristalina', were established during the 1983-84 wet season (Dec., 1983 to May, 1984), followed by a crop of maize (Cargill 111) irrigated by sprinkler during the 1984 dry season (June to Nov., 1984), and a second maize crop during the 1984-85 wet season (Dec., 1984 to June, 1985).

N Mineralization

The treatments established for the first maize crop to achieve objectives 1 and 2 are shown in Table 1. After planting maize, the amount of inorganic N accumulated in adjacent bare fallow plots was determined approximately every two weeks until maize harvest. Leaching was minimized with controlled irrigation until rainfall became sufficient to meet plant needs in September, 1984.

There was a significant ($P = .01$) linear relationship between inorganic N accumulated in fallow plots to a depth of 120 cm and aboveground N recovered in maize at harvest. The equation describing this relationship was:

$$N_p = 56.5 + \underset{(0.034)}{0.23}\, N_I \qquad R^2 = .62$$

where

N_p = total aboveground N in maize (kg/ha)

and

N_I = inorganic N accumulated in fallow plots to 120 cm (kg/ha).

Organic N added in mucuna tops (3.0% N) was more rapidly mineralized than that added in soybean residues (1.5% N). About 65% of the N in mucuna tops versus 40% of the N in soybean residues was mineralized in fallow soil during the first maize season. The proportion of organic N mineralized in mucuna tops was approximately the same regardless of the amount of dry matter added.

Residual Effects

All treatments in Table 1 except SR and MR were maintained during the second maize season to observe

Table 1. Mean dry matter and total N of aboveground plant materials incorporated in designated fallow and cropped (maize) plots.

Treatment	Grown During 83-84 Wet Season	Incorporated June 1984	D.M. t/ha	total N kg/ha
MT+R	Mucuna	Whole plant	8.8	260
MR	Mucuna	Roots (tops removed)	-	-
ST+R	Soybean	Whole plant minus grain	7.3	108
SR	Soybean	Roots (tops/grain removed)	-	-
MT	Bare Fallow	Mucuna tops from MR plot	8.5	252
HMT	Bare Fallow	Mucuna tops from extra plot	4.3	128
C	Bare Fallow	None (check)	-	-

Table 2. Mean dry matter grain yields and total aboveground N in 1984 and 1985 maize crops.

Treatment	I.D.	Aboveground Organic N Added		Grain		Total Aboveground N	
		1984	1985	1984	1985	1984	1985
				t/ha		kg/ha	
MT+R	Mucuna tops + roots	260	—	6.3	6.8	168	149
MT	Mucuna tops	252	—	5.6	6.6	168	147
HMT	Half Mucuna tops	128	—	5.1	6.0	149	137
ST+R	Soybean residue	108	—	5.3	4.7	116	98
MR	Mucuna roots	—	—	5.7	—	125	—
SR	Soybean roots	—	—	4.3	—	84	—
FMT	Fresh Mucuna tops	—	180	—	6.8	—	145
C	Check	—	—	4.9	4.6	120	111

residual effects. A new treatment of fresh mucuna tops (FMT) (5.6 t DM/ha, 180 kg N/ha) was then applied to a set of fallow and cropped plots in all reps. After the maize germinated, inorganic N was measured periodically in both fallow and cropped soil of the FMT and a check treatment (C). Aboveground maize plant samples were also taken at the same time to determine N uptake in both treatments.

Mineralization of the mucuna was rapid; 13 days after incorporation an increase of 56 kg/ha of inorganic N over the check was accumulated to a 60 cm depth. The increase in inorganic N in the profile due to mineralization of mucuna tops was reflected in greater N uptake by maize (Figure 1). Inorganic N that accumulated in fallow soil was significantly proportional to N uptake until heavy rains late in the season leached the inorganic N from soil profile (120 cm depth).

Mucuna tops showed a significant residual effect on maize grain yields and total aboveground N (Table 2). Even though total aboveground N was slightly less in the second crop, grain yields across all mucuna-tops treatments were from 8 to 17% greater than grain yields in the first crop. The 260 kg organic N/ha applied before the first crop (MT+R) gave the same grain yield and N uptake in the second crop as the 180 kg organic N/ha applied just before the second crop (FMT). There was essentially no residual effect from soybean residues.

Legume Roots and P

One explanation for the lower than expected grain yields from treatments MT and HMT in 1984 may be related to early phosphorus deficiency. Early in the season, maize plants on all plots except those where mucuna or soybean had grown showed visible signs of P deficiency. A mycorrhizal study revealed a significantly greater ($P < 0.01$ and $P < 0.1$, respectively) VA mycorrhizal population on maize roots where either soybean or mucuna roots were present. Total root length and P content in plant tissue were also significantly greater ($P = 0.1$) on these plots. The affected maize plants quickly grew out of their P deficiency symptoms, and final yield data showed no difference in P content. However, P may have been lacking long enough in the MT and HMT plots to have reduced potential grain yields.

Conclusions

1. There was a significant linear relationship between inorganic N accumulated in fallow soil to a depth of 120 cm and aboveground N recovered in maize at harvest.

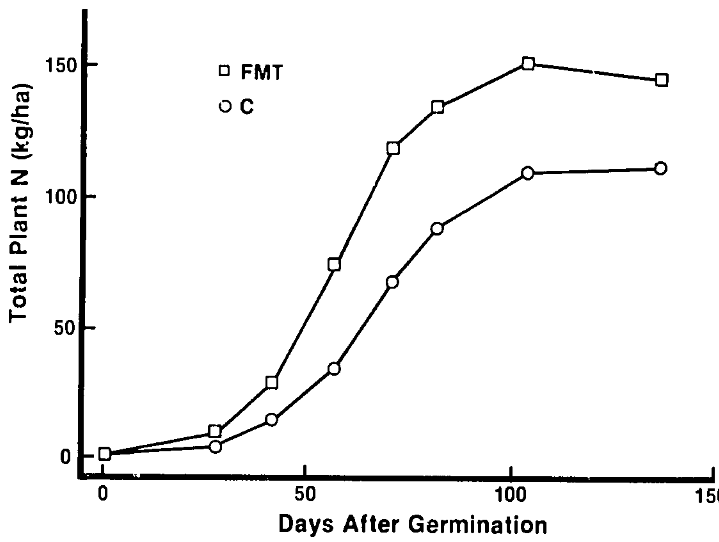


Figure 1. Total accumulation of aboveground N by maize during the 1984-85 wet season in the Cerrado. FMT = fresh mucuna tops applied as green manure; C = check.

2. More organic N was mineralized from mucuna tops than soybean residues due to differences in plant N concentration.

3. Maximum rates of N uptake by maize under the conditions of this experiment occurred between 40 and 90 days after germination, and the uptake was increased by adding organic N in mucuna tops.

4. At least two consecutive maize crops benefited significantly from organic N added in mucuna tops incorporated shortly before the first crop. The benefit was greater as the amount of N incorporated increased.

5. The two legumes used in this study appear to serve as hosts for increasing the indigenous mycorrhizal population in red-yellow latosols.

Implications

The measurement of inorganic N accumulated in bare fallow soil could be used as a field screening procedure to evaluate a large number of legume species for their potential N benefit to a succeeding maize crop (subject to the condition that leaching is minimized to recover as much of the soil inorganic N as possible). While green manures have been evaluated primarily for their ability to supply N, their contribution to mycorrhizal populations, and an improved uptake of P by maize, would increase their potential value in cropping rotations. Further work on this project will test a number of legumes in an attempt to find a green manure crop whose mineralization rate more closely matches the needs of maize.

Evaluation of the Mineralization Potential of Legume Residues Through Laboratory Incubation Studies

D. R. Bouldin, Cornell University
J. Quintana, EMBRAPA/CPAC
Allert Rose Suhet, EMBRAPA/CPAC

Studies in the acid savannas of Brazil have shown that legume green manures and other sources of organic matter can supply significant amounts of nitrogen to food crops. In the most effective nitrogen-management system, organic sources would mineralize at a rate corresponding to the needs of the crop. Devising such a system requires knowledge of the rates and periods of N mineralization for each organic N source and each set of soils and conditions. The objectives of this study, which is continuing at the Centro de Pesquisa Agropecuaria (CPAC), are 1) to develop and calibrate a laboratory incubation procedure that will assess the N mineralization potential of the soil; 2) to evaluate legume residues as sources of N using incubation and cropping experiments; and 3) to evaluate an incubation procedure as a soil test for N in field experiments.

Laboratory work was begun using soil samples and field results obtained in a companion project entitled "Nitrogen availability from legume crop residues and green manures to succeeding non-legume crops." Details of the field experiments will be found in that report. Soil samples from the 0-15 cm and 15-30 cm layers of the experiments were analyzed for ammonium and nitrate initially, and after one and two weeks of incubation at 35°C. Samples were pretreated in three ways: air-drying; air-drying followed by oven drying at 50°C; and air-drying followed by oven drying at 100°C.

Results

Correlations between corn yields and mineral N (NH_4 + NO_3) in laboratory samples were best when samples were oven dried and incubated. The correlations were as follows:

1984 corn yields and two-week incubation following 50°C oven drying	0.610
1985 (residual) corn yields and two-week incubation following 50°C oven drying	0.469
1984 and 1985 corn yields combined with above incubation	0.523

Figure 1 illustrates the average values for mineral N in fallow plots in the field (1984) and mineral N following two weeks of laboratory incubation with samples oven dried at 50°C.

Discussion

The results illustrate that the incubation procedures have merit as a quick method to evaluate gross differences among different green manures incorporated in the soil. Data from the field experiments are now being analyzed in detail, and a more complete set of incubations of soil samples from those plots is being run. Once these data are available a complete statistical analysis will be performed so that such details as the length of incubation and pretreatment of soil samples can be determined.

Because the field used for the original experiments had a sizable pool of readily mineralizable organic N, crop yields and mineral N content were high on the check plots. A new site for this experiment will be treated so as to deplete the pool of mineralizable N and thereby reduce the effect of the native N pool.

Additional correlations with field data will be obtained using experimental designs similar to those reported above. Work on this experiment will progress in conjunction with the companion studies reported elsewhere in this report, and will investigate various green manures and cropping sequences, comparing results from the wet season with those from the dry season.

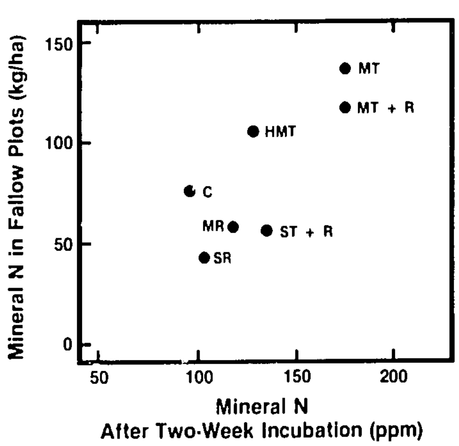


Figure 1. Mineral N in the top 60 cm of fallow plots 44 days after incorporating green manure, plotted against mineral N in incubated soil samples from the same plots. C = check; SR = soybean roots; ST + R = soybean tops plus roots; MR = mucuna roots; MT = mucuna tops; MR + T = mucuna roots plus tops; HMT = one-half mucuna tops.

Fertilizer Nitrogen Movement In Cerrado Soils

Susan J. Riha, Cornell University
R. J. Wagenet, Cornell University
Elias Freitas, EMBRAPA/CPAC

The objectives of this study, which is in its first stages, are 1) to develop a comprehensive description in the form of a simulation model of nitrogen movement and transformation in cropped soils of the Cerrado; 2) to use the model 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.

Literature Reviews

Work began with a literature review on the modeling of water and nitrogen movement in soils containing large pores and cracks (macropores). Preliminary conclusions of the review suggest that while dye studies and laboratory column techniques may reveal strongly non-homogeneous flow patterns in soils containing macropores, these results need to be interpreted with some caution. For some applications, simple, homogeneous models may quite adequately describe soil water movement. For other applications, such as those considering microbial reactions which may be localized in micropore or non-macropore regions, it may be necessary to use more detailed models that explicitly include the effects of macropores.

Planned Work

The next major objective is to design, program and test a comprehensive nitrogen simulation model. In addition to predicting the fate of fertilizer nitrogen, the model will consider transformations of organic nitrogen from the application of plant residues. The model will initially be evaluated using results from previous experiments. Two specific aspects of nitrogen management that currently appear important to consider are: 1) plant recovery of fertilizer nitrogen that has been leached to the lower portion of the root zone; and 2) the effect of management practices and the soil environment on the rate of nitrogen mineralization from plant residues. Field experiments are to be conducted at the CPAC, and appropriate meterological and soils data will be obtained for use in the model.

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.

The Effects of Gypsum Amendments on Charge Properties in Cerrado Soils

Murray B. McBride, Cornell University
Douglas Lathwell, Cornell University

The experiments reported here were conducted to determine the effect of gypsum amendments on the charge properties of two Cerrado Oxisols, a "dark red" Acrustox and a "red yellow" Acrustox. (Selected soil properties are summarized in Table 1.) The objectives were 1) to estimate the sulfate- and calcium-retention capacity of the A and B horizons of the two soils; and 2) to study the effect of sulfate adsorption on the development of charge in the soil.

Charge Characterization

Two g of air-dried samples were weighed in centrifuge tubes and washed with 0.1 N KCl to eliminate soluble aluminum. Afterward, another 20 ml of 0.1 N KCl was added and pH's adjusted with KOH or HCl to give a final range between 2 and 8. After 12 hours of equilibration the suspensions were centrifuged and the soils washed two times with 0.01 N KCl. After the last washing and centrifuging the supernatant pH's were recorded as well as the Cl, K, and Al concentrations. The K and Cl adsorbed were displaced by washing the soil with 0.5 N NH_4NO_3. The amounts of Cl and K, after correction for the entrained KCl, are estimates of the positive and negative charges respectively.

The values of the positive (AEC) and negative (CEC) charges as function of pH are summarized in Figures 1 and 2. Both the dark red and red yellow soils revealed a higher AEC in the B horizon compared to the A horizon. For the dark red soil, the CEC was the same in the A and B horizons. However, the red yellow soil had a higher CEC in the A than in the B horizon. The pH values at which the CEC was equal to the AEC, i.e. the zero point of net charge (ZPNC), were 3.86 and 4.46 for the A and B horizons respectively

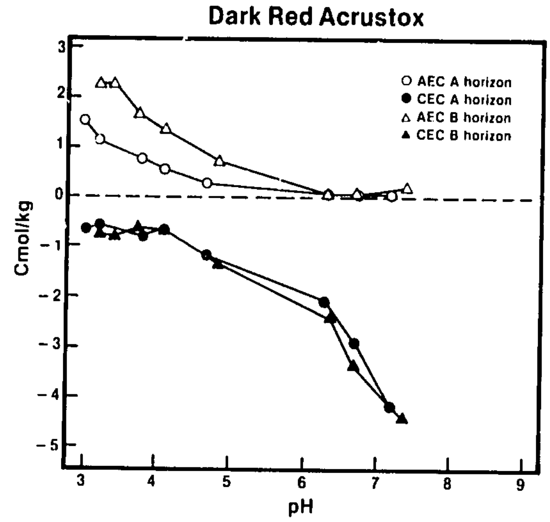


Figure 1. Variation of the anion exchange capacity (AEC) and cation exchange capacity (CEC) with pH in the A and B horizons of the dark red Acrustox.

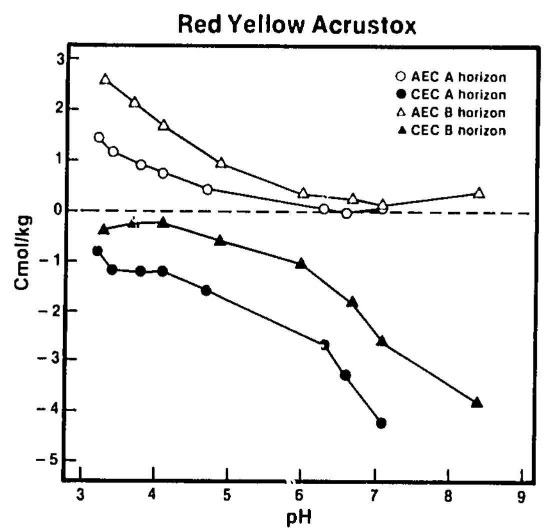


Figure 2. Variation of the anion exchange capacity (AEC) and cation exchange capacity (CEC) with pH in the A and B horizons of the red yellow Acrustox.

Table 1. Characteristics of the A and B horizons of two Cerrado soils, a Dark Red Acrustox and a Red Yellow Acrustox.

Soil		pH (1:1 H_2O)	Carbon (%)	Extractable Al (1 N KC1)	Mineralogy
Dark Red	A	4.8	2.82	0.56 cmol/kg	Kaolinite, gibbsite
	B_o1	5.4	0.96	0.03 cmol/kg	goethite & hematite
Red Yellow	A	4.7	2.39	0.47 cmol/kg	kaolinite, gibbsite
	B_o1	5.0	0.36	0.03 cmol/kg	goethite

in the dark red Acrustox; and 3.58 and 5.24 for the A and B horizons respectively in the red yellow Acrustox.

Potentiometric Titrations

Subsamples of 1.5 g of soil were suspended in 15 ml of 0.1, 0.01, 0.001 N KCl and the pH adjusted with HCl or KOH. The suspensions were stored in capped, 20 ml plastic vials and shaken twice daily for three days. After this time the pH's of the supernatants were recorded. The amounts of OH^- and H^+ adsorbed by the soil were estimated from the amount of acid or base necessary to bring the soil to a given pH minus the amount necessary to bring 15 ml of a blank solution (KCl solutions without soil) to the same pH.

The values of the points of zero salt effect (PZSE) or crossover point coincided with the zero point of net charge only in both A horizons. In the B horizons the crossover points were displaced around 0.5 cmol/kg towards the alkaline side.

The crossover points occurred at pH's 4.3 and 5.25 for the A and B horizons respectively of the dark red Acrustox; and at 4.25 and 5.2 for the A and B horizons of the red yellow Acrustox.

Discussion

The exchange complex of Oxisols is influenced by the high proportion of iron and aluminum oxides; this means that the soil may bear either a net negative or positive charge depending on the pH of the medium. The zero point of net charge (ZPNC) is the pH at which the negative equals the positive charge; below this pH the soil has a net positive charge (thus, a higher capacity to retain anions), and above it there is a negative net charge and so a higher cation retention capacity.

For the two soils studied, the ZPNC values found with the ion adsorption method are within the values reported for this kind of soil. The high ZPNC of the B horizon in the red yellow Acrustox causes the soil to have a net positive charge at the natural pH of the soil; all other soils have net negative charge at their natural pH's.

Both A horizons showed ZPNC values lower than the B horizons; this is probably due to the higher organic matter content in the upper horizons that tends to lower the ZPNC of the whole soil.

The potentiometric titrations give an estimate of the net adsorption of H^+ and OH^- (positive and negative charges respectively) as a function of pH and several electrolyte concentrations; this PZSE is generally assumed to be the equivalent of the ZPNC measured by the ion adsorption method. The results reported here show that in all cases the PZSE was higher than the ZPNC. This is also commonly reported in other studies, and is attributed to an incomplete substitution of the aluminum from the exchange surface, thus underestimating the amount of negative sites.

In order to understand the behavior of gypsum in these soils, further studies will concentrate on the relative adsorption of calcium and sulfate, and their effect on the charge status of Cerrado soils.

Ion Movement in Cerrado Soils: The Effects Of Amendments On Sulfur Availability

John M. Duxbury, Cornell University
Peter Motavalli, Cornell University

Recommended management practices for acid savanna soils include additions of large amounts of phosphorus fertilizer and lime, and amendments such as gypsum and silicates. Organic additions, such as green manures, are also being studied for their agronomic effects in these soils. Previous studies in the Cerrado have found a positive yield response to added sulfur, and increased movement of sulfur into the soils with additions of sulfate, lime, phosphorus and water. Studies have also suggested that organic matter may contribute a significant portion of the S available for plant growth in these soils. However, the effects of amendments on sulfur availability have not been well-explored. The major obstacle lies in distinguishing between the adsorbed S pool and the mineralized S fraction.

The objectives of this continuing study are 1) to determine the effects of selected inorganic and organic amendments to Cerrado soils on sulfur adsorption capacity and S movement into the subsoil; and 2) to describe the characteristics and rates of S mineralization in Cerrado soils and its response to additions of fertilizer and organic amendments. The work reported here consisted of two preliminary experiments conducted to assess the effects of inorganic and organic amendments on S availability in Cerrado soils.

Sulfate Analysis

The methylene blue reduction distillation procedure was extensively tested in order to assess its appropriateness for studying Cerrado soils. This method had been reported as the most sensitive technique for S determination. During this testing, several problems were noted with the methylene blue procedure. Many of the chemical reagents are extremely hazardous (e.g. HI, H_3PO_2 and Br_2). The procedure is time-consuming, with each sample requiring a minimum of 80 minutes to run. And, the sensitivity of the method was approximately 2 ppm SO_4^{2-}-S, which compares favorably to the turbidometric sulfate method, but is much less sensitive than ion chromatography (IC).

On the basis of these results, the methylene blue method was rejected in favor of IC, which is more sensitive and faster, and has the advantage of measuring the concentrations of several anions in one run (e.g. sulfate, nitrate, and phosphate).

Effects of Organic Amendments

The effect of organic-matter levels on sulfate adsorption and charge properties of tropical soils has been noted by several researchers. The higher levels of sulfate adsorption in the B horizons of some Brazilian soils has been attributed to the higher organic-matter content of the surface horizons. The objective of this experiment was to test the hypothesis that freshly added organic material would increase the CEC and lower the AEC of an acid soil over time. In addition, it was expected that organic-matter additions would have a greater effect on changing the surface-charge characteristics of a B horizon (containing less organic matter initially) than on the surface charge of an A horizon.

Materials and Methods

The chemical and physical properties of the Mardin silt loam (Typic Fragiochrept) from New York state used in the experiment are presented in Table 1. All soil was air-dried and passed through a 2 mm sieve. Air-dried alfalfa tissue (42% C, 3.1% N), finely ground, was the organic addition.

Treatments consisted of 0 or 2 g of alfalfa tissue per 100 g of soil (O.D. basis). Soil and alfalfa were well

Table 1. Chemical and physical properties or Mardin soil.

Horizon	pH 1:1 H_2O	pH 1:1 0.01 $CaCl_2$	Total C	Total N	Clay	Predominant Clay Minerals
			%	%	%	
A	4.9	4.0	4.56	0.28	15.1	chlorite, illite vermiculite
B	4.9	4.1	1.01	0.08	14.5	chlorite, illite vermiculite

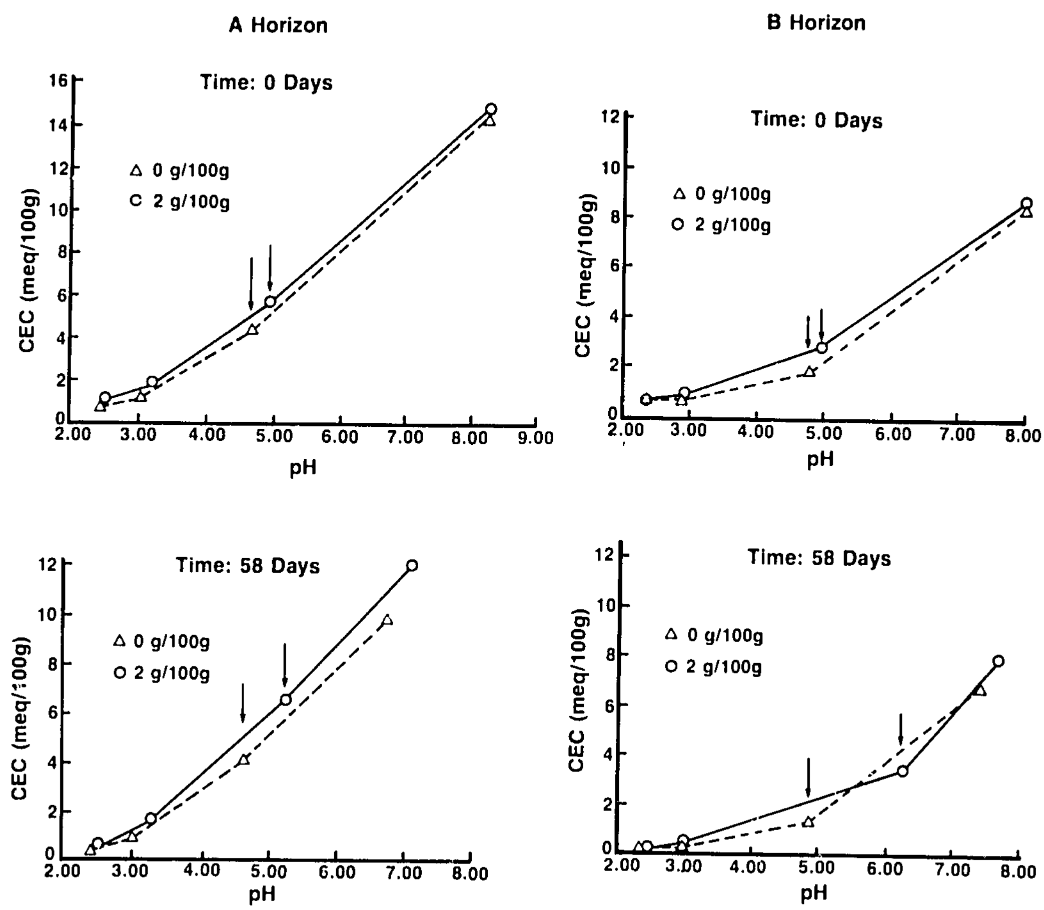


Figure 1. Effect of alfalfa addition on CEC of Mardin soil. Arrows indicate unadjusted soil pH.

mixed and the moisture content of the soil was adjusted to ⅓ bar water potential. Samples of the mixture containing 2.5 g soil (oven-dry basis) were placed in 50 ml centrifuge tubes, which were sealed with polyethylene film. The mixtures were incubated at 28° C for 0, 7, 14, 26, or 58 days. In order to compensate for evaporative losses, water was added weekly to return soil moisture content to ⅓ bar water potential.

At the end of each time period, triplicate samples of each treatment were analyzed for CEC and AEC using a variation of a washing procedure proposed by Gillman (1979). In this experiment, procedure $MgCl_2$ was used instead of $BaSO_4$ as the exchange solution, then Mg^{2+} and Cl^- were displaced using $Ca(NO)_3$. The displaced Mg^{2+} was determined by AA spectroscopy and the Cl^- by a mercury (II) thiocyanate method. To obtain CEC and AEC measurements at different soil pH values, 0, 1 or 2.5 ml of 0.1 N HCl, or 1 ml of 0.1 NaOH was added to triplicate samples after an initial washing with $MgCl_2$.

Results and Discussion

Results of CEC measurements for the 0- and 58-day incubation periods are presented for the A and B horizons in Figure 1. The addition of alfalfa increased the CEC of both the A and B horizons, but mostly because of its effects on soil pH. Alfalfa addition caused an immediate increase in pH of about 0.2-0.3 units, and the difference between amended and unamended soils became progressively greater with incubation. The largest observed increase in pH due to alfalfa addition was 1.36 pH units in the B horizon after 58 days of incubation (Figure 1).

In general, the addition of alfalfa had a small, if any, direct effect on the CEC of the soils. With soil from the B horizon, the CEC values for the two treatments appeared to lie on the same line. Incubation of the

A horizon soil with alfalfa resulted, however, in differences in CEC of about 0.5-1 meq/100 g over the pH range 4-7 after 58 days of incubation (Figure 1).

The CEC of the B horizon soil was less than that of the A horizon soil at all pH levels and at all incubation times. This difference can most probably be attributed to the higher organic matter content of the A horizon. Charge development in the B horizon soil was especially depressed relative to the A horizon soil at pH values less than 5, which may be due to more blockage of exchange sites on organic matter by Fe or Al in the B than the A horizon (the B horizon has less organic matter and more exchangeable Al). Blockage of exchange sites, which could nullify the effect of organic amendment on CEC at low pH levels, may however result in a beneficial reduction in the activity of Al^{3+} and hydroxy-Al ions.

AEC was generally not affected by the alfalfa addition. The Mardin soil used in the experiment did not have high AEC levels even at low pH. The highest AEC recorded was 0.36 meq/100 g for the B horizon at an adjusted soil pH of 2.35 and after 14 days of incubation with alfalfa.

Following these preliminary experiments at Cornell, studies will be conducted in Brazil, using existing field trials and an ion-chromatography unit at CPAC. These studies will investigate the effect of long-term applications of green manure, gypsum and phosphorus fertilizer on S movement and availability through analysis of soil profiles for exchangeable sulfate and other ions, and through S mineralization studies.

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.

Soil Morphology and Water Table Relations In Some Oxisols Of the Cerrado Region

Ray B. Bryant, Cornell University
Jamil Macedo, Centro de Pesquisa Agropecuaria dos Cerrados (CPAC/EMBRAPA)

It has been observed that water tables in soils on the high plateaus of the Cerrado region are typically higher in the red-yellow Oxisols than in the dark-red soils. Because water-table level affects such things as plant growth, drought tolerance and tillage practices, an ability to predict drainage characteristics from soil color patterns could be important in the selection and management of agricultural fields.

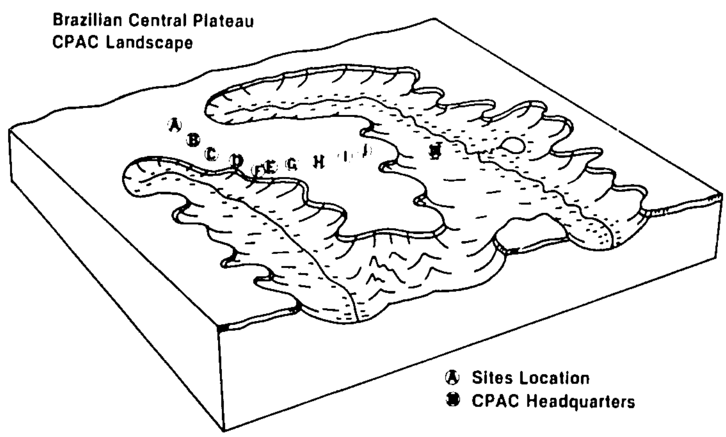


Figure 1. Sampling sites in two transects on a landscape in the Brazilian Central Plateau.

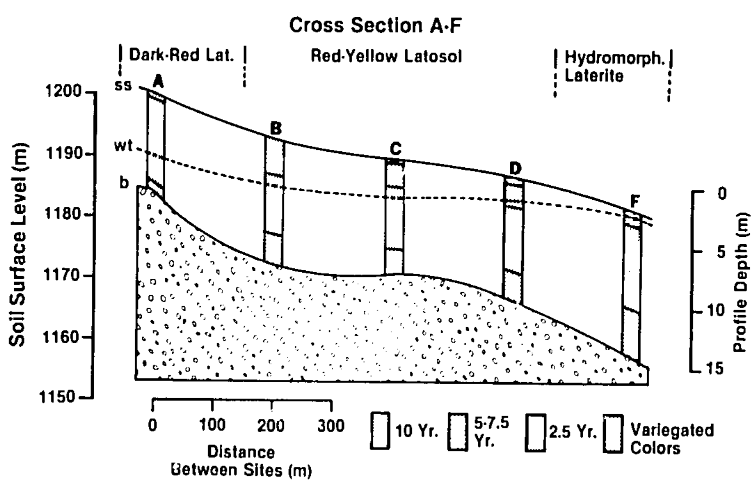


Figure 2. Distribution of soils along one transect in relation to the topography, and average depth to water table.

The objectives of this study, which was conducted at the CPAC at Planaltina, Brazil, were 1) to determine the genetic relationship between soil color patterns and natural drainage characteristics in Oxisols with restricted drainage; and 2) to develop morphological criteria for further development of the taxonomic or land capability classification of these soils with respect to natural drainage characteristics.

Soil Characterization

Characterization of the pedons sampled during the first year of this study has been completed. The well-drained soils are members of the Acrustox great group and the poorly drained soil is a Plinthaquox. In the Brazilian system, the well drained soils are classified as Dark-Red Latosols and Red-Yellow Latosols on the basis of iron oxide content and soil color. The Plinthaquox equates to a Hydromorphic Laterite soil. Deep cores were taken at ten sites along the two study transects (Figure 1). A percussion core-sampling rig was used to collect soil samples at 50 cm increments from the surface to bedrock (10 to 15 m). Fluctuations in water table depth were measured at weekly intervals. Sites A through F (Figure 2) represent the distribution of soils along one of the transects in relation to the topography, and average depth to the water table.

Soil Moisture

Gravimetric moisture contents measured in increments above a water table during the dry season show that capillary rise in these soils maintains the water content above ⅓ bar tension in the 1 m zone above the water table. Water content is above 15 bar tension in the zone 1 to 2 m above the water table. Precipitation and water table data collected from August 1984 through July 1985 (Figure 3) show a six- to eight-week delay in the rise of the water table in response to precipitation. The water-table level declines slowly for a similar period of time at the end of the rainy season.

Preliminary Conclusions

The schematic in Figure 4 shows the general relationships between soil color and water-table fluctuation zones in these soils. CBD extractable iron oxides in these soils are given in Figure 5. The data suggest the following preliminary conclusions:

1. The difference in iron oxide content and

mineralogy that is observed in the Red-Yellow Latosol appears to be the result of a pedogenic response to the imposition of a water table on a soil which previously had characteristics of a Dark-Red Latosol.

2. The hydrologic conditions of the Red-Yellow Latosol and the presence of organic compounds near root surfaces within the zone above the water table may have induced the selective reduction, dissolution and removal of hematite from the upper part of the soil profile and/or its transformation to geothite.

3. In the Red-Yellow Latosol (10 YR or 7.5 YR), the upper boundary of the 2.5 YR horizon with soft plinthic masses is indicative of the average depth to the water table.

4. The upper boundary of the 5 YR horizon is indicative of the shallowest depth to the water table.

Implications

The results of this study suggest that the crop-production potential of these soils may change with seasonal shifts in water table, which can be predicted by soil color. For example, precipitation data show a two- to three-week dry period in February, which is typical of the regional climate. Crops vulnerable to water stress at this stage of the growing season might benefit from moisture available in a Red-Yellow Latosol whose water table was within 2 m of the surface. After further data analysis, this study is expected to produce recommendations for diagnostic criteria to be used for proposing subclasses of the Acrustox great group.

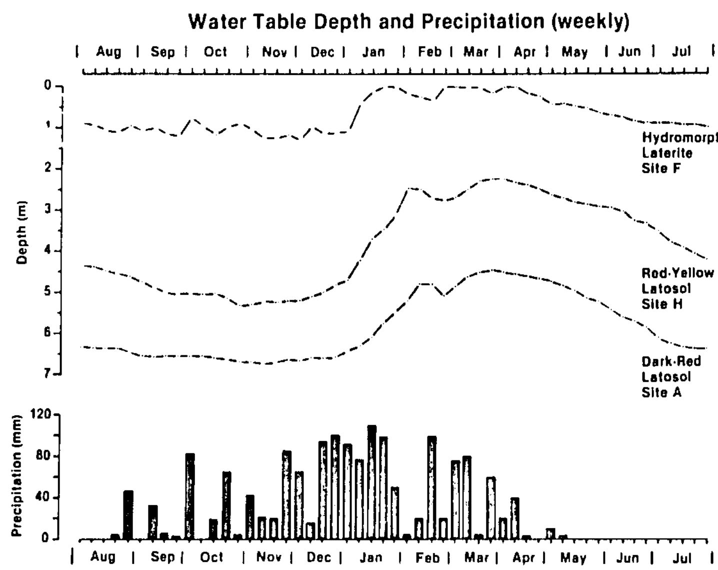


Figure 3. Relationship of precipitation to water-table level in three soils, August, 1984 through July, 1985.

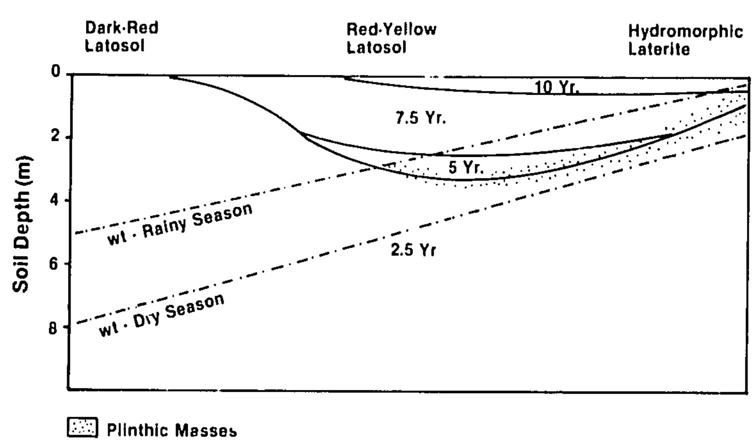


Figure 4. Relationships between soil color and water-table fluctuation zones in three Cerrado soils.

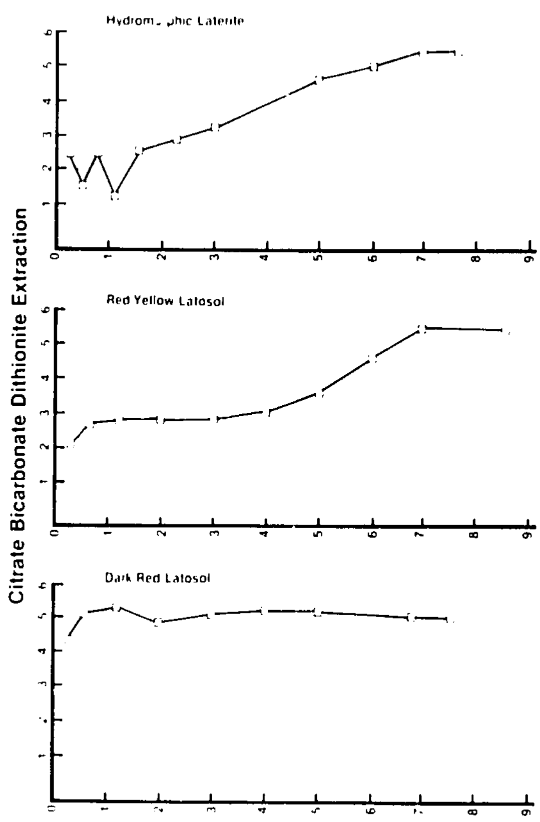


Figure 5. Extractable iron oxides by depth in three Cerrado soils.

Characterization of Root Restricting Zones in Cerrado Soils

Eric R. Stoner, Cornell University
Elias de Freitas, Jr., EMBRAPA/CPAC
Victor A. Snyder, Cornell University
K. Dale Ritchey, IICA/EMBRAPA

A study was conducted to characterize a root-restricting zone that had developed on a Typic Haplustox originally under Cerrado vegetation near São Gotardo, Minas Gerais State, Brazil. This area is part of the Guided Settlement Plan for the Upper Paranaiba (PADAP) and has been under cultivation as long as any Cerrado area, since the early 1970's. The study was undertaken in response to farmers' concern over yields of soybeans and wheat, which had declined in spite of adequate lime and fertilizer inputs. A soil profile on the site showed good chemical status (pH 5.8 to .2 m, zero Al).

Table 1. Wheat yield by tillage treatment on a compacted Typic Haplustox.

Tillage Treatment	Wheat Yield kg/ha	Yield Index	C.V. six reps.
Cross Chiseled	2260	133	9.3
Cheseled	2108	124	10.1
Disc Plowed	1887	111	7.5
Off-Set Heavy Disc	1840	108	9.7
Light Disc	1672	98	10.3
Direct Drilled	1702	100	6.6

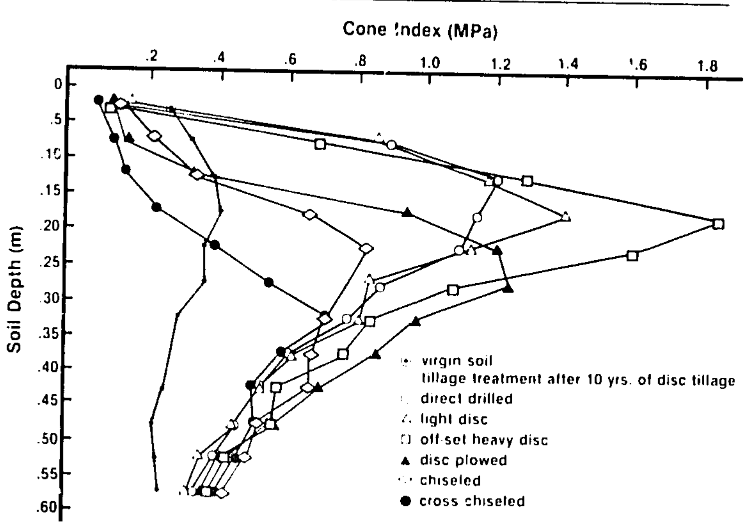


Figure 1. Mechanical impedance profiles of six tillage treatments on a Typic Haplustox, Minas Gerais, Brazil, compared with virgin soil conditions.

The objectives of the study were 1) to diagnose soil and management conditions that result in the development of root-restricting zones in Cerrado soils subjected to continuous annual cropping, 2) to determine the effects of root-restricting zones on soil-water dynamics in the field and the resulting implications for crop yields and soil erosion; and 3) to identify management practices that limit the formation of root-restricting zones.

Tillage Operations

Six locally available tillage operations were performed on the already compacted area prior to planting of wheat in early 1984. Mechanical impedance profiles (Figure 1) reveal the severity of compaction immediately below the depth of operation of disc tillage implements. Ten years of tillage exclusively with disc plows and disc harrows in a soybean/wheat rotation created a zone of high mechanical impedance. Additional tillage in the 11th year with disc implements only aggravated the situation. Chisel plowing and cross chiseling alleviated the mechanical impedance (Figure 1).

Yield Response

Direct-drilled wheat is used as a basis for comparison of other treatments because it represents the compacted state of the soil after ten years of disc tillage. Even though off-set heavy disc tillage shows a higher root index than chisel tillage (Figure 2), the critical difference in favor of chiseling is the development of roots deeper in the profile where subsoil moisture reserves are available to the plant.

Wheat yield by tillage is shown in Table 1. Yield results clearly indicate the benefit of the two chisel-plowing operations. It should be pointed out that low yields for direct drilling do not rule out this practice, but merely emphasize that reduced tillage or no-till systems will not work on already compacted soils unless something is done to alleviate the existing problem. Further work will be done to identify management practices that limit the formation of root-restricting zones.

Compaction and Calcium

A collateral study investigated the interaction between compaction and levels of calcium in Cerrado soils as it affects seedling wheat root growth. Five levels of calcium were established in subsoil samples of a Typic Haplustox and Typic Acrustox with the addition of calcium sulfate. Four levels of bulk density were created in 150 ml plastic cups, and pre-germinated wheat seedlings were planted five to a cup.

Although small, a significant difference existed between the two soils. The calcium deficiency in the Acrustox subsoil seemed to be more critical than in the Haplustox subsoil (Figure 3). In both soils reduction in mechanical impedance as well as increase in calcium levels were beneficial, increasing root growth. The interaction between compaction and calcium levels was significant. The interactive effect was more relevant as calcium in the soil was corrected, there being almost no compaction effect at low calcium levels. Since most Cerrado soils cultivated long-term have adequate calcium levels to at least 0.45 m, it becomes all the more apparent that soil compaction problems must be avoided for unrestricted root penetration in subsoil layers. Elevation of calcium levels through heavy liming or ion leaching is probably not sufficient to overcome root-growth restriction induced by abusive tillage practices.

Conclusions

1) Ten years of tillage exclusively with disc plows and disc harrows in a soybean/wheat rotation created a zone of high mechanical impedance in this Typic Haplustox.

2) Chisel plowing and cross chiseling alleviated the mechanical impedance, produced a positive yield response in wheat, and increased the depth of rooting.

3) The interaction between compaction and calcium levels was a significant factor in the root development of wheat seedlings. While there was almost no compaction effect at low calcium levels, compaction suppressed the response of seedlings to increased calcium in the soil.

Implications

It has been a widely held belief that the important soil-related constraints to crop production on Cerrado latosols would be chemical, not physical properties. This study indicates that long-term, mechanized cropping can create root-restricting tillage pans that seriously reduce crop yields and fertilizer efficiency on these soils. These pans may not be corrected naturally, as there are no shrink-swell or freeze-thaw cycles in these soils. But the study also shows that these pans can be corrected with proper management. New experiments, established on both compacted and uncompacted soils, will seek to determine how root-restricting zones develop, and will compare the effect of various tillage techniques on soil properties under a range of conditions.

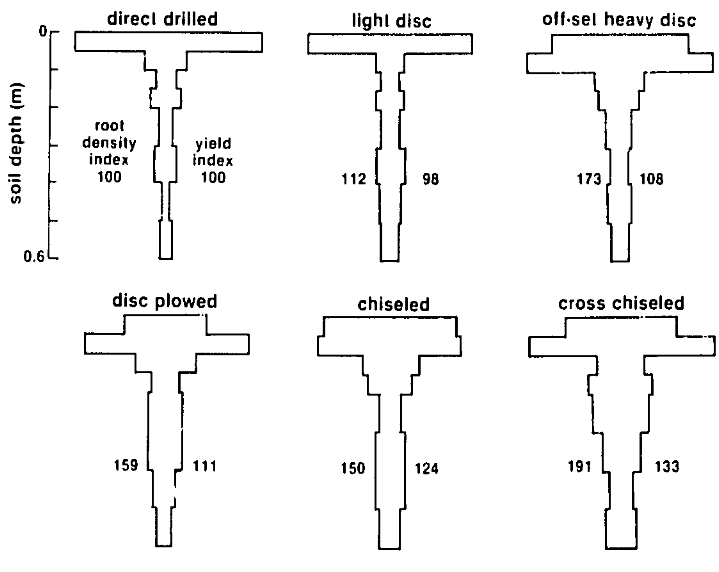


Figure 2. Root density profiles (cm root/cm³ soil) for six tillage treatments on a Typic Haplustox, Minas Gerais, Brazil, with root and yield indices.

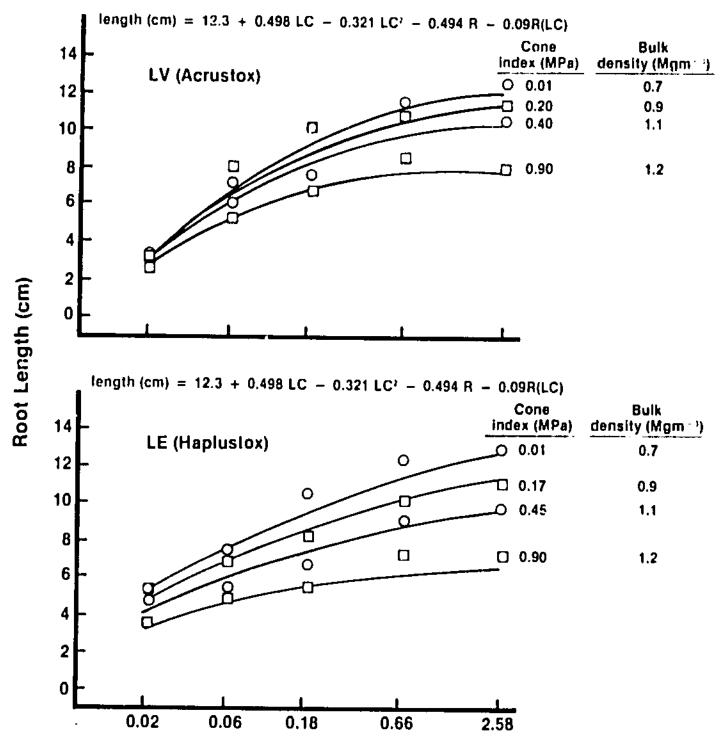


Figure 3. Effect of calcium level (LC = natural log of Ca concentration) and penetrometer resistance (R) in subsoil samples of Red-Yellow (LV) and Dark Red (LE) latosols on root growth of four-day wheat seedlings.

Contributions to New York Agriculture

A major emphasis of the TropSoils program revolves around efficient nitrogen management in crop-production systems. A concept which has developed over the last 15 years of research is that sound nitrogen management in Brazil and New York is governed by common principles and that, once some fairly simple climatic and soil variables are accounted for, the same general models of behavior apply. For example, previous work in Brazil demonstrated that sound fertilizer-nitrogen management for corn in Brazil and New York is identical. Recent studies indicate that management of legume residues and soil organic nitrogen in the two areas is very nearly identical. Hence, it is possible to interchange management experiences relatively easily.

Studies evaluating the contribution of legume nitrogen to a succeeding non-legume crop are finding that, in the acid-savannas of Brazil, where the growing season is determined by the length of the rainy season, certain legumes fix large quantities of nitrogen. A large fraction of the fixed nitrogen is subsequently mineralized to inorganic nitrogen and taken up by the following crop. The pattern of release appears to be similar to that of legumes grown in New York State, where the growing season is determined by the length of the frost-free period. It is likely possible to test various legumes using the same techniques at both sites to evaluate the contribution of legumes as nitrogen sources. It may be possible to test the same legume species and varieties in both places.

Some effort has been expended at Cornell to devise soil tests to measure the ability of soils to supply nitrogen to growing plants. This effort was sufficiently promising that work on soil test development is continuing at CPAC. The preliminary results from work being carried out there are promising, but still leave room for improvement. If this work is successful, such a test should be valid not only in Brazil and New York, but should be useful world-wide. The work done on fertilizer-nitrogen and/or legume-nitrogen management is equally valid and applicable whether done at CPAC or at Cornell.

Water and Ion Movement

Water and ion movement in soils is being studied both at CPAC and at Cornell. The evidence thus far obtained indicates that the general principle involved in ion and water movement can be applied in both environments. Therefore, models to describe and predict these phenomena are being developed. If useful models are developed, water availability and use by plants as well as the fate of ions in the soil environment can be predicted more accurately. This should result in more efficient water and nutrient use in both environments.

Root-Restricting Zones

Root-restricting zones of high mechanical impedance are forming in some Cerrado Oxisols as a result of common tillage and traffic practices. Similar problems are very common in New York soils and in other regions of the United States. The mechanical resistance of a soil to root growth depends strongly on soil moisture content. Since soil moisture is highly variable within and between growing seasons, the same will be true for soil mechanical impedance and resulting root development patterns. Reasonably accurate water balance techniques are available for predicting soil moisture probabilities from climatic probabilities and soil-moisture characteristics. If the relationship between soil mechanical impedance and moisture content were accurately known, one could use the existing water balance approaches to estimate the variation of mechanical impedance during the growing season.

Preliminary theoretical and experimental work conducted at Cornell and at CPAC has indicated the possibility of a very simple method for estimating the relationships between soil moisture content and mechanical impedance over a wide range of soil bulk densities. More detailed work to test and refine the method is currently being conducted on New York and Brazilian soils, with the goal of understanding how root-restricting zones in the soil form and how to prevent their formation in cultivated soils.

Publications, Cornell University

Bouldin, D.R., K.D. Ritchey and E. Laboto. 1985. Management of soil acidity. (To be published in proceedings of Acid Tropical Soils Workshop, IBSRAM).

Lathwell, D.J., J. Wolf, C.T. deWit and B.H. Janssen. 1987. Modeling long-term crop response to fertilizer phosphorus. *Agronomy Journal.*

Lathwell, D.J. and T.L. Grove. 1986. Soil-plant relationships in the tropics. Ann. Rev. Ecol. Syst. 17:1-16.

Macedo, J. and R. B. Bryant. 1987. Morphology and mineralogy and genesis of a hydrosequence of Oxisols in Brazil. *Soil Sci. Soc. of Am. J.*.

For more information about these publications contact: TropSoils, Dept. of Agronomy & Soil Science, University of Hawaii, Honolulu, HI 96822.

Semiarid Tropics
Texas A&M University

Much of the blame for the crisis of famine and hunger in semiarid Africa has been placed on drought, deforestation and a general decline in soil productivity. These problems have been most severe in a large region of sub-Saharan Africa known as the Sahel, where rainfall has decreased 30 to 40% during the past decade. Soil resources are so deficient in this region that introducing new germ plasm and increasing food-crop yields will likely be impossible unless soil-management practices are also improved. TropSoils' program in the semiarid tropics seeks to develop soil-management technologies that resource-poor farmers can adopt to create more productive, sustained farming systems on the marginal soils of this zone.

The primary research site for TropSoils work in the semiarid tropics is the Sahelian belt of Niger. The population density of this belt is 20 to 25 people per square kilometer, and more than 90% of these people are involved in subsistence agriculture, laboring almost entirely by hand. The principal food crop is pearl millet (*Pennisetum* sp.), which is often intercropped with cowpea. Other crops include peanut, sorghum, maize, rice and manioc.

The climate of Sahelian Niger is characterized by a June-to-September rainy season and a dry season throughout the remainder of the year. Rainfall is irregular, and normally comes in the form of convective storms. As much as 100 mm of rain may fall during a single storm. Potential evapotranspiration is approximately 2000 mm annually, while annual rainfall is only 300 to 600 mm. There are also periods of strong, dry winds, which transport dust from the Sahara during the dry season. In this region, it is common to find air temperatures higher than 40° C, and soil temperatures higher than 50° C at a depth of 5 cm.

Due to the demand for cropland, forage and fuel, Sahelian forests are being replaced with grasses, thorny bushes, scattered trees and areas of barren, crusted soils. Large areas of the Sahel have sandy soils that do not store water well. Sandstorms commonly bury or blast young crops. Soils with higher clay content form crusts immediately after rainfall begins, so that most of the rainfall in a field is lost in runoff. Crusting also inhibits the emergence of crop seedlings and the natural reseeding of forests.

Chemically, these soils are deficient for crop production. They are acid and high in Fe and Al, while low in available N, P, K, Ca, Mg and organic matter. Cation exchange capacities are low in many of the soils. And, spatial variability in the soils complicates the management of crops and the interpretation of research results.

The research reported here has been conducted in two general areas. In the first, the goal has been to characterize the soil-plant-atmosphere system by compiling and analyzing data on soils and climate, and by studying plant behavior in semiarid environments. In the second, the goal has been to develop and evaluate technology for managing soil water and fertility in order to improve the productivity of food crops and forests.

Contents

Soil Data Base

Baseline information about soils is vital to the development of soil-management technology in the Sahel. The soils are fragile and droughty, and commonly exhibit a chemistry deficient in nutrients and toxic to plants. Spatial variability of soil properties is common, and constrains the transfer of research results unless research sites are carefully assessed.

This section reports a range of studies related to soil classification and characterization, along with studies quantifying soil physical and hydrological properties and relationships. Some of these studies may lead to the development of technologies for intensive cropping systems in small valleys collecting runoff from lateritic plateaus. Others seek to quantify features of Sahelian soils such as crust formation and spatial variability. One study in this group, on the role of eolian dusts from the Sahara Desert, is not reported here because work has just begun.

Soil Genesis, Phosphorus and Micronutrients of Selected Vertisols And Associated Alfisols Of Northern Cameroon

Bernard P. K. Yerima, Texas A&M University
Larry P. Wilding, Texas A&M University

Vertisols cover about 1.5 million ha in northern Cameroon. Most of these resources are used for millet, sorghum, cotton and irrigated rice. Currently large tracts are used for forest regeneration. Adequate knowledge of soil-resource parameters is necessary as a basis for technology transfer to enhance food production and forest regeneration in this region. The objectives of this study were 1) to characterize the morphological, physical, chemical and mineralogical properties of Vertisols and associated Alfisols of northern Cameroon as a basis for soil-resource evaluation, soil classification and pedogenesis; 2) to determine soil fertility parameters of these soils as correlative with observed and measured properties; and 3) to assess the impact of these soil-resource conditions on reforestation in this tropical semiarid ecological region.

After field studies of soil/landform relationships, six Vertisols and one Alfisol were selected for detailed sampling and characterization (Figure 1). These soils occur on two geomorphic surfaces. In lowlands, they have developed from Quaternary lacutrine sediments on a nearly level ancient lake plain, which extends from northeastern Nigeria through northern Cameroon into southern Chad. In undulating uplands, Vertisols and Alfisols have developed from Precambrian schist. Most of the Vertisols have developed on slopes of less than 2% under a semiarid climate with a marked wet and dry season. Mean annual rainfall averages 600-900 mm (Figure 1) and decreases northwards. Mean annual temperature is 27 to 28° C. Vegetation is dominated by red acacia trees and sporobolus and hyperrhenia grass species.

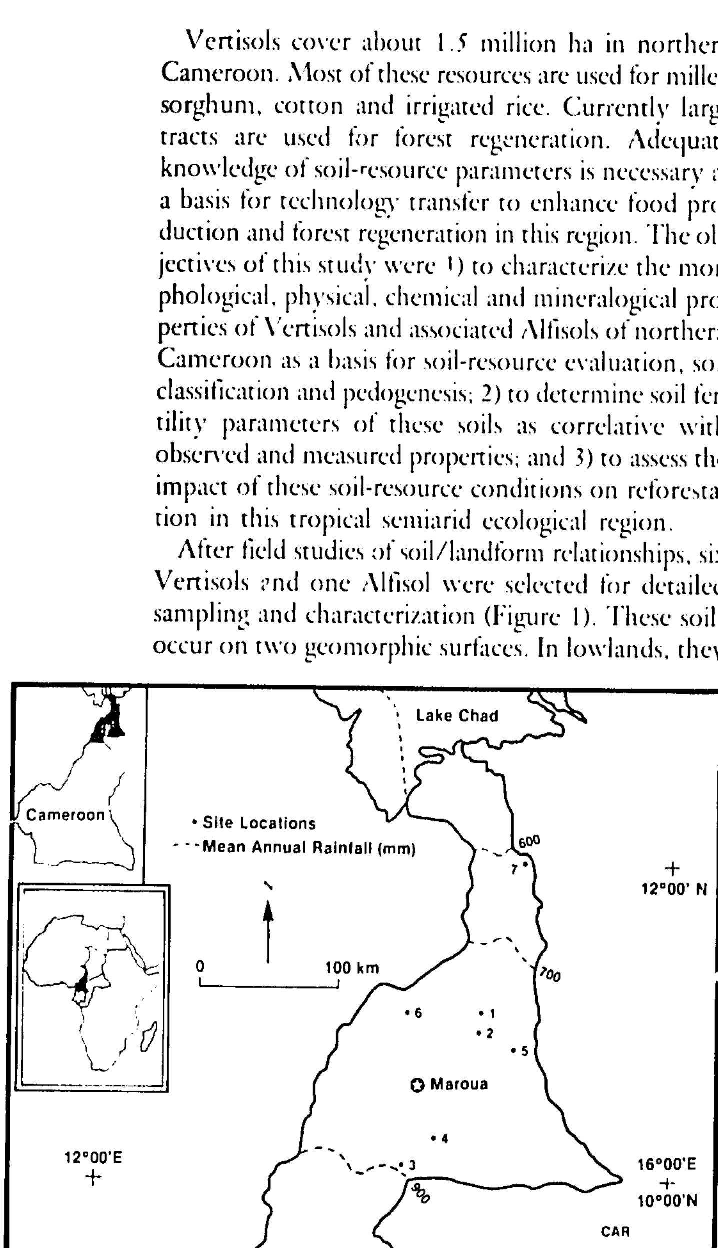


Figure 1. Map of northern Cameroon showing site locations: 1—Andirni; 2—Louba Louba; 3—Lam; 4—Laf; 5—Maga; 6—Mora; 7—Kousserie.

Procedures

Samples of representative soils were collected from pits 1.5-2.5 m deep. The soils were described morphologically. Bulk samples were collected from each horizon and undisturbed clods were collected for bulk density and fabric analysis.

Laboratory analyses included particle-size distribution, soluble salts, cation exchange capacity (CEC), extractable bases, pH, organic carbon, electrical conductivity, total and external surface area, bulk density, coefficient of linear extensibility (COLE), ⅓ and 15 bar water retention, microfabric analysis, skeletal and clay mineralogy, total and extractable (NH_4HCO_3—DTPA) micronutrients (Fe, Mn, Cu & Zn), and total and extractable (NH_4HCO_3—DTPA) phosphorus. Total micronutrients and P were determined by sodium carbonate fusion and mineralogy with optical x-ray diffraction, electron microscopy and infrared analyses. Elemental Ca, K, Fe, Ti and Zr of sand and silt fractions were determined by x-ray spectroscopy. Phosphorus fixation was done by equilibrating soil samples with given concentrations of P and analyzing the P remaining in solution colorimetrically. Statistical analyses and correlations with soil physical and chemical properties were performed to provide models for rapid soil-resource assessment.

Results

Northern Cameroon soils are largely dark gray to grayish brown. Organic carbon contents are low (less than 1.3%). Soils developed on the lacustrine plain exhibit more cracking and better self-mulching attributes than their upland counterparts. Gilgai or undulating microrelief is generally poorly developed, even though these soils have relatively high COLE and surface areas. Subsoils are more compact and dense than Vertisols found in the U.S.A. Most Vertisols of the plain have about 1 m of clayey soil materials overlying stratified sandy deposits. The subsoils are compact and dense and highly restrictive to root and water movement. Upland soils have similar adverse physical conditions but are deeper and more uniform with depth.

Physical and chemical properties are presented in Table 1. Base saturation is high (generally 70 to 100%) and pH's range from 6 to 8. The exchange complex is dominated by Ca and Mg. Elemental concentrations of Fe, Ca, and K in the sand and silt fractions of all soils indicate high nutrient reserves. The skeletal fraction of these Vertisols is composed of quartz, plagioclase and K-feldspars, hornblendes and mica; additionally, chlorite and hydrobiotite are contained in upland soils. The total clay fraction is composed of kaolinite, smectite, vermiculite, mica and K-feldspars, with smectite and kaolinite dominant in the fine clay

Table 1. Selected physical and chemical properties of the soils for the surface and weighted clay content for subsoils (25cm-1m) of selected northern Cameroon soils.

Site #	Soil Name	Depth (cm.)	Organic Carbon (%)	pH (H_2O) 1:1	Clay (%)	CEC / Clay	Base Sat. (%)	Surface Area, < 2mm fraction (m^2/g)	Bulk Density (1/3 bar) (g/cm^3)	COLE cm/cm
1	Andirni +	0-23	0.7	6.0	61	0.6	78	235	1.3	0.12
		25-100	0.5	6.6	62	0.6	75	—	1.3	0.11
2	Louba Louba +	0-15	1.0	5.6	68	0.6	72	260	1.0	0.15
		25-100	0.7	6.2	70	0.5	76	—	1.3	0.13
3	Lam*	0-15	0.6	7.8	49	0.8	97	265	1.4	0.08
		25-100	0.7	8.0	53	0.8	96	—	1.4	0.11
4	Laf*	0-19	0.8	7.1	39	0.7	84	190	1.4	0.07
		25-100	0.5	7.0	42	0.7	86	—	1.6	0.07
5	Maga +	0-20	0.7	5.7	52	0.6	55	195	N.D.	0.09
		25-100	0.5	6.4	55	0.5	76	—	N.D.	0.12
6	Mora*	0-10	0.6	6.8	8	0.8	61	30	1.5	—
		25-100	0.2	6.2	20	0.6	59	—	1.6	0.03
7	Kousserie +	0-16	0.8	6.8	31	0.6	85	105	1.4	0.04
		25-100	0.3	8.0	30	0.6	94	—	1.4	0.09

Note: The Andirni, Lam and Laf soils are classified as Entic Pellusterts, the Louba Louba and Maga as Typic Pellusterts, the Mora as an Arenic Haplustalf and the Kousserie as an Entic Chromustert.

* Indicates upland soils; + indicates lowland soils.

Table 2. Total and ammonium bicarbonate—DTPA extractable forms of Fe, Mn, Cu and Zn in selected horizons of the Louba Louba and Lam soils.

		Micronutrients							
		Total				Extractable			
Horizon	Depth (cm)	Fe (%)	Mn	Zn	Cu	Fe	Mn	Zn	Cu
			(ug/g)						
				Louba Louba*					
A1	0-15	6.0	725	205	50	62	23	2	5
Bw	76-100	2.8	625	165	35	10	5	1	3
2BCtk2	175-185	2.7	260	130	35	5	2	1	1
				Lam +					
Ap	0-15	5.0	1230	200	70	8	4	1	3
Bk2	85-114	4.1	1110	150	70	4	4	1	3
Ck	200-240	3.5	1360	190	35	3	6	1	1

* Represents Quaternary lacustrine plain soils

+ Upland Precambrian schist soils

fraction of the lowland soils and smectite dominant in the upland soils. Most of the kaolinite and smectite in the lowlands is inherited in the lacustrine sediments. However, smectite in the uplands is formed through weathering of base-rich rocks. Vermiculite occurrence is attributed to mica weathering.

Nutrient reserves of total and extractable Fe, Mn, Cu and Zn are presented in Table 2. Adequate micronutrients are present for Fe, Mn and Cu, but Zn is low and may be deficient. Surface horizons of the seasonally flooded lacustrine soils exhibited much higher micronutrient concentrations, which decreased with depth. This is attributed to their co-association with poorly crystallized oxides and hydroxides of Fe and Mn that undergo seasonal reduction during periods of flooding. Also, greater concentrations of Zn and Cu in the flooded soils are attributed to greater solubility at lower pH's. Extractable micronutrients are much lower in upland soils due to higher pH's. Also, $CaCO_3$ surfaces serve as chemisorptive sinks for micronutrients, resulting in prospective nutrient deficiencies.

Total P ranged from about 200 to 570 ug/g (Table 3). Organic P ranged from about 5 to 90 ug/g and decreased with depth consistent with decreasing organic carbon distribution. Inorganic P is attributed largely to Ca-phosphate forms in response to alkaline pH's. Extractable P (Table 3) was higher in surface horizons of the seasonally flooded soils and lower in upland soils. This may reflect the higher pH values of the latter or the precipitation of Ca phosphates in the calcareous upland soils.

High P adsorption was associated with high clay contents and amorphous Fe and Al contents. The P-sorption studies were evaluated using the Langmuir equations. These studies indicated P is adsorbed on high and low energy phases, with P-sorption maxima on the low energy sites being three to four times greater than P-adsorption maxima for high-energy sites. The amount of P required in equilibrium solution for a given crop recommendation can be obtained by reading from the intersect of the curve of P remaining in solution versus P-added (Figure 2). For example, to obtain a concentration of 0.2 ppm (ug/g) P in solution for the Louba Louba, Maga, Laf and Lam soils, about 290, 190, 145 and 90 kg P/ha, respectively, should be added.

Statistical predictive models developed in this study for parameters such as COLE, CEC, micronutrients and P-adsorption maxima, versus soil chemical and physical properties, are presented in Table 4. These models constitute very useful tools for economically predicting these parameters from routine or existing physical and chemical data.

Conclusions

1) The adverse physical properties of these soils pose great problems in the reforestation program. The dense and compact subsoils limit plant rooting and water infiltration. Also, high shrink-swell potentials and cracking on desiccation prune the rooting system by shearing fine tree roots. Localized saline sodic areas in lowland soils pose constraints for tree species that are not salt-tolerant.

2) Northern Cameroon soils developed from lacustrine clays over sands have weakly developed slickensides indicative of few desiccation/rewetting cycles. Paucity of slickensides is attributed in part to their mixed mineralogy and low overburden pressures. Segregated Fe is indicative of prolonged seasonal flooding and alternating oxidation/reduction conditions. Soils derived from upland schist contain better

Table 3. Forms of P in selected horizons of the Louba Louba and Lam soils.

Horizon	Depth (cm)	Organic P	Inorganic P	Total P	Extractable P
		(ug/g soil)			
			Louba Louba*		
A1	0-15	90	480	570	1/5
Bw	76-100	55	520	580	2.1
2BCt2	175-185	25	160	185	0.3
			Lam +		
Ap	0-15	65	130	195	0.2
Bk2	85-114	30	205	235	0.1
Ck	200-240	5	590	595	0.4

* Represents Quaternary lacustrine plains soils
+ Upland Precambrian schist soils

expressed slickensides, probably due to higher amounts of smectitic mineralogy and higher overburden pressures. Lack of gilgai expression is attributed to wet-dry seasonal rainfall distribution. The Vertisols have more compact and dense subsoils than Vertisols found in the U.S.A.

Implications

This work demonstrates the need to modify tillage management in Vertisols to reduce flooding hazards, increase infiltraton and utilize subsoil moisture. Soils are too wet during the early part of the rainy season and too dry during a major part of the plant-growing season, hence practices for both removal of excess water and conservation are needed. These may include bedding, mulching, establishment of tree seedlings in structurally modified subsoils, use of supplemental irrigation, and surface drainage of excess water to impoundment catchment structures.

The macro- and micronutrient status of these soils is adequate, but P and Zn are low. Because available micronutrients are not always correlative with nutrient uptake, fertilizer applications of both macro- and micronutrients should be calibrated with adapted and improved hybrid crop varieties under field conditions.

Because about three to four times the amount of P is adsorbed on the high-energy phase than on the low-energy phase from P-sorption studies, it is impractical to saturate high-energy, P-sorption sites with fertilizer. This means that banded P applications will be necessary. Phosphorous application rates between 100 and 300 kg P/ha will be required to sustain a solution concentration of 0.2 ppm in these clayey soils.

Table 4. Regression equations relating COLE, CEC, total Zn and Cu, & P - adsorption maxima (PAM) to some physical and chemical properties for selected northern Cameroon soils.

Equation	r**
COLE = - 0.004 + 0.002PCL	0.821**
COLE = - 0.048 + 0.003ESA	0.759**
COLE = 0.003 + 0.004SAT	0.745**
EC = 3.06 + 0.139SAT	0.942**
CEC = 4.86 + 0.512PCL	0.658**
Zn = 1.52 + 0.537 log PA	0.683**
Zn = 2.41 - 0.221 log Fe	0.509**
Cu = 0.37 + 0.950 log PA	0.608**
Cu = 1.98 - 0.414 log Fe	0.509**
	R**
PAM = - 1.21 + 4.94 log PCL - 1.324(Log PCL)	0.992**
PAM = 0.673 + 2.56 log ESA - 0.62(Log ESA)	0.981**
PAM = 0.32 - 9.72 log AAL - 7.80(Log AAL)	0.962**
PAM = 3.05 - 1.31 log AFE - 1.33(Log AFE)	0.889**

PCL = percent clay; ESA = external surface area; SAT = total surface area; PA = percent sand; Fe = percent iron; AAL = amorphous aluminum; AFE = amorphous iron.

** Indicates significant at the 0.01 level.

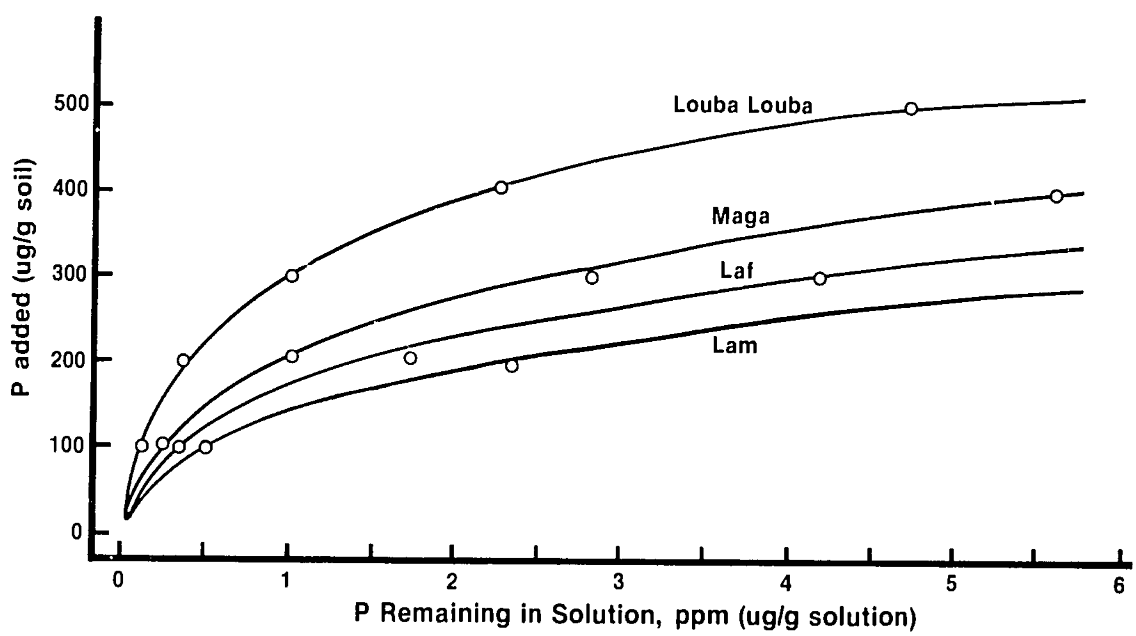


Figure 2. Plot of P-added versus concentration of P remaining in solution from selected northern Cameroon soils.

Clay Dispersibility in Sandy Soils Of the Sahel, West Africa

Larry P. Wilding, Texas A&M University
Larry T. West, Texas A&M University
Frank G. Calhoun, Texas A&M University

Sandy soils of the Sahel serve as major land resources for millet, cowpeas and groundnut production. These soil systems are acid, highly weathered, slightly buffered and poor in organic matter, and are composed primarily of resistant minerals including quartz, kaolinite and geothite (iron oxides). These infertile soils are in distinct contrast with fertile, base-rich arid and semiarid soils of North America. They have formed under paleo-climates considerably wetter than contemporaneous semiarid tropical environments, as evidenced from extensive laterite outcrops, buried paleosols and highly leached soil systems. Physically, these soils exhibit weak structural aggregation, weak textural differentiation (subsoil argillic horizons) and low water retention. They have a propensity to form thin surface crusts and seals, and are highly subject to wind and water erosion.

The objectives of this work were to determine the role of clay content, distribution and water dispersibility on erosion and management of sandy soil resources.

Methods

Soils representative of the ICRISAT Sahelian Center near Niamey, Niger were sampled and described for routine characterization and special studies in support of a soil survey. Particle-size distribution employing both electrolyte dispersion (total clay) and distilled water (water dispersible clay) were determined by pipette analysis. The zero point of charge (ZPC) of selected samples was determined from potentiometric titration curves. Oriented clods from selected horizons were impregnated with a polyester resin-acetone solution for thin-section microfabric analysis. Natural fabrics and sand grains were examined by scanning electron microscopy (SEM) and microprobe techniques.

Table 1. Physical and chemical properties of the Dayobu and Labucheri pedons.

		Particle-size Distribution (mm)						
				clay				
		Sand	Silt	Fine	Total	Water Dispersed*	pH	
	Depth	2-0.05	0.05-0.002	< 0.0002	< 0.002	< 0.002	H_2O	KCl
Horizon	cm	%						
			Dayobu (Ustoxic Quartzipsamment)					
A1	0-15	92.5	3.0	2.1	4.5	4.3	5.1	4.0
A2	15-27	91.7	3.2	2.9	5.1	4.1	4.9	3.9
Bt1	27-44	92.1	3.2	2.6	4.7	3.7	4.8	3.9
Bw	80-103	92.5	3.2	1.7	4.3	3.6	4.8	4.0
BC	126-150	94.5	1.9	1.6	3.6	3.4	4.8	4.0
C	173-200	94.6	2.9	2.5	2.5	2.4	4.9	4.1
			Labucheri (Psammentic Paleustalf)					
A1	0-18	93.8	3.3	2.3	2.9	3.7	5.4	5.2
A2	18-30	91.0	3.8	2.7	5.3	5.6	5.6	5.0
Bt1	30-51	87.4	5.6	4.3	7.0	7.9	5.7	4.9
Bt2	51-71	85.2	4.3	5.4	10.5	10.9	5.3	4.3
Bt5	178-200	85.5	5.4	4.7	8.7	8.6	5.2	4.6
C	430-460	90.0	4.9	2.8	5.1	4.8	5.0	4.2
Btb	620-640	83.2	7.3	5.4	9.5	9.9	5.1	4.7

* Slightly higher values for water dispersible vs. electrolyte dispersible clay for some horizons in the Labucheri pedon are within the experimental error of determination.

The sand fractions were subjected to the following treatments prior to analysis: no treatment, water dispersion, calgon (electrolyte) dispersion, and calgon dispersion after iron removal with sodium citrate-sodium dithonite.

Results

Textures of the soils were sand and loamy sand. Sand contents were generally greater than 85%, and clay content was less than 15% (Table 1). Soil pH in water ranged from 4.3 to 5.8, and pH in KCl was generally 0.5 to 1.0 unit lower. The ZPC, as measured, ranged from 2.8 for the Labucheri A horizon and Dayobu C horizon to 3.2 for the Labucheri Bt2 horizon (Figure 1). However, a unique crossover did not occur for all electrolyte concentrations. The difference between the zero point of titration and the ZPC (Figure 1) indicates that a significant proportion of the net charge in these soils is permanent charge.

Based on microfabric and SEM observations, the clay fraction in these soils is distributed as surface coatings around sand grains and as clay bridges between these grains. Nearly all the clay (80-100%, Table 1) is water-dispersible. This means that the clay is easily displaced from the sand grains and charged sufficiently without an electrolyte dispersant to maintain stability in suspension. Free-iron oxides are in small quantities and thus do not serve as a cementing agent in these soils; SEM images of sand grain surfaces appear identical with and without iron-removal treatments. The clay appears to be physically rather than chemically bonded to severely pitted quartz grain surfaces. This could explain the high percentage of water dispersible clay fraction.

The wide separation in pH between the ZPC of the unbuffered soil pH would favor clay dispersibility. The ZPC of these soils is low (pH 2.8 to 3.0) relative to the natural soil pH's of 4.5 to 5.5. This results in negatively charged colloids that maintain suspension stability. Low organic-matter contents would also enhance the ease of clay dispersion.

It is clear from microfabric, SEM and microprobe analyses that clays in these soils are readily displaced from sand grains in surface horizons and translocated to subsoils forming agrillic horizons (Figure 2). Coatings of the sand grains are thinner in surface horizons and clay bridges less frequent compared to subsoils. In subsoils the pores between sand grains are smaller and partially plugged with clay relative to surface horizons. The free iron-oxides associated with clay coats are responsible for the red color imparted to these soils.

Conclusions

1) The propensity for sandy soils in the Sahel of Africa to exhibit weak structural aggregation, thin surface crusts and argillic horizons is a direct consequence of the high degree of the total clay fraction which is water-dispersible. Upon raindrop impact, the clays are easily detached from sand grains and removed from surface horizons via surface runoff, translocation to subsoils, or wind deflation.

2) A close correlation exists between the color of the soil, its clay content, thickness of clay coats sur-

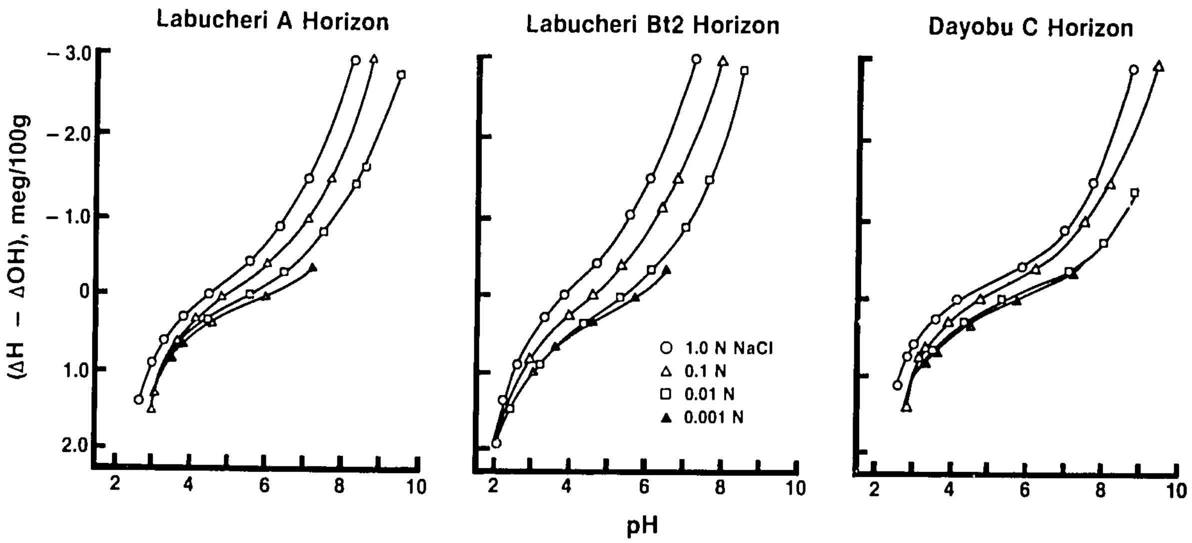


Figure 1. Zero point of charge titration curves for selected horizons.

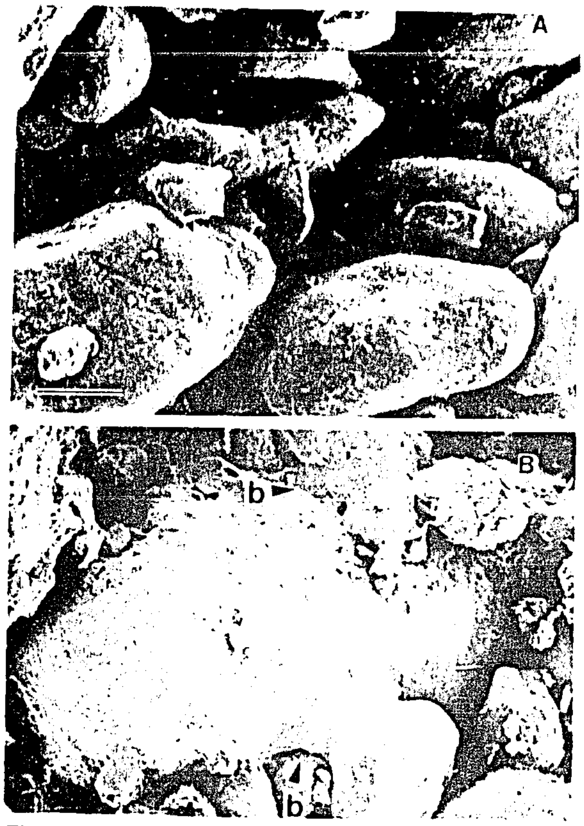


Figure 2. SEM micrographs of fracture surfaces from the Bt horizon of the Labucheri pedon. A: A1 horizon; B: Bt2 horizon, bar length 0.1 mm; b: clay bridge.

rounding sand grains and water-stable aggregation.

3) Loose, noncohesive sand grains in surface horizons are readily subject to wind erosion. Physical collision of sand grains during saltation transport maintains grains without clay coats and reduces cohesiveness by eolian deflation of finer-grained separates.

Implications

With intense, short-duration rainfall events, sufficient clay may be released from the sand grains to partially plug pores and decrease infiltration. If, upon drying, the clays become preferentially oriented, a thin, weakly expressed crust or surface seal may form a few millimeters below the soil surface. Both these phenomena would tend to impede infiltration, reduce plant-available water, and increase runoff and erosion. This agrees with field morphological observations of crusts developed on thin soils of laterite-capped plateaus.

Erosion of sandy soils exposes argillic horizons at the surface. These horizons have lower infiltration rates than coarser-textured surface horizons. Additionally, the exposed argillic horizon often becomes very hard and compact. Water infiltration into the exposed argillic horizon "crust" is greatly reduced and runoff is increased. Most areas with exposed, crusted argillic horizons are barren of vegetation, and special management is necessary to reestablish crops or other vegetation.

Resistance to penetration is higher in argillic horizons than in surface horizons and increases as the soil dries. Measurements with a pocket penetrometer yielded penetration resistances of 0.3, 1.0 and 4.5 kg/cm for a moist A horizon, moist Bt horizon and dry Bt horizon, respectively. The higher penetration resistance in the argillic horizon coupled with a weak grade of structure may impede root growth into the agrillic horizon.

Soils in this area are highly weathered, have a low buffering capacity, and have low capacities to store and supply nutrients. Accumulation of clay in Bt horizons, even in minor amounts, alters the physical-chemical properties of the subsoils. Increased clay in subsoils increases nutrient and water storage capacities and reduces saturated hydraulic conductivity, which slows the downward movement of the saturated wetting front. Conversely, increased clay contents should increase unsaturated hydraulic conductivities, which could enhance the soil's ability to supply water to plants. Even slight changes in clay contents may decrease leaching losses of bases and mobile fertilizer nutrients. Increased cationic retention and slower rates of leaching may account, in part, for the high base saturation in lower B horizons of soils with argillic horizons. Soils lacking argillic horizons have high exchangeable Al levels, which may be attributed to either current or past leaching in these Psamments.

Iron Oxide Properties Versus Strength of Ferruginous Crust And Iron-Glaebules in Soils

Harbi Shadfan, Texas A&M University
Joe B. Dixon, Texas A&M University
Frank G. Calhoun, Texas A&M University

Iron oxides have a dual role in soils. They are present in fine particles in many friable soils, yet they abound in ferruginous crusts and hard nodules of soils. The factors that control the hardening have been investigated and a hypothesis was advanced that the crystallinity of the iron oxides may relate to the hardness of ferruginous soil materials. The objective of this study was to examine the hypothesis that crystallite size relates to hardening of ferruginous crusts and nodules.

Procedures

Samples were selected of laterite from India and Venezuela and nodules from three Ultisols and one Alfisol from Texas. Strength of the ferruginous portions of the samples was determined with a penetrometer. The amounts of amorphous and crystalline iron oxides were examined to test their relationship to hardness. Crystallinity in this case refers to crystal size as determined by x-ray diffraction line broadening and calculation by the Scherrer equation.

Results

Amorphous iron oxides were negatively correlated with strength of the cemented materials (Figure 1). Aluminum-for-iron substitution was greater in the soft than in the hard ferruginous materials. Kaolinite was more abundant in soft than in hard soil materials. Goethite and hematite iron oxides were more abundant in hard than in soft ferruginous materials. This relationship was shown by both chemical and physical (x-ray diffraction) analyses. There was a positive linear relationship between total amount of iron oxide and the strength (Figure 2). Also, the size of the iron oxide crystallites and the strength of the material were positively correlated (Figure 3). This may be because the crystals interact more under pressure as they become larger. They may exclude softer material such as kaolinite as the iron oxide crystals grow. Also, the larger iron oxide crystals form a more continuous phase on a macro scale than do the finer ones.

Conclusions

As iron oxide crystals become larger, they contribute more to the hardness of ferruginous material in laterite and in soils.

Finer, more aluminum-substituted iron oxides tend to occur in softer soil material.

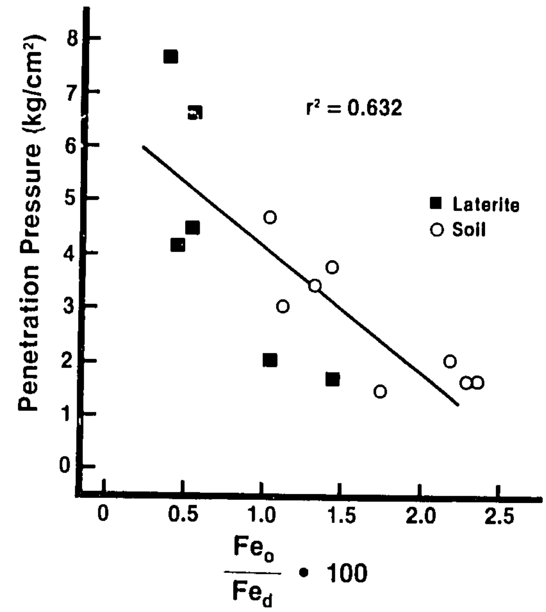


Figure 1. Relationship between extracted Fe-oxalate/Fe-dithionite and penetration pressure of samples from laterite and plinthitic soils.

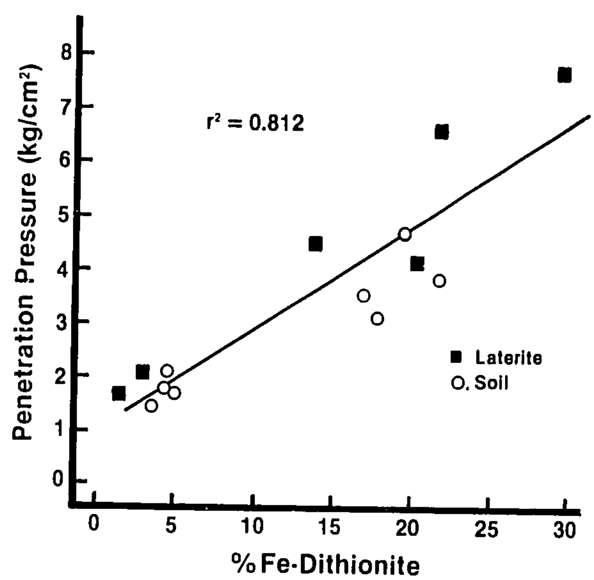


Figure 2. Relationship between dithionite extractable iron and penetration pressure of samples from laterite and plinthitic soils.

Implications

The hardening of laterite involves recrystallization of iron oxides from solution and the exclusion of most aluminum common in fine iron oxides. Thus, the hardening process is very slow (>> 100 years) for laterite and probably can not be attributed to agricultural practices. Erosion of friable soil over laterite is more likely to be a threat to agriculture than hardening of soil into laterite.

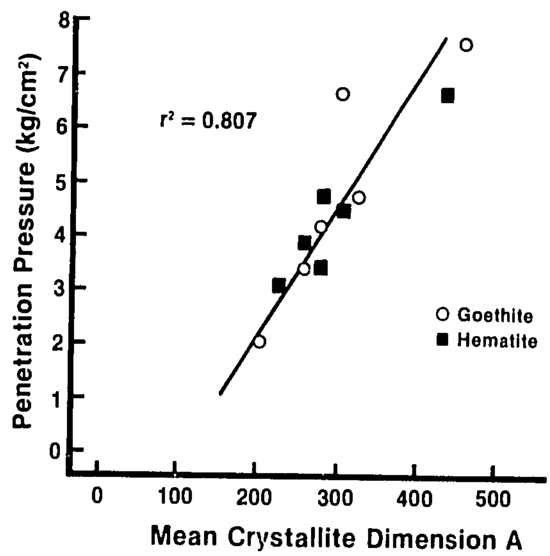


Figure 3. Relationship between MCD and penetration pressure in laterite and plinthitic soils.

Soil Crusting: Compaction Of Soil Particles Due to Impact Of Raindrops and Drying

Harbi Shadfan, Texas A&M University
Joe B. Dixon, Texas A&M University
Frank G. Calhoun, Texas A&M University

The crusting of soil reduces water penetration and interferes with seedling emergence. It is an old problem but no economic solution has been found for soils in general. Crusting is caused by several factors, and corrective measures may not be the same in all soils. The objectives of this review were 1) to summarize the literature on soil crusting and 2) to develop ideas on how further research on corrective measures should be conducted.

Procedures

Many methods have been employed to determine how crusts form and the strength that they develop. Various soil properties have been analyzed (e.g., particle size, shape, roughness, and composition) and correlated with crustal properties.

Results

Most soil crusts can be classified into one of three categories: calcareous and saline crusts; compact crusts due to the impact of raindrops and drying; and ferruginous crusts and soils hardened due to iron compounds. The second type is the topic of this report. In soils compacted by raindrops and drying, soil structure is broken down and the finer, dispersed particles fill the voids between coarser particles. More points of contact between particles are formed and the soil becomes stronger. On drying, the particles are brought closer together and strength increases further.

Silt content has frequently been correlated with soil crusting. Kaolinite clay contributes to soil crusts in some cases. Montmorillonite clay may contribute to soil strength, but on drying it shrinks and forms cracks. The amount of each particle size fraction influences soil crusting. Sand, except for fine sand, does not generally contribute to the formation of soil crusts.

The presence of organic matter improves soil structure and thus resists soil crusting. Where the soil particles are well-aggregated, redistribution of particles is less likely to occur and soil crusting is not a problem.

In contrast, sodium as an exchange ion promotes dispersion, parallel particle orientation and crusting on

drying. Divalent and trivalent ions tend to flocculate soil particles and reduce the tendency for crusting. Crusts formed from soils with different ion saturations become less dense and more porous in the following order:
$Li^{+} > Na^{+} > K^{+} > Ca^{++} > Mg^{++} > Fe^{+++} > Al^{+++}$.

External factors also influence the formation of soil crusts. Intensity and distribution of rainfall, radiation and wind velocity contribute to the properties of soil crusts. Slow drying promotes stronger crust development. Temperature of drying is negatively correlated with the modules of rupture of soil crusts.

Conclusions

1) Soil crusts are caused by several factors that relate to the degradation of soil structure and the redistribution of individual particles into closer contact.

2) Overcoming soil crusting problems will require investigation of local conditions in a given case and selection of corrective measures to counter those conditions.

3) Economic factors may be a deterrent to overcoming soil crusting problems in many cases.

Implications

Where crusting is a problem, careful assessment of the causative factors may permit curtailing the problem by choosing the best combination of cultural practices. Selection of soil and plant type, time of seeding, gypsum application and many other factors may require testing and adjustment to minimize the effects of crusting and its impact on crop production. Complete control of soil crusting where intense rainfall occurs may require restructuring the soil. Such a drastic change will require much research, especially in dry regions where soil organic matter is low. Gradual improvement in soil structure may be feasible and economic in some cases.

Soil Properties Versus Crust Strength of Some Texas and West African Soils

Harbi Shadfan, Texas A&M University
Joe B. Dixon, Texas A&M University
Frank G. Calhoun, Texas A&M University

Strength of soil crusts is influenced by particle size distribution, but studying the influence of the kind and amount of clay has given inconsistent results. Some workers have reported stronger crusts with montmorillonite and others with kaolinite. Crust strength tends to be greater where clay is present, yet appreciable montmorillonite clay causes shrinking and cracking of the crust. The objective of this study was to determine the influence of different soil properties, including the kind and amount of clay, on the strength of natural and synthetic crusts.

Procedures

Samples of soil were obtained from the Rolling Plains of Texas, where crusting is a problem to seedling emergence, from a poorly structured local soil in eastern Texas, and from the ICRISAT Sahelian Center, Niger. These soil samples from West Africa were taken for characterization purposes.

Chemical and mineralogical properties of the soils

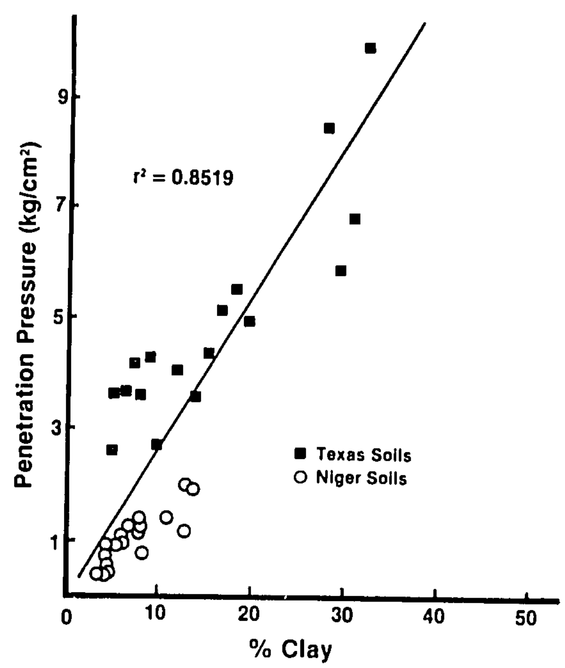


Figure 1. Correlation between penetration pressure and clay %.

were measured by standard methods and crust strength was determined with a penetrometer under controlled laboratory conditions.

Results

During field sampling of crusts in Texas, it became evident that local microrelief influences crust composition and strength. Clay particles are eroded into low areas and sand and silt are concentrated often in strata near the higher points in the field. Thus, there is diversity of the crust formed by rain in different parts of the surface of the field, i.e. ridges and valleys produced by tillage and in the lower parts of the landscape. Changing the configuration of the land surface may aid in reducing crust strength over seedlings. Ridges appear to have the least crust development in poorly structured soils after exposure to intense rainfall.

Samples from Niger are more sandy than those from Texas (Figures 1 and 2). The extremely sandy character and low crust strength of samples from the ICRISAT Sahelian Center suggest that these soils do not form the worst surface crusts among the soils of Niger. A sample population with a wider range of particle size is needed to make a more meaningful comparison.

There is more montmorillonite in the clay of the Texas samples than those from the ICRISAT Sahelian Center. The montmorillonite clay also may contribute to the higher strength of the soils from Texas than from Niger, although the limited published data on mineralogy versus crust strength disagree on this point.

A range of strength values for soil crusts between 1.85 kg/cm^2 and 6.0 kg/cm^2 was selected as a trial guide for soils with a crusting problem for seedling emergence. Lesser crustal strengths are too weak to be a problem and greater strengths may involve cracking and more diversity. From the data plotted in Figure 3 it is evident that many of the Texas soils are in the problem range, but only two of the samples from Niger were in that range. Thus, a wider range of sample properties is needed to determine the magnitude of the crusting problem in samples from Niger, to examine relationships between crusting and other soil properties, and to test corrective measures.

Implications

A wider population of soil clay contents containing different mineral assemblages is needed to adequately test the relationship between crust strength and type and amount of clay. Several other soil properties should be examined in order to determine their relationships to crust formation (e.g., kind and amount of organic matter, iron oxides, and restructuring amendments) to provide a better basis for field experiments on crusting. The area sampled in Niger probably does not represent a serious crusting problem due to rainfall impact because the soils are too sandy.

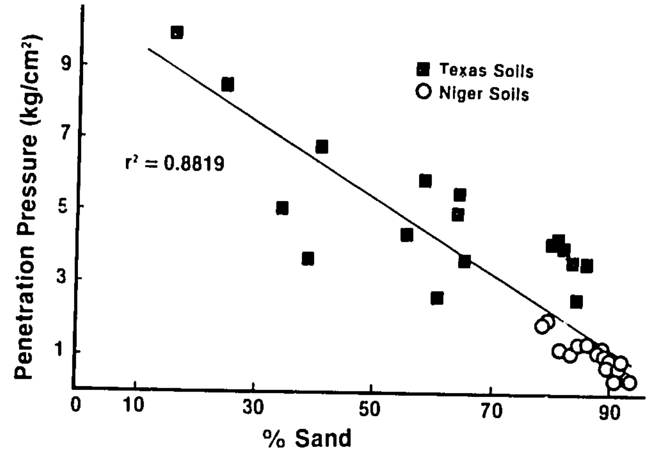


Figure 2. Correlation between penetration pressure and sand %.

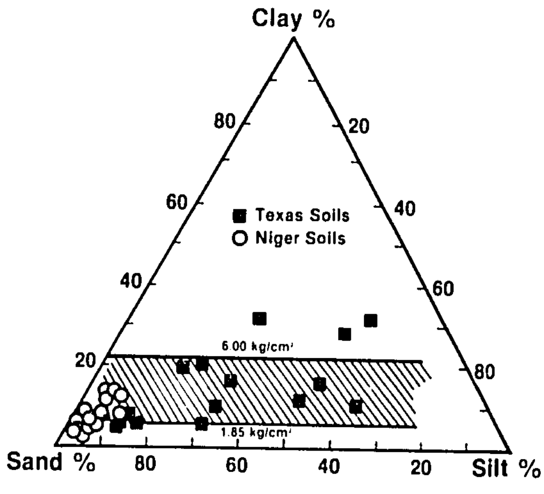


Figure 3. Textural triangle showing the upper and lower limits of crust strength.

Soil-Geomorophology-Hydrology Relationships of Semiarid Tropical Landscapes

Larry P. Wilding, Texas A&M University
Elisabeth Bui, Texas A&M University

A common feature of Sahelian Africa is the dallol, a fossil valley of mostly sandy alluvium wind-sculpted into low dunal terraces accompanied by depressed segments of abandoned channels. The dallols of Niger have been described as unique soil resources with the potential of supporting small-scale, subsistence irrigation and more intensive cropping than has been practiced there traditionally. The objectives of this continuing study are 1) to establish spatial variability in soil resources relative to landform stratigraphy and hydrology in the Dallol Bosso; 2) to characterize and classify major soil resources in the Dallol Bosso as baseline data for research and information transfer; and 3) to monitor seasonal fluctuation in groundwater levels and corresponding water-quality parameters in the Dallol Bosso.

The Dallol Bosso averages about 15 km in width, runs north to south, and may follow a reactivated Pan-African fault in the Pre-Cambrian basement. The dominant wind direction is E-W. Soils, geomorphology and stratigraphy were examined along two E-W sections of the valley representing different agro-ecological zones: one in a pastoral-millet interface zone (300-350 mm rainfall/yr) and the other in a cropped millet zone (600-650 mm rainfall/yr). In both zones, the same five geomorphological units were found: plateaus capped by ferruginous sandstones (laterite), alluvial fan surface, dunes, and sand-filled channels of the Dallol. The dunal unit and sand-filled channels were the focus of this work.

Sampling and Characterization

Eight representative pedons were sampled along the two transects for detailed physical-chemical-mineralogical characterization corresponding to dunal and channel units. Samples of pedogenically formed ironstone and deeper stratigraphic borings to about 8 m were also collected. About 200 samples in total are under analysis. Selected data for the eight soils are given in Table 1.

Soils of dunal landforms are well-drained, strongly oxidized and consist of deep sands without textural development (Quartzipsamments or Torripsamments), deep sands with loamy lamella banding in subsoils (Alfic Ustipsamments and Quartzipsamments), and sandy soils with continuous subsoil textural development (Psammentic Haplustalfs). Soils in abandoned channels are more variable in texture and less well-drained than dunal counterparts. They are generally grayer in color and contain segregated iron in response to seasonally high water tables and reduction. Ironstone sheets and nodules have formed contemporaneously at the margins of some abandoned channels in response to a decline in rainfall and lowering of water tables during recent geologic periods. Na salts have also accumulated in soils of some abandoned channels, especially in the southern sector of the Dallol Bosso. Major soils include deep sands (Aquic Quartzipsamments), dark-colored sandy or loamy soils (Aquic Haplustolls), and wet loamy soils with plinthite (Aeric Haplaquents). Soils in the dallols generally have lower exchangeable Al, higher pH's and base saturation, and greater base recharge capabilities than upland sandy soils in the Sahel.

Soils of the Dallol Bosso are highly subject to wind erosion, especially in the drier northern sector. Here Acacia tree roots are commonly exposed at the base of the trunk, reflecting deflation of surficial sands to the subsoil. The tree canopy apparently creates a venturi effect.

Scanning electron microscopy (SEM) of fine sands from valley sediments (eolian and fluvial sources) and from Continental Terminal sandstone indicate that chemical dissolution features on the grain surface have

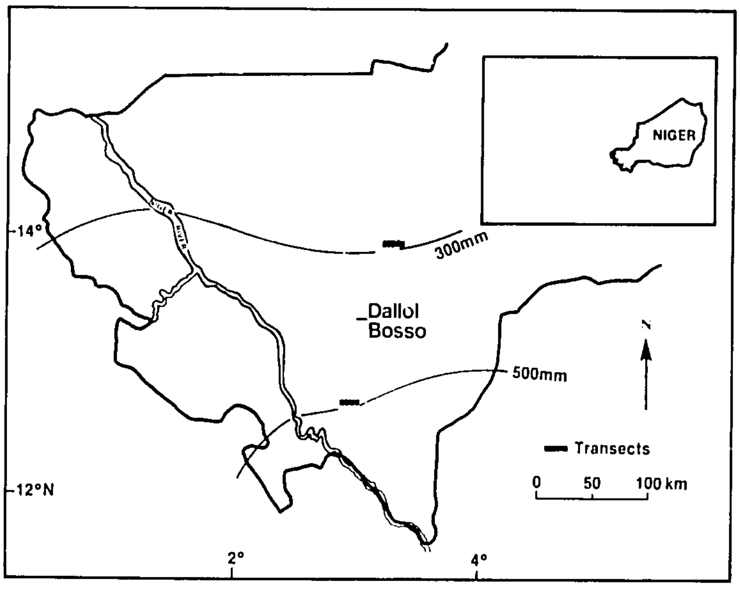


Figure 1. Location of transects within the Dallol Bosso and relationships to mean annual isohyets.

Table 1. Selected physical and chemical data for soils of the Dallol Bosso, Niger.

Pedon #	Landform Position	Tenative Classification	Depth (cm)	Sand % 2-0.05 (mm)	Silt % 50-2 (mm)	Clay % < 2 (mm)	pH (1:1) H_2O	Base Sat. %	CEC (meq/ 100 g)	CEC/g Clay
Southern Transect										
1	Dune	Typic Usti-	0-31	97.1	4.2	3.7	5.2	32	1.1	0.33
		samment	31-78	84.5	8.9	6.5	5.1	22	2.0	0.30
2	Channel	Aquic Quartz- ipsamment	0-60	91.1	5.0	3.9	6.8	75	1.2	0.31
3	Dune	Alfic Ustro-	0-30	91.5	1.2	7.3	6.2	93	2.0	0.26
		pept	55-150	81.6	3.3	15.1	6.4	95	8.5	0.59
4	Channel	Aeric Halaquept (intergrade to Plinthaquept)	0-54	69.0	12.0	19.0	8.9	100 (ESP = 68)	12.1	0.64
5	Dune	Alfic Usti- pasmment	0-30	92.5	4.1	3.4	6.1	93	1.4	0.41
Northern Transect										
6	Dune	Psammentic	0-25	88.7	8.2	3.1	6.5	100	1.6	0.52
		Haplustalf	65-95	87.1	7.2	6.1	6.0	61	3.1	0.51
7	Dune	Ustic Torripsamment	0-60	96.3	0.4	3.3	5.5	48	1.2	0.40
8	Dune	Ustic	0-40	94.6	3.8	1.7	5.2	80	0.5	0.29
		Torripsamment	40-74	89.2	7.1	3.8	5.3	62	1.3	0.34

developed during pedogenic weathering, and that these features mask characteristic transport features. Factor analysis of quartz grain-size and shape distributions suggest that sorting by wind on the basis of both size and shape is occurring. The medium to fine and more angular sand fractions appear most susceptible to wind transport.

Soil-distribution patterns within transects of the dallol are being placed on 1:60,000-scale aerial photobase maps to correlate major soil resources of the Dallol Bosso with geomorphic landforms and stratigraphy of valley deposits. Spatial variability will be quantified by transect data and satellite samples collected during the mapping process. Transects with elevation control will illustrate landform positions where salts and iron-oxide sheets are depositing in the dallol.

Groundwater Levels and Quality

In July, 1985, nine access tubes were emplaced in the Dallol Bosso at locations representing three different geomorphic landforms: an alluvial fan interfacing with the upland plateau, four dunal terrace sites in the dallol proper, and four abandoned alluvial channels in the dallol (Table 2). After installation, the tubes were allowed to come to equilibrium with the surrounding environment. Bimonthly water-table readings were begun in December, 1985; water samples will be collected for chemical assay, including water-soluble cations and anions (Na, K, Ca, Mg, Cl, SO_4, HCO_3, CO_3, pH, and EC (about 54 samples/yr). This work will not only establish seasonal flux of water table levels but probable consequences of such dynamics in terms of important soil properties for crop productivity and management.

Implications

These studies will provide a critical data base for TropSoils research at Chikal and elsewhere in the Dallol Bosso, and will serve as a comparative reference to sandy soils at the ICRISAT Center, Sadore, Niger. Soils in the Dallol Bosso are spatially more variable in soil texture, drainage and mineralogy than those of the ICRISAT Center. Detailed characterization of the dallol's soil resources will be important to the transfer of research and soil-management technologies.

Table 2. Access tubes installed in Dallol Bosso to monitor water-table levels.

Site #	Location (Village)	Landform in Dallol Bosso	Soil Taxonomy Placement	Depth Tube Placed below Surface (m)	Water Table at Time of Installation (m)
1	Kotaki	Terrace dunal plain	Typic Ustipsamments	7.20	6.80 (7/25/85)*
2	Kotaki	Abanded fluvial channel	Aquic Haplustolls	2.50	2.10 (7/25/85)
3	Maoureydo	Abanded fluvial channel	Typic Ustipsamments	1.65	1.42 (7/30/85)
4	Maoureydo	Terrace dunal plain	Typic Ustipsamments	4.03	3.60 (7/30/85)
5	Kou Koubi Kwara (near E. Bui's site #2)	Abanded fluvial channel	Aquic Haplustolls	2.31	1.82 (7/27/85)
6	Kou Koubi Kwara (E. Bui's site #1	Terrace dunal plain	Typic Ustipsamments	6.10	5.87 (7/27/85) 6.08 (7/30/85)
7	Baleyara	Abanded fluvial channel	Fluventic Ustropepts	2.70	1.72 (7/26/85)
8	Baleyara	Terrace dunal	Typic Ustipsamments	4.94	4.46 (7/26/85)
9	Kale Pate	Alluvial fan	Alfic Ustipsamments	7.90	7.70 (7/31/85)

* Date access tubes installed

Calibration of Two-Probe Gamma-Gauge Densitometers

C.H.M. van Bavel, Texas A&M University
Robert J. Lascano, Texas Agricultural Experiment Station
J.M. Baker, Texas A&M University

The measurement of bulk density and volumetric water content in soils is important to characterize, for example, water use by crops, soil evaporation, and other components of water balance. Currently, the only instrument commercially available to measure both bulk density and volumetric water content is the two-probe gamma-gauge densitometer. This instrument has wide applications in agriculture and can give very accurate measurements. However, for its proper use each instrument has to be calibrated with a laboratory procedure that was proposed in 1964 by Reginato and Van Bavel. Recently, the validity of this procedure has been questioned and it has been suggested that it is more practical to calibrate the two-probe gamma gauge in the field using conventional core methods and a semi-empirical data fit.

This study was undertaken to support research in which the neutron method is being used for routine measurements of volumetric water content as the means of establishing the water balance of semiarid crops, both in West Africa and Texas. The objective was 1) to verify the laboratory calibration procedure proposed by Reginato and Van Bavel using commercially available equipment; and 2) to demonstrate that a "field" calibration is not necessary.

Procedures

The laboratory procedure consists of measuring the physical constants needed in Beer's law for calculating soil density from field measurements. These constants, the attenuation coefficients for water and soil, are obtained by measuring the count rates through a glass tray with water or glass plates, respectively. The count rate in air is then found by extrapolating to zero density. Three commercial instruments (Troxler, model 2376 gamma-probe) were calibrated using this procedure.

Results

Results obtained from the laboratory calibration of three two-probe, gamma-gauge densitometers are given in Table 1. The results show that the values obtained for the soil and water attenuators in each calibration are similar, but significantly different at a level of probability exceeding 95%. However, the ratio of the two values equals the theoretical value of 0.906 in each case within 0.003, the LSD at 90% probability being 0.014. The differences found among the three values for the soil and water attenuators are ascribed to geometrical and electronic differences between individual instruments. These differences indicate that a separate calibration is required for each instrument.

Conclusions

The two-probe gamma-gauge densitometer, as commercially available, meets all tests of the physical principles it embodies. Hence, a specific instrument can and, indeed, should be calibrated and checked in the laboratory to fully realize its potential accuracy. Doing so by "field" calibration degrades the precision, is laborious and, in some instances, impractical.

With the results obtained it has been conclusively shown that the laboratory procedure proposed by Reginato and Van Bavel is accurate and should be used for calibration. This study has also demonstrated that there are significant differences among instruments, and that individual calibration is necessary.

The so-called factory calibration, based on count rates in four solid standards of known density but of different composition, is irrelevant to the use of the method in soil physics and hydrology.

Table 1. Results from laboratory calibration of three two-probe, gamma-gauge densitometers.

Instrument No.	Count Rate in Air	Soil Attenuator Average	Soil Attenuator SE	Water Attenuator Average	Water Attenuator SE
	X 1000 CPM	X $10^{-3}m^3/kg$			
1	294.1	1.572	—	1.733	—
2	281.8	1.641	0.007	1.806	0.013
3	309.9	1.603	0.010	1.763	0.016

Field Calibration of Neutron Meters Using a Two-Probe Gamma Density Gauge

Robert J. Lascano, Texas Agricultural Experiment Station
J. L. Hatfield, USDA/Agricultural Research Service
C. H. M. van Bavel, Texas A&M University

The neutron method to measure the volumetric water content of soil is used extensively in field studies to measure water content and the change of soil-water storage over time. From these measurements scientists can calculate seasonal water use by crops and determine several components of the water balance. The water balance is given by the sum of the inputs and outputs to the system. The inputs are rainfall and irrigation, and outputs the losses due to soil evaporation, to plant transpiration, and to drainage below the root zone.

In order to use the neutron method with the greatest possible accuracy each unit must be calibrated for the soil in which it will be used. The field calibration is obtained by establishing a relation between the neutron count rate and volumetric water content. The volumetric water content is usually determined by taking, close to the neutron access tube, undisturbed soil samples of known volume or disturbed samples. In the latter case a separate measurement of the soil bulk density is required. In either case, the procedure is laborious, lacks detailed resolution, and an accuracy that matches that of measuring the count rate.

This study was undertaken to support research in which the water balance is being investigated for crops grown in semiarid climates, both in West Africa and Texas. The objective was to propose and evaluate an alternative approach to field calibration of the neutron meter, using a two-probe gamma gauge to measure volumetric water content in detail.

Procedures

For the purpose of calibration, four sets of aluminum access tubes were installed 0.36 m apart to a depth of 1.7 m in a 50 x 50 m plot at Lubbock, Texas. The calibration procedure consisted of two steps. First, the bulk density profile was calculated from the simultaneous measurement of gravimetric water content and gamma count rate. Second, using the bulk density profile, subsequent gamma count rates at the same time and depth were converted to volumetric water-content values. These values are then related to the corresponding neutron count ratio values, made at the same time and at the same depth, to derive the calibration relation.

The measurements were done over a seven-month period and a total of 13 sets of volumetric water contents and count ratios were obtained. To establish a range of water contents, the plot was planted with sunflowers. Readings were made before planting, at harvest, and after a flood-irrigation of 200 mm.

Results

An example of the bulk density profile obtained at one of the sites is given in Figure 1. This profile of bulk density was obtained by simultaneously measuring the gravimetric water content and scanning the profile with the two-probe gamma-gauge densitometer. There was an abrupt change in bulk density between 0.9 and 1.3 m, the corresponding caliche depth. The water-content profiles obtained also recorded sharp discontinuities in the profile and thus it was possible to correlate neutron count ratios to water content. A plot of all volumetric water content values against count ratio for one of two neutron probes calibrated is shown in Figure 2. The coefficients of the linear regression ($y = mx + b$) and other statistical parameters

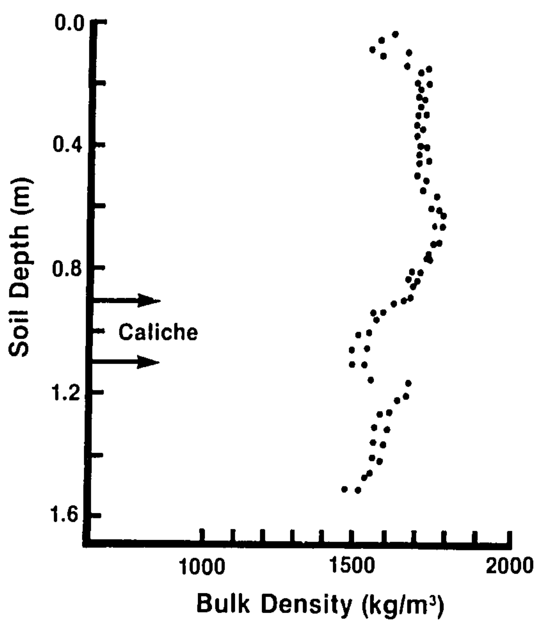


Figure 1. Soil bulk density (kg/m³) as a function of soil depth (m) for one site, measured on two dates. The caliche depth varied between 0.9 and 1.2 m.

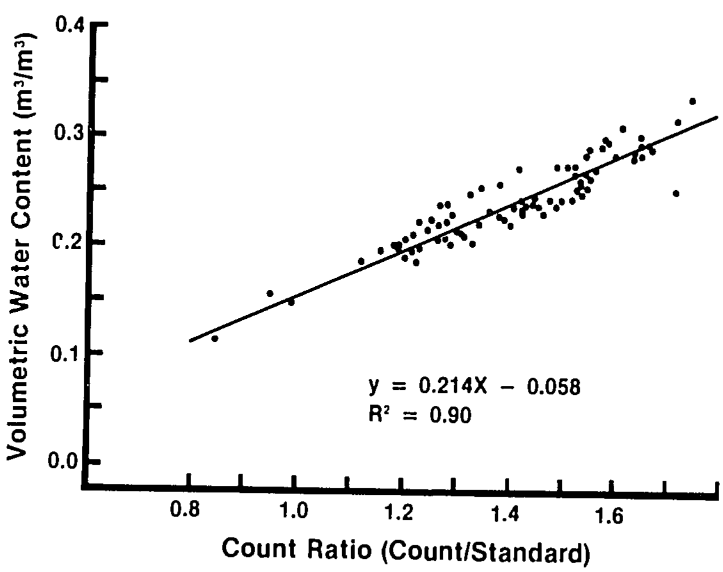


Figure 2. Volumetric water content (m³/m³) as a function of count ratio. The equation of the line is given.

are given in Table 1. In this analysis only data obtained between 0.3 and 1.5 m depth were used. For both instruments the standard error (SE) of the slope was less than 5%, and that of the intercept 20% These results clearly show that it is necessary to calibrate neutron meters individually and that the procedure used in this study is accurate, as indicated by the high R^2 values.

Conclusions

An improved method to calibrate neutron meters in the field has been proposed and evaluated. The method consists of using a two-probe gamma-gauge densitometer to first measure dry bulk density at a site and then the volumetric water contents, as often as needed. The proposed procedure is accurate and has wide applications. The advantage of the method is that a site can be used repeatedly to collect data for a wide range of water content.

Table 1. Coefficients of the linear regression (y = mx + b) and other statistical parameters in the calibration of two neutron probes (only data obtained between 0.3 and 1.5 m depth were used).

Probe	Data Points	Slope		Intercept		R^2
		m	SE(%)	b	SE(%)	
1	96	0.2141	3.7	-0.0583	19.3	0.90
2	84	0.1763	4.9	-0.0504	20.3	0.85

Implications

On the basis of the results of this study, a practical schedule for adequate calibration of a neutron meter would be as follows: 1) install two access tubes to the desired depth at a site with uniform, dense vegetation (two hours); 2) calibrate the gamma probe in the laboratory (one day); 3) after an adequately long dry period, scan the profile with both the gamma and neutron probes (three hours); and 4) irrigate the site and repeat readings after a day or so (three hours). This method has wide applications and can be used to obtain a calibration equation that will yield accurate determinations of seasonal water use by crops.

A Simple Method to Calculate Distribution of a Scaling Factor From Soil-Water Retention Curves

Robert J. Lascano, Texas Agricultural Experiment Station
Leo Stroosnijder, Wageningen Agricultural University, The Netherlands

The statistical variation in space of soil hydraulic properties can adequately be described by a distribution function of scaling factors. These scales have two purposes. First, to simplify and combine measured hydraulic properties of numerous locations within an experimental unit into representative means.

The second purpose is to predict soil-water flow through an area. Once the distribution of the scaling factor is known, key values of this distribution factor can be used in dynamic simulation models to predict the variability of hydraulic processes.

The difficulty with the scaling procedure is that numerous measurements of the hydraulic properties are required to obtain the statistical distribution of the scaling factor, which is based upon the concept of similar media. The measurement of the hydraulic properties is laborious and time consuming; thus, there is a need for a method that would simplify the characterization of the statistical properties of the scaling factor. The objective of this study was to propose and evaluate a method to obtain the statistical properties of the scaling factor based upon calculated soil-water retention curves from measured pore-size distributions.

Procedures

Soil-water retention curves are calculated by combining soil textural analysis with a model that predicts the soil-water retention curve from particle-size distribution and bulk density values. Soil texture with its corresponding particle-size distribution is measured using a laser light-scattering method, and soil-water retention curves are calculated with a model proposed by Arya and Paris. Values of the scaling factor are found by the method proposed by Warrick and coworkers.

In order to evaluate the proposed method, soil samples were collected every 1.0 m along a 100 m transect in a Norwood soil. Particle-size distributions of the 100 samples were measured using a MICROTRAC analyzer. One hundred soil-moisture retention curves were generated using the Arya-Paris model and subsequently 100 values of the scaling factor.

Results

A plot of the fractile diagram and cumulative probability distribution of the scaling factor is given in Figure 1. The scaling factor ranged between 0.615 and 1.593, and the scale factor could be fitted neither to a normal nor lognormal distribution. The semivariogram of the scaling factor obtained along the 100 m transect is shown in Figure 2. From this figure it can be concluded that the range at which the semivariance becomes constant is 20 m. This means that the values of and hence the soil's hydraulic properties beyond 20 m would be considered to be independent of one another.

Conclusions

The proposed method to calculate the distribution of a scaling factor from calculated soil-water retention curves can be used provided certain precautions are followed. It is necessary to compare measured and predicted soil-water retention curves to at least verify the applicability of the predicted function to generate the scaling factor. The main purpose of the method is to calculate the range of the scaling factor and not to predict the soil-water retention curves.

Implications

The use of deterministic models to simulate hydrological processes does not give an estimate of their statistical variability. In order to generate an expected range of values it becomes necessary to scale the hydraulic properties of the soil being modelled. This range can be simulated using the concept of similar media to derive the appropriate scale factor. With the method proposed this factor can easily be calculated and applied to study the statistical variability of hydraulic processes.

With the crop model being developed, incorporating the scaling factor, it will be possible to evaluate in West Africa, for example, how different soil textures affect water storage, crop water use, and soil evaporation.

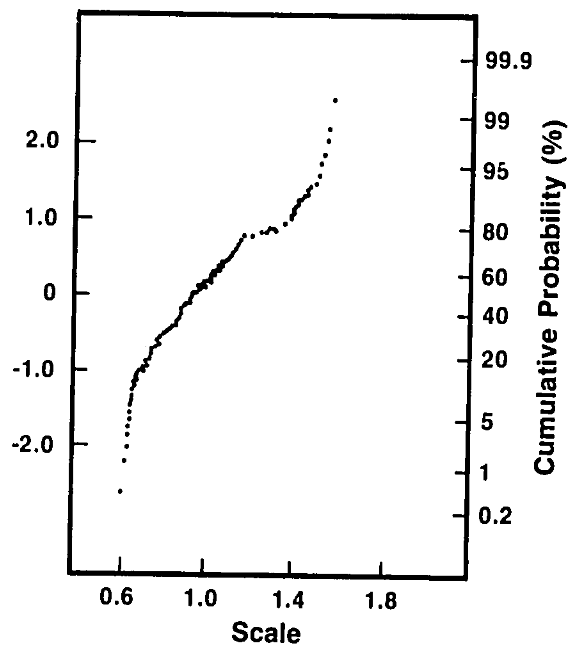


Figure 1. Fractile diagram and cumulative probability plot of the scale factor obtained along a 100 m transect.

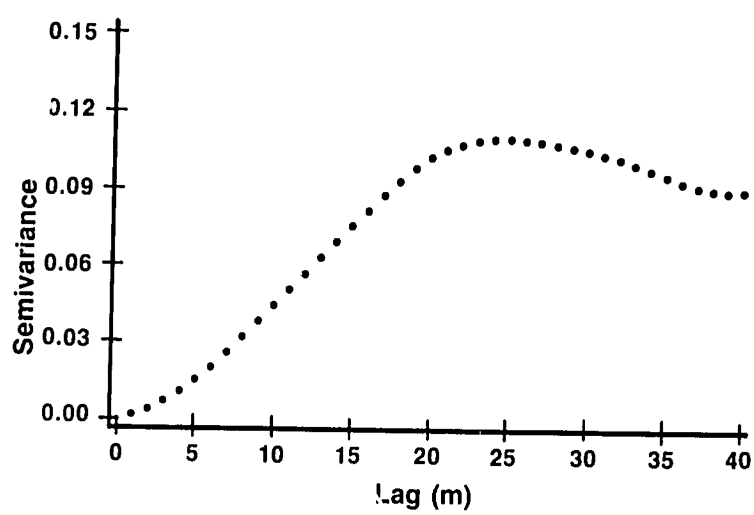


Figure 2. Semivariance for the scale factor obtained along a 100 m transect.

Simulation and Measurement Of Evaporation From a Bare Soil

Robert J. Lascano, Texas Agricultural Experiment Station
C.H.M. van Bavel, Texas A&M University

With a combined water and energy balance model it is possible to realistically simulate the process of water evaporation from a bare soil. The water and energy balances are given by the sum of the inputs and outputs to the system. Direct measurement of soil evaporation is difficult and sometimes not practical, and there is a need for a simple algorithm to correctly calculate soil evaporation based on soil hydraulic properties and weather parameters.

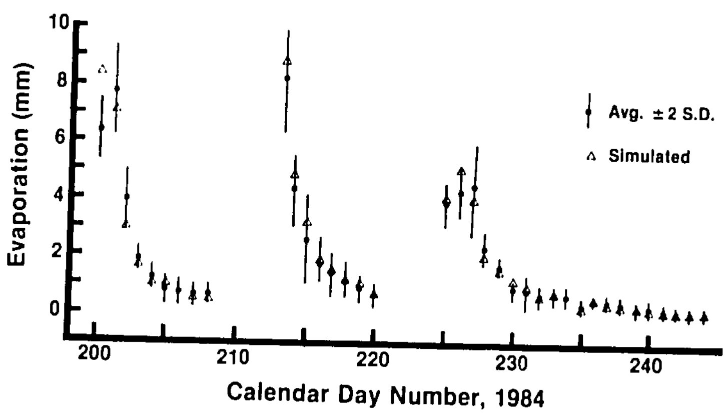


Figure 1. Comparison between measured and simulated daily evaporations as a function of calendar day number for three drying cycles. The bar equals two standard deviations.

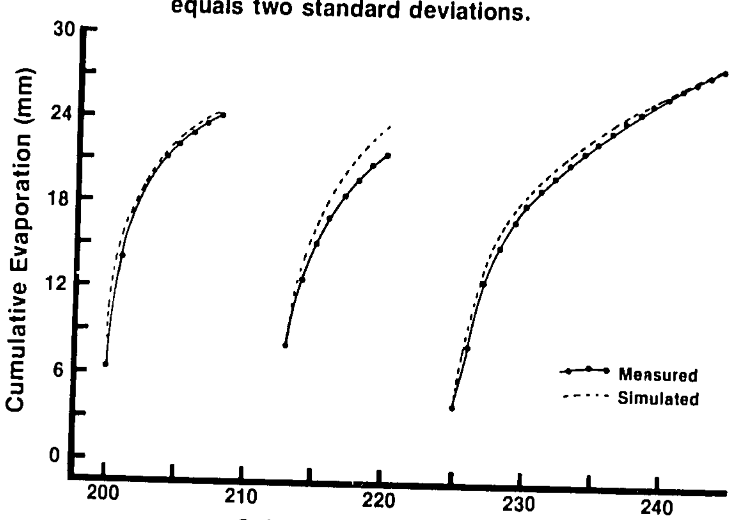


Figure 2. Comparison between measured and simulated evaporation as a function of calendar day number for the three drying cycles.

In this model evaporation is calculated by the combination method, which finds the surface temperature that satisfies the energy and water balance at the soil surface. The inputs to the model are weather variables (solar radiation, air temperature, wind speed, relative humidity and rainfall) and soil hydraulic properties (the soil-water retention curve and unsaturated hydraulic conductivity).

This research effort represents the first step towards developing a model that will correctly calculate the water use of crops that have an incomplete canopy cover, a characteristic of most of the crops grown under dryland conditions in semiarid West Africa and Texas. The objective of this study was to verify the evaporation rates calculated with the proposed model by comparing them with measured values.

Procedures

This study was conducted in Lubbock, Texas, using a 50 X 50 m bare field with a smooth surface. As part of the data required to verify different aspects of the model, measurements were made of volumetric water content, soil temperature, evaporation, soil hydraulic properties and weather parameters. Soil evaporation was measured using "microlysimeters", which are short, undisturbed, closed-bottom, removable soil cores, installed in the soil surface.

The period for which measured and simulated results were compared was July 19 to September 2, 1984. Three drying cycles of different duration were studied. The first cycle was nine days, the second eight days, and the third 20 days long. The first two cycles started the day after the plot was flood-irrigated with 75 mm of water, and the third cycle after a period in which a total of 81 mm fell over three days.

Results

Measured and simulated daily evaporation rates for each of the three drying cycles are given in Figure 1. The corresponding cumulative amounts are given in Figure 2. The results clearly indicate that the model correctly calculates the evaporation rates. This result is also supported (data not shown) by the close agreement between measured and calculated volumetric water-contents profiles, soil temperature profiles, and net radiation values.

Conclusions

Experimental verification of bare soil evaporation rates computed with a model shows good agreement between measured and simulated daily and cumulative evaporation, over a wide range of soil wetness and temperature. The model predicts cumulative evaporation within one standard deviation of the measured values and, in 34 of 37 cases, daily rates were also within one standard deviation of the measured means. Predictions of water and temperature profiles also showed good agreement.

Implications

The proposed model is an accurate method to predict bare soil evaporation rates, as well as soil water content and temperature profiles from known soil properties and measured weather data. As the method employs no empiricisms derived from locally measured data, it is generally applicable.

Currently a crop model that will calculate the water use over time is being developed and tested. This model can be applied directly to evaluate the water use of millet as it is grown in West Africa.

Causes and Control of Pronounced Plant-Growth Variability

Robert G. Chase, TAMU
Andre Bationo, ICRISAT
Mamadou Ouattera, INRAN
Michael Klaij, Wageningen Soil Tillage Laboratory

Spatial variability in plant growth and soils is common in the Sahel. This variability, which is frequently pronounced even over very small areas, complicates the management of crops. It can also mask treatment differences and confound experimental results. The objectives of this three-part study were 1) to identify the causes of pronounced variability in plant growth over short distances; 2) to describe spatial variability of soil chemical and physical parameters in the Labucheri series soils; and 3) to make available practical methods for decreasing or eliminating much of the variability in crop growth, thereby increasing yield in farmers' fields.

Causes of Variability

Farmers were interviewed in six selected sites near Niamey during the 1983 and 1984 growing seasons. Each agricultural problem-area identified by these farmers was studied with respect to types and extent of soil variability. Obvious causes included termite mounds, proximity of crops to trees, and damage by insects or disease. Less obvious sources of variability were determined from identifying very different soil types, or from a history of land use. This category includes sites previously used for such things as houses, feed lots, threshing sites and corrals, and sites which had recently been manured. A third category of causes that are not readily explainable, including differences in chemical properties among soils that look alike, is of principal interest to this project. These causes decrease farmers' yields and invalidate researchers' experiments. Variability is also influenced by short-term, physical factors such as sand blast and burial of young plants, and redistribution of rainwater on the soil surface.

Relative crop yield was studied in four soils (the Dayobu, Labucheri, Tondi, and Zogoti series) found at the ICRISAT Sahelian Center. During the 1983 growing season these soils were shown to have greatly different capabilities in supporting millet growth and production when taken from fallow and without P application (Landeck, 1984). The following year, P treatments were applied to the same soils, which were previously unfertilized, to determine the response of millet to P application in each (Figure 1). These studies show that crop growth and response to fertilizer application are quite different among soil series, although the soils appear identical to the eye. These differences are due to soil chemical and physical differences, factors that must be taken into consideration when choos-

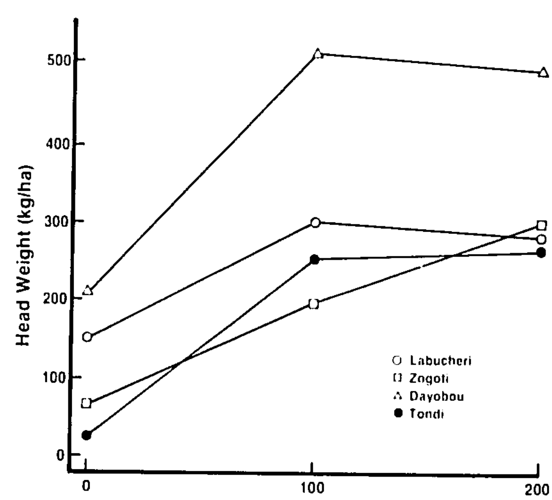


Figure 1. Millet head weights as a function of soil type and P application as single super phosphate.

Table 1. Millet yields from two adjacent 7.0 x 5.25 m plots uniformly planted and fertilized.

Plot	Total Hills	Hills Surviving	Number Heads	Head Weight	Grain Weight	Stalk Weight
				kg/ha	kg/ha	kg/ha
Poor	49	11	27	158	124	470
Good	49	44	157	1,302	1,030	2,340

Table 2. The F values of correlations drawn between some chemical and physical properties of 101 surface soil samples (1-10 cm depth) and plant height 35 days after planting and final whole-pocket head yield at the end of the season. (F = 6.90 and 3.94 for significance at r=0.01 and 0.05, respectively)

	Surface level of Field	Coarse Sand	Fine Silt	Silt	Clay	Organic Matter	Bulk Density	Brey 1 Phos.	Exch. Bases	CEC	Exch. Acid	Exch. A1	pH (H_20)	pH (KC_1)
Plant Height	16.15	1.07	0.001	11.71	1.90	0.15	0.61	0.76	16.16	8.48	29.52	39.77	10.95	20.11
Yield Per Pocket	4.73	0.71	0.003	0.007	0.076	1.66	0.45	0.79	2.95	0.001	8.29	7.83	0.20	1.22

ing sites for experimental plots or in making management and fertilizer recommendations to farmers.

Variability Description

To describe the spatial variability in crop growth, millet yields were measured in two adjacent plots in a field uniformly planted and fertilized. The severity of variability is demonstrated by the data in Table 1, which show an eight-fold difference in grain yield from the two areas.

To describe variability in soil properties, 1,250 surface soil samples (0-10 cm) were taken in a grid pattern from a 2 ha field at the ICRISAT Sahelian Center (ISC) and analyzed for soil pH and 15-bar water. The results have been combined with data on bulk density, penetrometer resistance and plant-growth

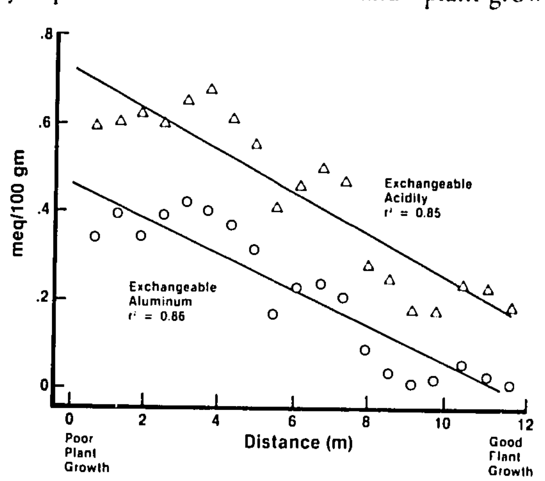


Figure 2. Exchangeable acidity and Al along a transect.

parameters from the same plots. Statistical analysis is expected to quantify the variability of the factors studied, and determine the applicability of these techniques for defining soil characteristics in Sahelian soils.

Another set of 101 soil samples was taken from two 50 m transects in a highly variable field at the ISC. The samples have been analyzed for bulk density, soil texture, pH (H_2O and KCl) K, Na, Ca, Mg, organic material, CEC, exchangeable acidity, and exchangeable Al. Plant heights were measured at each sampling site and throughout the 50 x 50 m area delineated by the transects. Correlation identified factors in land evaluation, silt content, CEC, pH and exchangeable acidity/Al, to be associated with crop variability (Table 2).

Further studies in farmers' fields and at the ISC confirmed a strong correlation between acid soils and poor crop growth (Figure 2). Additional soil sampling in the 50 x 50 m intensive-study area resulted in data on soil pH, exchangeable acidity/Al, bulk density, soil moisture and crop growth and yield parameters (see for example, Figure 2), which will be analyzed for correlations between soil physical/chemical properties and crop growth and yields as well as for stability in the position and extent of the affected areas between years.

Variability Management

Pot studies on soils taken from a highly variable field at the ICRISAT Sahelian Center showed that the application of lime (CaOH) to these soils just before planting did not have an effect on plant-growth variability. In subsequent studies it was determined that the application of a combination of nutrients (N, P, S, Ca, and Mg) permitted good crop growth in three-week old plants grown in pots of poor soil. A marked decrease in growth was seen when Mn and salts of chloride were applied. Plant and soil samples from these studies are being analyzed.

Preliminary tissue analyses indicate that poor growth may be the result of Al and/or Mn toxicity (Table 3), explaining the negative effect of applications of Mn and salts of chloride. The poor growth response to liming appears to be due to the short-term ineffectiveness of lime in removing Al from solution. Later studies showed that two wetting/drying cycles of the soil after lime applications improved plant growth, presumably due to the precipitation of complex aluminum oxides/hydroxides from the soil solution. Phosphorus application to poor soils appeared to decrease Al in plant tissue, due to increased plant growth or to Al precipitation (Table 4). Further experiments are being conducted to study this effect.

Good soils have a surface layer of low pH not found in poor soils (Figure 3). It was observed in the field that when a hole was dug 15 cm deep in poor soil, and allowed to fill with blowing sand of higher pH, millet grew better in the filled area than in the surrounding, undisturbed soil.

As this project continues, results from pot studies and the associated laboratory analyses of soils and plants will be tested in two farmers' fields. Results from soil-amendment studies will be compared with results from experiments in which the A horizon is manipulated through soil removal, mulching and deep tillage.

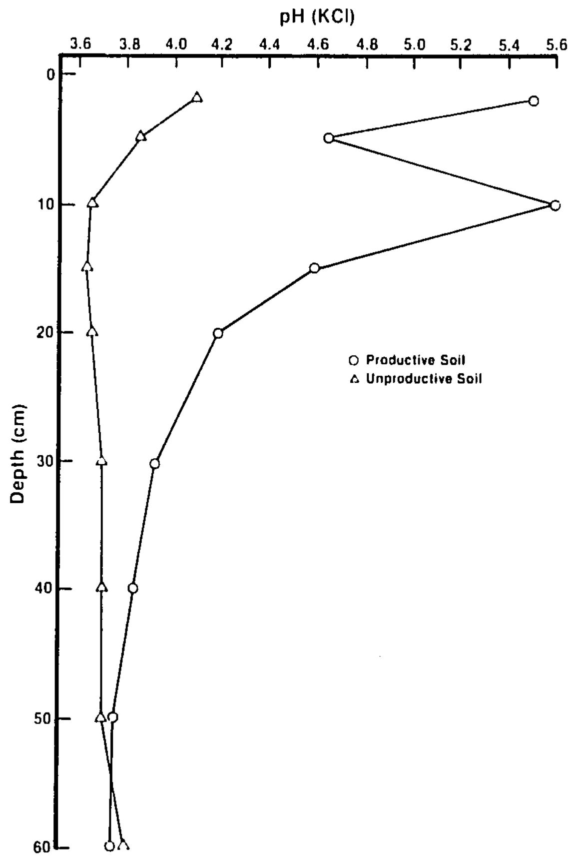


Figure 3. Profiles of soil pH in two adjacent areas of a Lubucheri soils, one that supports good plant growth and one that does not.

Table 3. The effect of liming productive and unproductive Labucheri Soil, without drying, on soil pH H_2O, and manganese and exchangeable aluminum in 20-day-old millet-plant tissue (unpublished data from MS thesis by J. Wendt, Texas A&M University).

Soil/Treatment	Soil pH	Mn (ppm)	Al (ppm)
Productive Soil, Unlimed	5.4	149	335
Productive Soil, Limed	6.0	122	618
Unproductive Soil, Unlimed	4.6	888	2715
Unproductive Soil, Limed	6.0	220	2058
Unproductive Soil, Limed 2x	7.1	77	1697

Table 4. The effect of adding N and P and all micro and macro nutrients on 20-day-old millet seedling yield and tissue Al content (unpublished data from MS Thesis by J. Wendt, Texas A&M University).

Soil/Treatment	Yield, g/pot	Al in Plant, ppm
Productive, Control	1.67	440
Productive NP	3.58	na
Productive, All Nutrients	6.26	380
Unproductive	0.15	2790
Unproductive, N,P	2.07	580
Unproductive, All Nutrients	2.95	290

Water and Energy Balance Of Sahelian Soils

Robert G. Chase, Texas A&M University
Philip Serafini, ICRISAT
M.V.K. Sivakumar, ICRISAT
Andre Bationo, International Fertilizer Development Center
John Heermans, Forest and Land Use Project
Juan Seve, Forest and Land Use Project

These studies were established to define the temperature and moisture profiles of selected Sahelian soils. This information would be useful to researchers who select crop varieties or develop soil-management technologies for the region.

Agricultural Soils

The objective of this experiment was to describe the temperature regime in an important Sahelian agricultural soil.

Climatological data (air temperature and humidity, wind speed and direction, rainfall and solar radiation) were collected at the ICRISAT Sahelian Center every two hours during a 22-month period ending April 26, 1985. Four replications of three surface treatments were established in June, 1983, in a millet crop on a Labucheri series soil at the Center. The treatments were a control, a white surface and a black surface. Within each plot, soil temperature profiles (surface, 2, 5, 10, 20, 50, 100, and 150 cm) were taken at two-hour intervals. Temperatures at depths of 2 and 3 m were taken periodically. Soil moisture profiles to a depth of 3 m were taken regularly throughout this period using the neutron probe and gravimetric sampling.

Results

The soil temperatures at the three-meter depth remained fairly constant at around 31° C all year, while temperatures at 50 cm fluctuated from 28.5° C in January to 35° C in June. The influence of surface treatment and rainfall on surface and subsurface temperatures is shown in Figure 1. The entire soil temperature profile to a depth of 150 cm was significantly influenced by both surface treatments (Figure 2). Soil water content decreased from one to

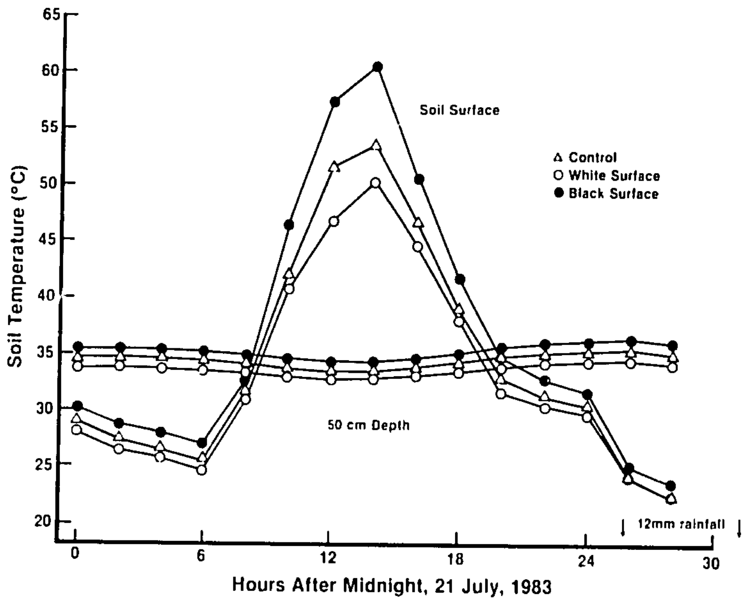


Figure 1. Soil temperature fluctuations in a sandy soil as a function of surface-color treatment and depth.

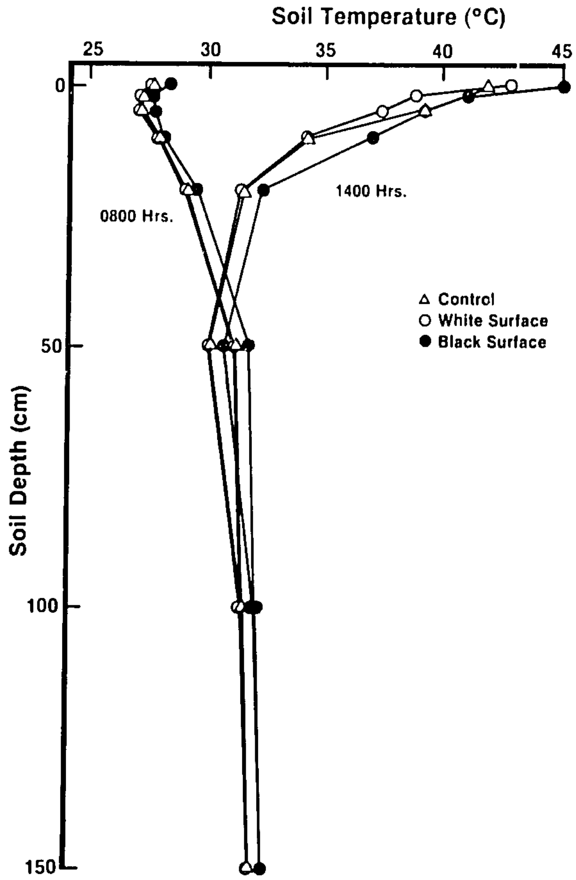


Figure 2. Soil temperature profiles in a sandy soil as a function of surface color at 0800 and 1400 hours on July 22, 1984.

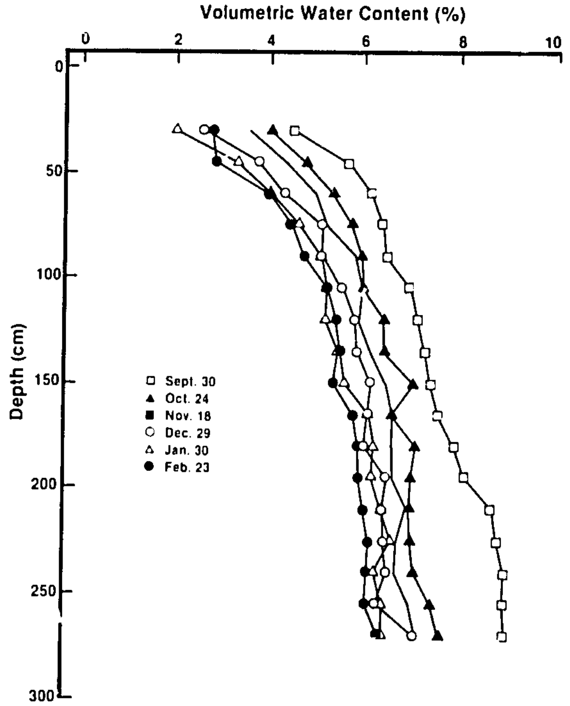


Figure 3. Moisture loss from the profile of a sandy soil from Sept. to Feb., 1983-84.

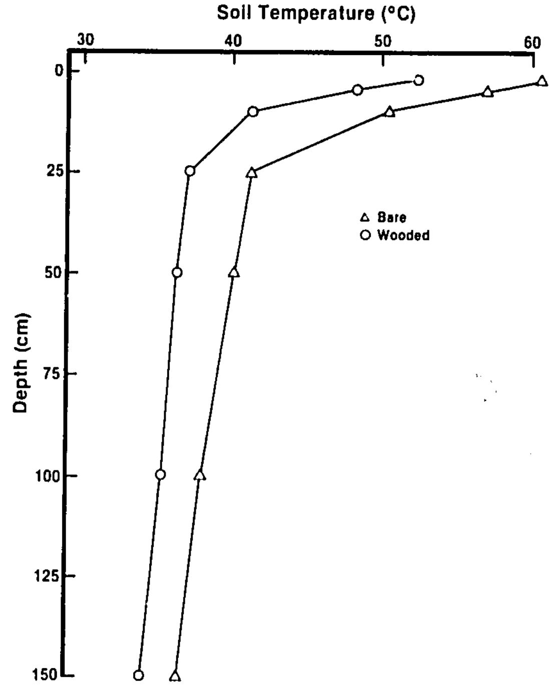


Figure 4. Temperature profile of forest soil on May 27, 1985, before the rainy season began.

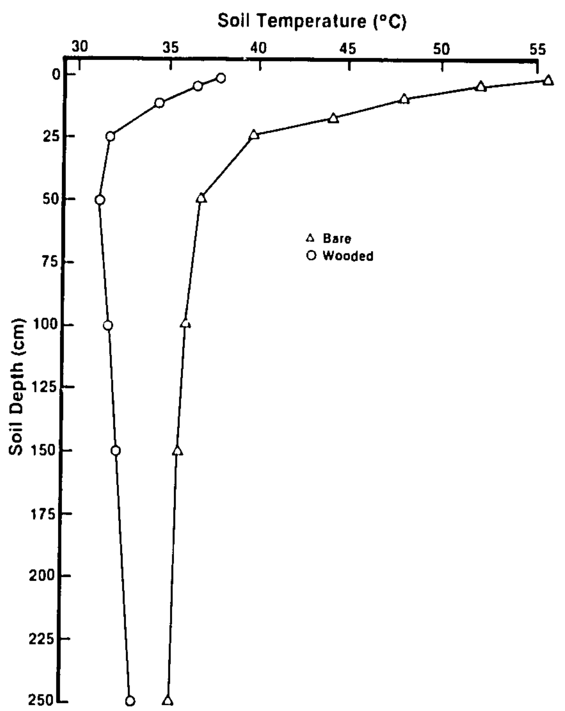


Figure 5. Maximum soil temperatures for a wooded and a bare soil, July 28, 1985.

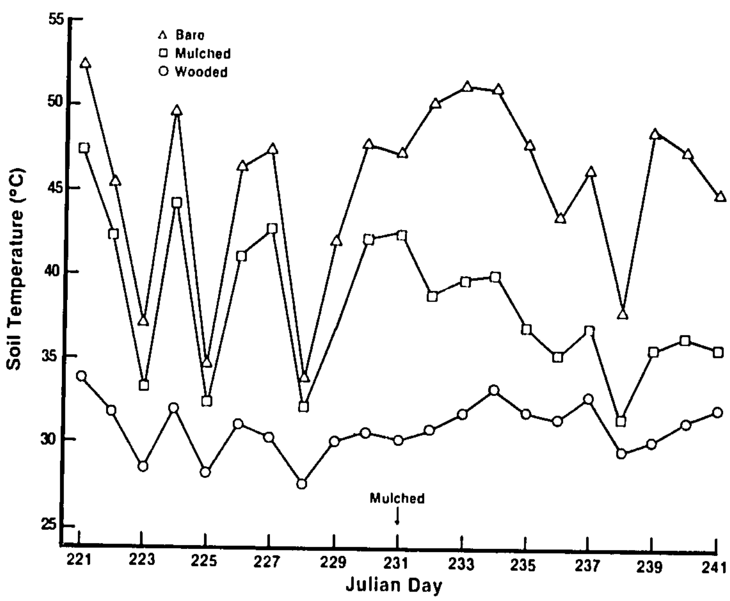


Figure 6. Soil temperature (2 cm depth) on August 19, 1985 in a vegetated area and in two crusted soil areas, with or without mulch.

two percent by volume throughout the profile during the first two-thirds of the dry season (Figure 3).

This study has shown that, during the cropping season, the soil at 50 cm depth is about 15 and 5° C warmer than soil at like depth in Texas and India, respectively. Programs in those areas breed millet and sorghum varieties for use in the Sahel. These differences in soil temperatures, which affect soil chemistry, soil microbiology and plant physiology, must be taken into account when selecting for germplasm to be evaluated in Niger.

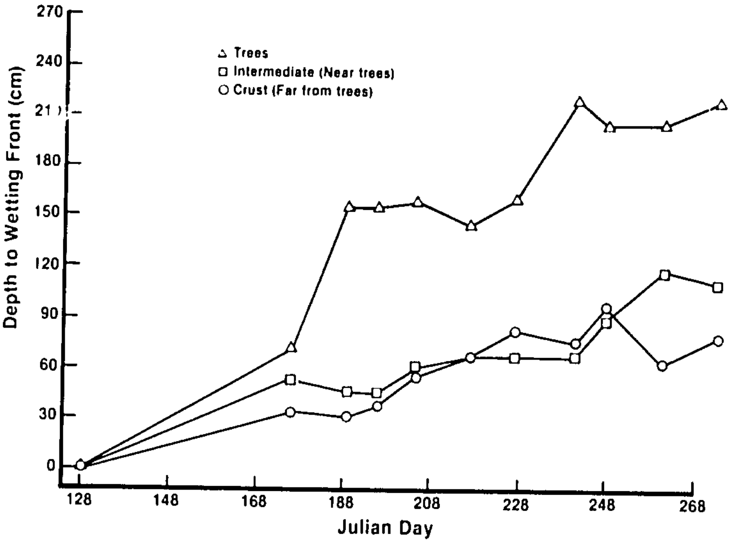


Figure 7. Depth of the wetting front during the rainy season, 1985, as a function of position in the forest.

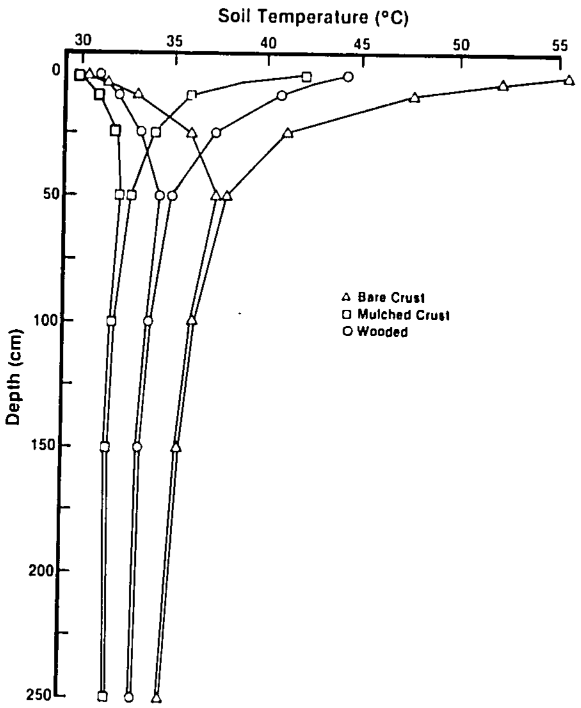


Figure 8. Maximum and minimum soil temperature profiles in three areas of the Guesselbodi Forest on Oct. 11, 1985.

Forest soils

The objective of this experiment is to define the difference in soil temperature and vapor pressure deficit brought about by two adjacent but strikingly different forest environments.

In the Guesselbodi forest, soil temperature profiles are being taken at depths of 2, 5, 10, 25, 50, 100, 200, and 250 cm in a wooded area and in an adjacent crusted area. In both areas, the wetting front was also monitored by neutron attenuation techniques to find the relation between rainfall and water entry into the soil of the two zones.

Soil temperature profiles at the time of maximum and minimum surface soil temperature show that, before the rainy season began, the bare trees reduced peak surface soil temperatures by 7° C (Figure 4). During the rainy season, the soil temperature profiles show a marked effect of the vegetation on soil temperature throughout the profile (Figure 5). During this season, differences in surface soil temperatures between vegetated and barren areas can approach 20° C (Figure 6). Both natural vegetation and applied mulch decrease soil temperature fluctuations at 2 cm depth.

Water infiltrates deeper in soils that are vegetated than in barren soils (Figure 7). During the rainy season, data collected show that relative humidity between the middle of the vegetated area and an area three meters away from the tree line (2 m elevation) may reach 10% or more during the day while air temperatures differed by 3-4° C. Hot, drier air moving from the barren areas may have an effect on the evapotranspiration within the vegetated areas. After the rainy season, heat flux during the year's second hot season increases temperatures in the deep soils, as shown by the slope of the temperature curves in Figure 8.

In comparing aerial photographs of the research site taken in 1984 with those of the same area taken in 1950, it was determined that, depending on location, between 35 and 60% of the vegetation had been lost in this 34-year period. The pronounced difference in microclimate between vegetated and adjacent barren areas, as demonstrated in these studies, suggests that the loss of vegetation in Sahelian forests might have an increasingly severe effect on the remaining vegetation and perhaps on the macroclimate as well.

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. If the family's needs are met, part of the crop is sold or traded for such things as salt and cloth.

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 larger areas farmed less intensively. Thus, land productivity and per-hectare yields 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, but in other semiarid environments as well.

Influence of Tiller Removal On Growth and Production of Millet

Naraine Persaud, Texas A&M University
Mamadou Ouattara, INRAN/DRE
Mohamadou Gandah, INRAN/DRE
Jada Gonda, INRAN/DRA

During their growth cycle millet plants produce many tillers, the number depending on genotype. Apparently, traditional varieties have been selected locally for high tillering capacity, probably for a number of reasons: Millet residues are used for housing, village industry and animal feed at the end of the season; the semi-erect leaves may function as rainfall-harvesting surfaces; and tillers provide additional surface for photosynthesis, perhaps compensating for the short growing period. Only a small percentage of these tillers produce fertile heads, however, and the remainder transpire water, widening the ratio of water used to grain yield. Two objectives of this study were 1) to study the effect of tiller removal on the growth and yield of several millet varieties under different soil-water conditions and levels of fertilizer application; and 2) to investigate the effect of tiller removal on soil-moisture use efficiency.

Table 1. Effect of irrigation level, variety, fertilizer application and tiller removal on millet yield, plants per pocket and fertile heads per pocket at harvest.

Irrigation Level	Yield, kg/ha	Plants/ Pocket	Fertile Heads/ Pocket
233 mm	382	11.1	2.9
309 mm	560	12.1	3.6
P(≥t)	0.07	0.1	0.1
Fertilizer			
None	395	10.7	2.8
22.5 kg P_2O_5 + 45.0 kg N/ha	548	12.5	3.6
P(≥t)	0.01	0.01	0.01
Variety			
Zongo	339	11.6	2.0
HKP	603	11.5	4.5
P(≥t)	0.01	0.1	0.01
Tiller Removal			
No Removal	484	14.1	3.5
Removal Twice	459	9.1	3.0
P(≥t)	0.1	0.01	0.06

Note: A split-plot design was used with irrigation level as the main plot treatment and factorial combinations of variety, fertilizer, and tiller removal as the sub-plot treatments. There were three replications. Plot size was 10 x 10 m. sq.

Effects on Yield

Two experiments were conducted, one under irrigation by sprinklers, February to May, 1985, and the other under rainfed conditions, July to September, 1985. Treatment effects observed on several occasions during the two studies are shown in Table 1 and Table 2. The results show a significant increase in yield under rainfed conditions when the tillers were removed once during the elongation stage. For the irrigated experiment, there were no interactions between treatments on yield. Removal of tillers twice at elongation and at flowering depressed yields (Table 1). The ANOVA revealed highly significant interactions between fertilizer x variety on plants per pocket and fertile heads per pocket at harvest, between irrigation level x tiller removal on plants per pocket, and between irrigation level x variety on fertile heads per pocket (Table 3). The variety HKP was clearly superior to Zongo, producing more fertile heads/pocket with no fertilizer and low irrigation.

Water Use

At the planting, 24 locations in the experimental field were augered and gravimetric moisture determinations were made on these samples taken to a depth of 2 m at 20 cm intervals. These data showed an initial storage of 29 mm in the 2 m profile. At harvest, each plot was sampled at two locations in the same manner as at planting. Assuming no drainage below 2 m, Table 4 shows the results for water used for the various treatments. As a percentage of total water applied, the lower level of irrigation was more efficiently used, 83% versus 78%. The field capacity of the sandy dune soils used in this experiment is approximately 10%, and penetration of the water deeper into the profile may account for the lower efficiency. The non-fertilized plants yielded 0.19 g/kg water used versus 0.25 g/kg for the fertilized plants. Corresponding values were 0.28 g/kg for the HKP plants versus 0.15 g/kg for the Zongo plants (Tables 1 and 4).

Discussion

These results indicate that more experimentation will be necessary to determine the usefulness or practicability of the tiller-removal technique with various cultural practices and to elucidate the mechanism involved. The results will indicate whether tiller removal has potential as a low-input technique for soil-water management. If proven successful, the technique would increase the resiliency of the millet grower by helping him to tailor his crop biomass to the varying pattern of local rainfall. Yield may also be stabilized, and the tillers removed may be used as animal fodder.

Table 2. Effect of removing tillers (50% at elongation) on rainfed millet yield, fertile heads per pocket, dry weight per head, dry matter and plants per plot at harvest.

Tillers Removed	Grain Yield kg/ha	Fertile Heads per Pocket	Weight/Head g	Dry Straw kg/ha	Plants/Plot
No	607	2.1	44.3	1189	547
Yes	670	2.3	43.9	1122	426
P(t)	0.05	0.1	0.1	0.1	0.06

Note: A complete randomized design with six replications was used. Plot-size was 9 x 9 m. sq.

Table 3. Interactions between treatments on plants per pocket and fertile heads per pocket at harvest.

	Variety			Irrigation Level	
	Zongo	HKP		233mm	309mm
		Plants per Pocket at Harvest			
No Fertilizer	10.4	11.0	No Tiller Removal	13.1	15.1
Fertilized	12.9	12.2	Removal Twice	9.0	9.2
		Fertile Heads per Pocket at Harvest			
No Fertilizer	1.8	3.9	Zongo	1.9	2.0
Fertilized	2.1	5.2	HKP	3.9	5.1

Table 4. Water use as influenced by irrigation level, variety, fertilizer application and tiller removal.

Tiller	Total Irrigation = 233 mm				Total Irrigation = 309 mm			
Removal	Zongo*		HKP		Zongo		HKP	
	NF**	F	NF	F	NF	F	NF	F
None	192***	207	185	197	239	260	232	238
Twice	195	193	175	199	240	245	235	243

Overall Means by Factor

Factor	Mean	Factor	Mean
Irrigation		Variety	
233 mm	193	Zongo	221
309 mm	242	HKP	213
Fertilizer		Tiller Removal	
None Added	212	None	219
Fertilized	222	Twice	215

* Millet variety

** NF = not fertilized; F = fertilized

*** mm of water used = total irrigation + initial storage to 2 m - final storage.

Pearl Millet (*Pennisetum Typhoides*) Response to Soil Variability In Sandy Ustalfs

John W. Wendt, Texas A&M University
Robert Chase, Texas A&M University
Lloyd R. Hossner, Texas A&M University

Variability in millet stands is a major constraint to grain production in the Sahel. Millet growth is irregularly distributed and can range from highly productive stands to completely barren areas over distances as short as two meters. Zones between these extremes are characterized by declining plant growth, delayed maturity, shorter and poorly filled grain heads and diminished yields. In the unproductive areas of the field, drought seems to accentuate poor millet growth by forcing roots to forage at greater depths for water and nutrients.

The objectives of this study were 1) to determine the causes of variability in millet stands; and 2) to seek methods to eliminate the source of this variability.

Procedures

Field studies were conducted at the International Crop Research Institute for the Semi-arid Tropics (ICRISAT) Sahalian Center, 40 kilometers south of Niamey, Niger. Soil data collected earlier from the research site indicated that bulk density and soil texture were not significantly related to millet growth. However, KCl-extractable Al and soil pH in 1M KCl were significantly correlated with plant height throughout the growing season. In the present study a 15 m transect was selected in a part of the field where millet growth declined continuously from an excellent stand to an area completely devoid of vegetation. Soil samples were collected in increments to a depth of 65 cm at each end and at an intermediate location in the transect. The top 15 cm of soil was sampled at 26 locations along the transect to provide soil for chemical analyses and pot studies. Bulk samples of soil from a productive and unproductive region were also collected to provide material for additional pot studies on liming and nutrient experiments. The major soil in this field belonged to the Labucheri soil series, a sandy, siliceous, isohyperthermic psammentic Paleustalf.

Results

Soil profiles were analyzed at the extremes and midpoint of the transect. The chemical analyses indicated low effective cation exchange capacity (ECEC) (less than 1.3 cmol/kg) and highly variable amounts of saturating cations. Of particular interest is the variation in the Al + H saturation of the exchange sites, calculated as the sum of exchangeable Al + H divided by the sum of the exchangeable Ca, K, Mg, Na, Al and H x 100. The data are plotted with depth at three locations in the transect (Figure 1). All soil profiles had a low Al + H saturation at the surface. However, the Al + H saturation of the unproductive soil increases to 45% at a depth of only 3.5 cm.

The Al + H saturation of the productive soil rises more slowly, reaching 45% saturation at a depth of 35 cm. The soil at the intermediate location was 45% Al + H saturated at about 12 cm. Soils at both the unproductive and intermediate locations had greater than 50% Al + H saturation in the top 15 cm of the profile. All soils have potentially toxic levels of exchangeable Al within 35 cm of the surface. Increases in exchangeable Al + H are accompanied by decreases in exchangeable Ca in all profiles.

Analyses of the top 15 cm of soil show that pH decreases and exchangeable Al + H increases along the transect from the productive to the unproductive site (Figure 2). Exchangeable Ca, Mg and K also increased along the transect from the unproductive to the productive site. A correlation matrix showed that pH, Al + H saturation and exchangeable Ca, Mg,

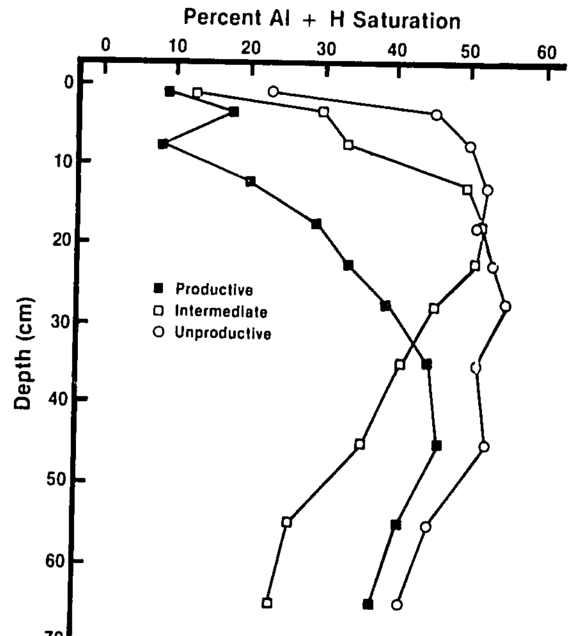


Figure 1. Percent Al+H saturation with depth along a transect from an unproductive to a productive area.

Al and Al + H all correlated very strongly with position on the transect. However, the best positive correlations with shoot weight were with exchangeable Ca (r = 0.72), Mg (r = 0.66), and K (r = 0.72). Negative correlations were with Al + H (r = -0.69), and % Al + H saturation (r = -0.72).

Millet growth in soil from along the transect was closely associated with plant Al content (Figure 3). Aluminum reached concentrations as high as 1400 μg/g in plants from those pots where little millet growth occurred. Aluminum concentrations of less than 600 μg/g appeared to be necessary to achieve optimum growth in this experiment.

An additional factor that was identified in this study was the extremely high manganese content of millet shoots when the millet plants were grown in low pH soils taken from the field and used in pot studies (Figure 4). The range in plant Mn was less than 200 μg Mn/g in soils of pH greater than 5.5 to more than 1600 μg/g in plants from the very acid soil of the unproductive site.

Conclusions

This study strongly suggests that Al toxicity is the major growth-limiting factor to millet at the field site studied. The very presence of Al toxicity problems in an ustic, semi-arid environment is in itself noteworthy. Al + H saturation values of the cation exchange sites of over 60% are clearly indicative of soil-acidity problems. Increased plant Al concentrations correlated very well with poor millet growth.

Other element toxicities and deficiencies are also indicated by this study. Manganese toxicity is a consideration in the very acid unproductive areas. Potassium and phosphorus concentrations in many of the plants were well below suggested critical values cited in the literature. Plants grown in soils taken from relatively productive areas in the field responded dramatically to fertilizer inputs. The low ECEC of these soils should permit neutralization of soil acidity with very small inputs of lime. In addition to lime input, the soils will require the addition of other essential plant nutrients to encourage optimum yield.

Variability in millet stands across the semi-arid Sahelian region of West Africa is common. This study indicates that in the region around Niamey, Niger variability in millet stands may be closely associated with acid subsoils with high Al + H saturation. Correction of soil factors that contribute to spatial variability could, in itself, significantly increase production of millet in west Africa.

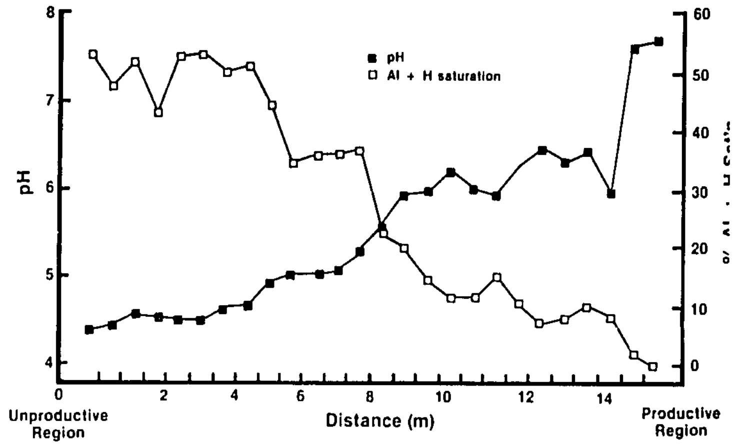


Figure 2. Percent Al + H saturation and pH of the surface 15 cm of soil along a transect from an unproductive to a productive area.

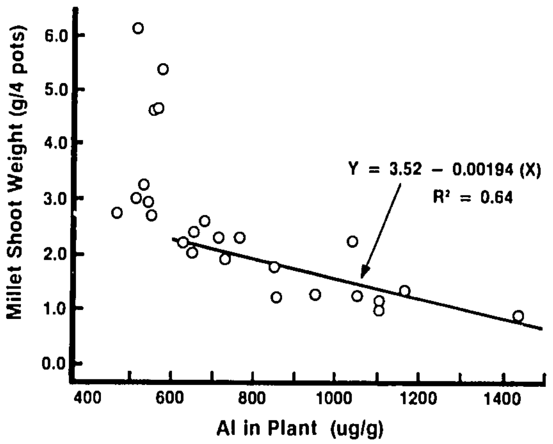


Figure 3. Shoot weight vs. Al concentration for plants grown in the surface 15 cm of soil taken along a transect from an unproductive to a productive area.

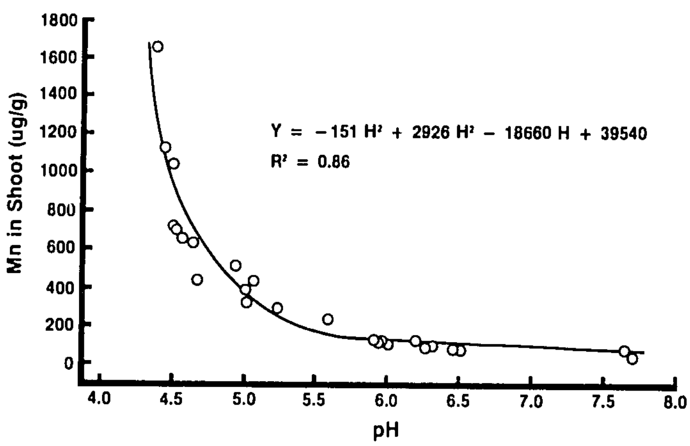


Figure 4. Shoot Mn concentration vs. soil pH (1:1) for plants grown in the surface 15 cm of soil taken along a transect from an unproductive to a productive area.

Phosphorus Fertilization and Relationships of Root Distribution And Soil Water Extraction

Arthur B. Onken, Texas Agricultural Experiment Station
Charles W. Wendt, Texas Agricultural Experiment Station
Jim Mabry, Texas Agricultural Experiment Station

The importance of the subsoil in providing water and nutrients to a crop has been recognized for many years. When chemical or physical constraints to root proliferation are removed, some crops are able to withstand drought by exploiting subsoil water and nutrients. It has also been shown that certain nutrients, phosphorus in particular, are more available to plants in moist soil than in dry soil. In semiarid regions, where the topsoil is likely to be dry enough to restrict nutrient uptake, there may be an advantage in placing some of a crop's fertilizer deep in a moist soil zone.

The objectives of this study were 1) to determine if P fertilizer applied to a P-deficient subsurface zone in a soil profile would enhance water uptake from that zone and/or other zones even though the topsoil was adequately fertilized; 2) to determine if placing P fertilizer in a P-deficient subsurface zone would increase the yield of cotton and grain sorghum even if the surface soil was adequately fertilized.

First-Year Study

This study was conducted in 1984 with cotton and grain sorghum on Acuff loam at the Texas A&M Agricultural Experiment Station near Lubbock. The soil area selected was known to be low in P in a zone between approximately 35 cm and 90 cm. Cotton and sorghum were grown in adjacent fields and were handled as separate experiments. Treatments for both crops were 1) a check with no subsoiling or deep P; 2) subsoiling only; and 3) fertilization with P at 90 kg/ha P_2O_5 (11-30-0 liquid) placed 40 cm deep by means of tubes attached behind curved subsoiler chisels. The chisels were run 25 cm on each side of the crop row. Treatments were designated check, 0-P and 90-P.

The entire study area received 22 kg/ha P_2O_5 (0-46-0) and 45 kg/ha N (urea) in bands placed 15 cm to the sides and 15 cm below the expected position of the seed furrow. All fertilizer application and subsoiling were done on May 2. On May 20 a preplant irrigation of 9 cm and 12 cm was applied to the cotton and sorghum plots respectively. There was no more irrigation during the season. Rainfall for the growing season amounted to 25.6 cm. Monthly totals were: June, 11.2 cm; July, 1.6 cm; August, 8.5 cm; September, trace; October, 4.3 cm. Cotton (GSA 71) and grain sorghum (NK 2778) were planted in rows 1 m wide on June 1 at seeding rates of 28 kg/ha and 4.5 kg/ha respectively. The cotton was hand-thinned to approximately 110,000 plants/ha in late June. The sorghum stand of approximately 56,000 plants/ha was somewhat irregular due to poor emergence caused by a soil surface crust that formed after a 2 cm rainfall on June 3 and 4.

A randomized block design with three replications was used for each crop. Soil water was determined with a neutron probe moisture meter at 30 cm intervals to a depth of 180 cm. These measurements were taken every two weeks except during the period of most rapid soil-water extraction, mid-July to mid-August, when measurements were made each week. Every other row was furrow diked in late June. The dikes were maintained throughout the season in the sorghum. They were removed at the last cultivation on August 21 in the cotton.

At 60 days after planting cumulative profile depletion for cotton for the 0-P and 90-P treatments was

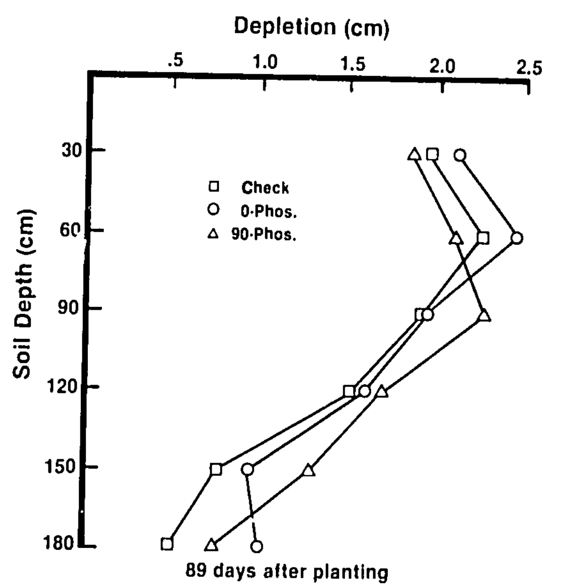


Figure 1. Soil water depletion for cotton in a study of the deep placement of P (cumulative cm per 30 cm depth.

Table 1. Cumulative soil water depletion for 180 cm profile in 1984 cotton crop (cm per total profile).

Treatment	7/17 (46 DAP)	7/24 (53 DAP)	7/31 (60 DAP)	7/08 (68 DAP)	8/15 (75 DAP)	8/29 (89 DAP)	9/12 (103 DAP)	10/3 (124 DAP)
Check	3.1	4.9	6.1	8.2	6.2	9.0*	11.2	12.5
0 Phosphorus	3.0	5.0	7.1	8.8	6.8	10.4	12.1	13.4
90 Phosphorus	3.6	4.6	6.8	8.9	6.6	10.2	12.5	13.0

DAP = Days After Planting

* The check was significantly (0.10 level) less than 0 phosphorus and 90 phosphorus on 8/29 in cotton.

Table 2. Cumulative soil water depletion for 180 cm profile in 1984 sorghum crop (cm per total profile).

Treatment	7/17 (46 DAP)	7/24 (53 DAP)	7/31 (60 DAP)	8/08 (68 DAP)	8/15 (75 DAP)	8/29 (89 DAP)	9/12 (103 DAP)	10/3 (124 DAP)
Check	3.8	5.4	6.9	8.4	5.6	7.9	9.2	10.2
0 Phosphorus	2.8	5.4	7.4	8.9	6.4	8.9	10.2	11.5
90 Phosphorus	2.8	5.3	7.4	8.9	6.9	8.9	10.4	10.9

DAP = Days After Planting

slightly greater than for the check (Table 1). By 89 days after planting depletion in the 0-P and 90-P plots was significantly larger at the 10% level of probability. It can be seen in Figure 1 that this difference was due to the depletion at depths of 90 cm and below. By the end of the growing season these differences were

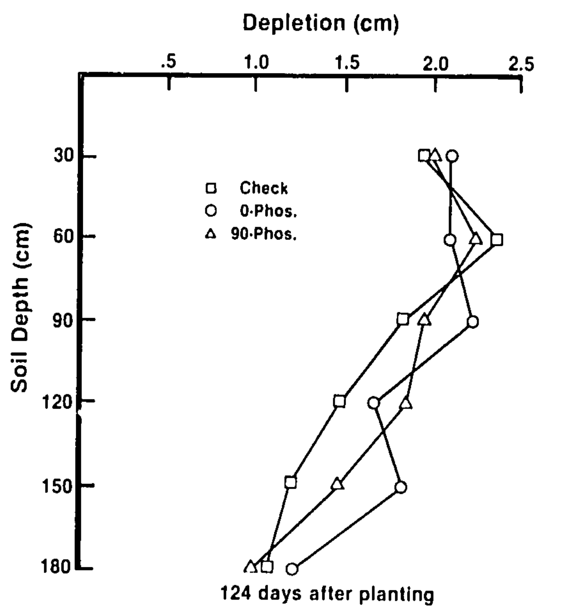


Figure 2. Soil water depletion for sorghum in a study of the deep placement of P (cumulative cm per 30 cm depth).

not significant. The average seasonal depletion by cotton was 13.0 cm.

Average soil water depletion for grain sorghum was 10.9 cm (Table 2). Although the chiseled treatments with and without P had more cumulative depletion on most dates following 60 days after planting, none of the differences were significant even at the 10% level of probability. In general, subsoiling increased water uptake from the lower portion of the profile in both cotton and sorghum (Figures 1 and 2). Deep P showed no advantage over subsoiling in enhancing soil water uptake.

Average yield was high for both crops (5000 kg/ha grain sorghum and 470 kg/ha lint cotton); however, there were no differences due to subsoiling or deep placement of P.

Second-Year Study

In order to determine the residual effects of the 1984 treatments, sorghum and cotton were planted May 29, 1985. The new rows were placed on the original rows, with no further subsoiling or P additions. Anhydrous ammonia was side-dressed on the sorghum on June 28 at 65 kg/ha N. Rainfall for the growing season totaled 24.3 cm for sorghum and 34.7 cm for cotton. Monthly values were: June, 15.5 cm; July, 4.7 cm; August, 4.14 cm; September, 10.4 cm. No irrigation was used. Furrow dikes were used throughout the growing season.

Second-Year Results. Total soil water extraction was not influenced by treatment in either cotton or sorghum. However, in both crops water removed at the 120 cm zone was influenced by deep placement of P. In cotton the water uptake at 120 cm in the 90-P treatment was slightly greater than in the check plots (Table 3). In the sorghum study the uptake from the 120 cm depth was slightly greater for the 90-P than in the 0-P (subsoiling only) treatment (Table 2). These differences do not appear important except that somewhat similar enhancement of water uptake from deeper depths occurred in 1984. In 1984 deep placement of P had no advantage over subsoiling only. These slight increases in extraction from deeper depths for both treatments for both years were largely offset by less extraction in the upper portion of the profile.

Average yield for both crops was not as high as in 1984; mean yield for cotton was 386 kg/ha, and mean yield for sorghum was 3,050 kg/ha. However, these yields were above average for dryland crops in the region. There were no differences due to treatment.

Table 3. Soil water depletion for 180 cm profile in a 1985 cotton crop.

Treatment Depth, cm	Check	0-Phosphorus	90-Phosphorus
		cm	
30	1.7 a*	1.5 a	1.6 a
60	2.9 a	1.9 a	2.1 a
90	2.1 a	1.9 a	1.9 a
120	1.1 b	1.2 ab	1.5 a
150	-0.1 a	0.2 a	0.2 a
180	-0.2 a	0.2 a	0.0 a
Total	6.6 a	6.9 a	7.4 a

* Means followed by the same letter are not significantly different at the 0.05 level (Duncan). Comparisons can be made only within individual rows.

Table 4. Soil water depletion for 180 cm profile in a 1985 sorghum crop.

Treatment Depth, cm	Check	0-Phosphorus	90-Phosphorus
		cm	
30	1.8 a*	1.9 a	0.8 b
60	1.5 a	1.8 a	0.8 a
90	1.8 a	1.7 a	1.8 a
120	1.7 ab	1.0 b	2.1 a
150	1.3 a	0.7 a	1.1 a
180	0.6 a	0.1 a	0.4 a
Total	8.7 a	7.3 a	7.0 a

* Means followed by the same letter are not significantly different at the 0.05 level (Duncan). Comparisons can be made only within individual rows.

Conclusions

1) In the first cotton crop, the subsoiled-only and deep-P treatments showed slightly greater soil water depletion at the 90 cm depth and below from approximately 46 days after planting to 89 days after planting, compared to the check.

2) In the first grain sorghum crop, soil water depletion at 120 and 150 cm, from about 60 to 103 days after planting, was slightly greater for the subsoiled-only and deep-P treatments.

3) In the first year, subsoiling alone was as effective as deep placement of P in enhancing soil water uptake.

4) In the second year, water uptake in the 120 cm zone was slightly greater (significant at 0.05 level) for the P treatment compared to check plots; the sorghum crop's water uptake from the 120 cm depth was slightly greater for the P treatment than for the subsoiled-only treatment (significant at 0.5 level).

5) Total profile extraction and crop yield for both years were not significantly influenced by subsoiling or deep-P application. However, it should be pointed out that precipitation in both years was well distributed and adequate for above-average yields.

Sorghum Water-Use Efficiency And Fertilizer Relationships

Arthur B. Onken, Texas Agricultural Experiment Station
Charles W. Wendt, Texas Agricultural Experiment Station

Research in the Sahel and in the Texas High Plains has shown that correcting deficiencies of nitrogen and phosphorus in the soil can significantly increase the water-use efficiency of dry-land crops, thereby improving yields. As genotypes of grain crops such as sorghum differ in their ability to extract nutrients from the soil, they might also differ in their ability to extract water from the soil. The objective of these studies is to enhance the water-use efficiency of crops by determining which genotypes and fertilizer rates produce the best results in soils deficient in nutrients and water.

Sorghum Water-Use Efficiency

A series of greenhouse studies was initiated to evaluate sorghum lines previously identified as different in either nitrogen- or phosphorus-use efficiency, for water-use efficiency. For purposes of these studies, water-use efficiency was defined as milliliters of water required to produce a gram of dry matter. A nitrogen-deficient Amarillo loam and phosphorus-deficient Brownfield loamy fine sand were placed in 12-liter plastic containers for these studies.

For the water-deficiency studies, the pots were brought to field capacity after having the plants thinned to four per pot. The plants were then grown without additional water, until the point of wilting and when less than 10 ml of water were used per day. For the studies with adequate water, the amount of water used by the plants was added back to the pots when approximately 50% of the available water had been used. These plants were harvested at 35 to 45 days. All pots had two inches of perlite applied to the surface to retard evaporation. Water use was determined by weight loss. P was applied to the N-deficient soil and nitrogen was applied to the P-deficient soil to ensure adequate quantities for plant growth.

Results

The data in Table 1 show consistent differences in water-use efficiency among sorghum lines. Since evaporation was controlled, these results represent a difference in dry-matter production per unit of water transpired. It is interesting to note that, among the lines grown in N-deficient soil, SC630 and SC325 consistently used less water per gram of dry matter than 77CS1 under limited-water conditions. However, under adequate-water conditions, 77CS1 used less water per gram of dry matter than SC630 and SC325. For the lines grown on P-deficient soil, SC167 and MB9-41 used less water per gram of dry-matter production than TX2536 under water stress. There were no significant differences when water was adequate. Using these data, additional studies in a greenhouse and in field plots were designed and conducted.

Interactions of Line, Water and N

A greenhouse study using the N-deficient Amarillo loam, SC630 and 77CS1, five N levels (0, 10, 20, 40 and 80 ppm), and two water levels (deficient and adequate, as before), was conducted to investigate the interaction effects. All other methods used were the same as given for the previous study. Analysis of variance of the data indicates that N rate, sorghum line, water level, and the interactions of line x N rate, water x line, and water x line x N rate had significant effects on water-use efficiency. Increasing the N rate significantly increased the water-use efficiency of both

Table 1. Water use-efficiency (m1 used/gm oven dry tissue produced) for several sorghum lines grown in a greenhouse in N-deficient and P-deficient soil at two water levels.

N-Deficient Soil

Line	Water Deficient Trial 1	Water Deficient Trial 2	Water Sufficient Trial 3
	m1 H_2O/gm tissue		
SC630	246 a	395 a	225 b
SC325	264 a	401 a	219 b
R6956	274 a	404 a	205 ab
77CS1	351 b	441 b	191 a

P-Deficient Soil

Line	Water Deficient Trail 1	Water Deficient Trial 2	Water Sufficient Trial 3
	m1 H_2O/gm tissue		
SC167	406 a	434 a	202
MB9-41	414 a	460 b	207
SC175	428 ab	494 c	196
TX2536	468 b	489 c	237

lines under limited water conditions and under adequate water for SC630, but not for 77CS1. In general, the water-use efficiency for both lines was higher under water-deficient conditions. The three-way interaction of water x line x N rate apparently was due primarily to the lack of response of 77CS1 to increasing N rates.

Table 2. Water requirement (pounds grain produced/inch of water ET) and grain yield of four grain sorghum lines grown on dry land at Halfway on P-deficient soil.

Line	Water Requirement	Grain Yield
	lbs grain/inch H_2O	lbs/a
MB9-41	266 a	3089 a
TX2536	212 ab	1868 ab
SC175	141 bc	1263 bc
AC 167	103 c	543 c

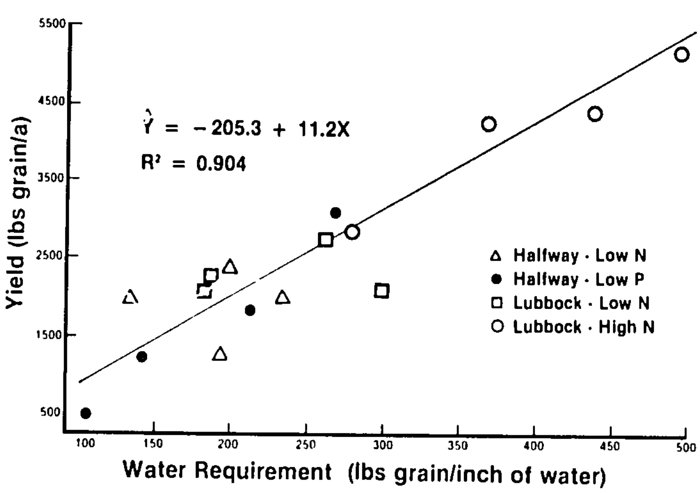
Field Studies

Four field studies were conducted. The sorghum lines previously showing differences in P-use efficiencies (MB9-41, TX2536, SC175 and SC167) were planted on P-deficient soil (Pullman clay loam) at Halfway, Texas. N was applied at 80 pounds per acre. The four sorghum lines previously showing differences in N-use efficiency were planted on N-deficient soil at Lubbock (Amarillo loam) and Halfway (Pullman clay loam) and on a soil (Amarillo loam) at Lubbock fertilized with N at the rate of 160 pounds per acre. P was either adequate by soil test (Lubbock) or applied at 40 pounds per acre (Halfway) for the N test plots. Plants in these tests were grown without irrigation. Halfway received 15.4 inches of rain and Lubbock 15.1 inches for the year. Water use was measured by neutron probe. Grain yields were obtained at the end of the season and water requirement calculated as pounds of grain produced per inch of water used as ET.

Table 3. Water requirement (pounds of grain produced/inch of water ET) and grain yields for four sorghum lines grown on dry land at two locations and two N-levels.

	Lubbock				Halfway	
	Low—N		High—N		Low—N	
Line	Water Requirement	Grain Yield	Water Requirement	Grain Yield	Water Requirement	Grain Yield
	lbs/in H_2O	lbs/a	lbs/in H_2O	lbs/a	lbs/in H_2O	lbs/a
R6956	297	2665 ab	494	5212 a	131 b	1999 ab
77CS1	185	2260 ab	366	4273 a	192 ab	1262 b
SC325	182	2102 b	278	2863 b	233 b	1978 ab

Results. The data in Tables 2 and 3 show significant differences in grain yield and water requirement among the sorghum lines in each of these studies. The pounds of grain produced per inch of water increased dramatically with the addition of fertilizer N (Table 3). It is of interest to note that under low soil N lines R6956 and SC325 ranked differently with respect to water requirement between the two locations. At Lubbock, R6956 produced the most grain per inch of water and SC325 the least. At Halfway, this order was reversed. The cause of this is not known but deserves investigation.



Grain Yield and Water Use

A most interesting relationship found in these studies was between grain yield per acre and water requirement (Figure 1). Using data from all four field studies, a highly significant ($R^2 = 0.90$) positive linear relationship was found between grain yield per acre and water requirement (grain/H_2O). Thus, it would appear that the factor resulting in increased grain production per inch of water ET will result in increased yields per acre. Fertilizer coupled with proper lines was most effective in these studies. It has previously been shown that SC325 is non-responsive to applied N, relative to SC630 and R6956. This same behavior is shown in Table 3, and the resulting effect on relative water requirement is evident. Thus, if fertilization is to be effective in improving grain production per unit of available water, it must be applied to sorghum lines responsive to fertilizer applications.

An additional greenhouse study was conducted to evaluate the use of a hydraulic press in measuring leaf-water potential in sorghum. Use of such simple equipment would greatly facilitate field research dealing with drought responses of sorghum both in the U.S. and in developing countries.

Conclusions

While these studies are not complete, some preliminary conclusions may be reached from results to date:

1. Differences in water-use efficiency (water used/unit of dry matter) among sorghum lines are significant but not large. However, large differences were found in water requirement (lbs. grain produced/inch of water) among lines.
2. Water requirement (lbs. grain produced/inch of water) increased dramatically with the addition of fertilizer. There was, however, a strong line x fertility x water interaction, indicating the most efficient use of available water will occur only when fertilizer is applied to lines responsive to fertilizer.
3. A highly significant positive relationship exists between grain yield and water requirement.

Further work on this project will determine the relationship between water- and nutrient-use efficiencies, water requirement, and the interactions of sorghum genotype and fertility levels on these relationships.

Evaluation of the Sandfighter Under Sahelian Conditions

Robert G. Chase, Texas A&M University
Philip Serafini, ICRISAT
Botorou Oundabar, INRAN
Mdm M. Dicko, ILCA
Michael O'Neil, Projet Productivite

The implement known as a sandfighter was first developed to stabilize sandy soils and protect emerging crops in West Texas. The objective of this study was to evaluate the effectiveness of the sandfighter in controlling wind erosion in farm fields in the Sahel.

Initial Testing

The tractor-drawn sandfighter successfully stabilized sandy soils at the ICRISAT Sahelian Center (ISC) and at INRAN's Kolo Station during the stormy 1983 season. Tests confirmed that the sandfighter is as effective in making stable clods and holes in moist sand when drawn slowly by animals as when drawn at intermediate speeds by a tractor. High working speeds, necessary in Texas soils, were less effective (Table 1).

Table 1. Hole volume, clod number and clod volume created by the sandfighter pulled at various speeds in dune soils.

Speed (km/h)	Hole Volume cm3/m2 *	Clod Number per m2	Clod Volume cm/m2
5	6.847 b	19.25 b	1624 b
10	6.775 b	20.45 b	1573 b
15	4.773 a	4.40 a	151 a

* In each column, means followed by the same letter are not significantly different (p = 0.05).

Table 2. Effect on crop establishment by five passes of a sandfighter over the tops of emerging millet.

Treatment	Average Pockets Planted per Plot	Average Pockets Surviving, % *
Control	325	63.3 b
Sandfought	336	46.5 a
Difference	11	16.8

* Means followed by the same letter are not significantly different (p = 0.05).

It was observed that during a heavy rain, the sandfought fields had a higher infiltration rate than those which had not been sandfought. This difference may be due to several factors, including the fracturing of surfaces crusts, an increase in surface water storage of nearly 7 mm due to holes made by the tool, and an increase in soil surface area.

The sandfighter caused considerable damage to millet crops when pulled over the plants (Table 2). While the sandfighter has been used effectively in cotton in Texas, it must be designed as an interrow tool if it is to be used in millet.

Design Modifications

Prototype animal-drawn sandfighters have been designed and built in Niger and have been seen to work well at animal-traction speeds. However, if the sandfighter is to be useful in protecting millet seedlings, it must be used at planting, and as soon after a rainfall as possible. The direct competition for labor between planting and sandfighting at this critical period would preclude sandfighting when it would do most to protect germinating millet.

A new animal-drawn sandfighter was developed with removable planting tines. The tines cut four rows of paired holes on each rotation, leaving a 1.3 m x 0.75 m plant-spacing pattern. The paired holes are spaced about 10 cm apart for proper seed and fertilizer placement. While making the holes, the machine stabilizes the soil between the rows of paired holes. The planting tines can be removed to allow additional sandfighting between rows after plant emergence.

The new sandfighter was used successfully during the 1985 rainy season, when approximately one hectare was planted, fertilized and sandfought at the ISC. Traction and speed tests indicated that this version of the sandfighter can stabilize one-half hectare per hour while eliminating the need for the local planting tool and increasing planting speed. The use of the sandfighter could, therefore, help to relieve the labor bottleneck in the planting season.

Potential of Contour-Strip Water Harvesting For Cereal Production

Naraine Persaud, Texas A&M University

These field-plot studies were designed to evaluate the response of millet and sorghum to the contour-strip method of rainfall harvesting (CSRH), in order to determine the potential of this technology for cereal production in Niger. The project's objectives were 1) to determine the potential of CSRH to increase growing periods, plant populations and yields, and to make possible the cultivation of cereal crops with higher water requirements than millet; 2) to determine the fate of the harvested rainfall, including its redistribution and storage in the soil and its use by the crop; 3) to determine the influence of CSRH on the efficiency of chemical-fertilizer use by crops; and 4) to determine the influence of CSRH on crop plants' root growth and root distribution.

New-Project Update

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

The field-plot experiments compared CSRH to the traditional method of rainwater management at three sites distinct in their pedology and rainfall climatology. These comparisons were combined with various levels of fertilizer application and planting density. Improved millet and sorghum varieties were the test crops. Field data on yields, soil-moisture status and fluxes, and plant phenology are being analyzed.

When completed, this study is expected to help determine whether CRSH has potential for improving cereal yields and diversifying cereal production on the sandy soils of Niger. It will also help to orient future research in this area.

Soil Moisture Relations Of Sandy Soils of Niger

W. A. Payne, Texas A&M University
Charles W. Wendt, Texas Agricultural Experiment Station
Naraine Persaud, Texas A&M University

The ability of the soil to retain water and supply it to plants is one of the major constraints to agriculture in the tropics. In the Sahel, the principal cereal crop, millet, is sown predominantly on sandy soils characterized by low clay and silt content, low water-holding capacity, and poor structure. In order to address this constraint, the researcher must look to ways in which to improve the supply of moisture to the millet plant. Any attempt to achieve this, however, must be based on quantitative information on the water balance of the soil and plant system. This study was undertaken towards acquiring such information. It's objectives were 1) to measure pertinent physical and hydrological properties of representative soils traditionally cropped in millet; 2) to quantify the water balance of bare and cropped sandy soils in three different rainfall zones; and 3) to evaluate the potentials of some low-input technologies to increase the availability of soil water to plants.

Physical and Hydrological Properties

The three sites chosen were N'Dounga (psammentic paleustalf), Chikal (typic torripsamment), and Kala Paté (alfic ustipsamment). Their respective rainfalls for 1985 are given in Table 1. Parameters measured on these soils were particle-size distribution, bulk density, infiltration rates, soil moisture-pressure potential relations, hydraulic conductivity, and "plant available" water. Particle-size analyses were performed using the hydrometer method, while bulk densities were determined using rings of known volume. Infiltration rates were measured by ponding water at a constantly maintained level in a double-ring infiltrometer. The rate at which water was supplied to the inner ring was considered as equal to the soil's infiltration rate. Saturated hydraulic conductivity was measured by laboratory methods on undisturbed soil cores, while unsaturated hydraulic conductivities were obtained using calculation methods. Soil moisture-pressure potential relations were obtained from field tensiometric data and a pressure plate apparatus. "Plant available water" in profiles 190 cm deep was estimated as the cumulative difference between field water retention capacity and 15 bar water content.

Sand contents for each of the three sites varied from 85 to 95%. Silt contents were nowhere greater than 2%, while clay contents varied from 4 to 14%. Clay content at N'Dounga was 2-4% higher than those at Kala Paté and Chikal. Bulk density ranged from 1.50 to 1.68 g/cm^3. Infiltration rates were, predictably, very high, with one-hour average rates of 18 to 25 cm/hour. Saturated hydraulic conductivity was measured at 59 cm/hour, while unsaturated hydraulic conductivity was calculated as .03 cm/hour at 12% volumetric water content and .004 cm/hr at 8% volumetric water content. Field water retention capacity ranged from 8 to 14% volumetric water content, depending upon clay content, while the lower limit ranged from 1 to 5%,

Table 1. Long-term results of water balance study

Site	Treatment	Rainfall (mm)*	Cum. Water Loss: Growing Season (mm)	Cum. Water Loss: Entire Study (mm)	Average Daily ET: Growing Season (mm)	Average Daily ET: Dry Season (mm)	Yield (tons/ha)
Chikal	Cropped	219	214	221	2.38	.04	.330
	Bare	219	172	230	**	**	
Kala Pate'	Cropped	392	321	384	3.57	.25	.443
	Bare	392	317	383	**	**	
N'Dounga	Cropped	311	273	313	3.03	.13	1.170
	Bare	311	192	259	**	**	

* 10 mm, 36 mm, and 33 mm fell at Chikal, Kala Pate', and N'Dounga, respectively, before planting.
** Drainage occurred after July in bare plots.

depending upon clay content. Standard laboratory methods, i.e. those that equate field water retention capacity with water content at .33 bar pressure potential, underestimate the retention capacity of these soils. A better approximation would be water content measured in the field at .04 bar pressure potential (Figure 1). These soils lose most of their moisture before a pressure potential of .33 bar is attained, underlining their poor ability to retain water against gravitational force. Indeed, tensiometric data indicate that overall movement of moisture is downward during the growing season, even after a relatively long dry period. Plant available water in a profile 190 cm deep was about 155 mm (Figure 2).

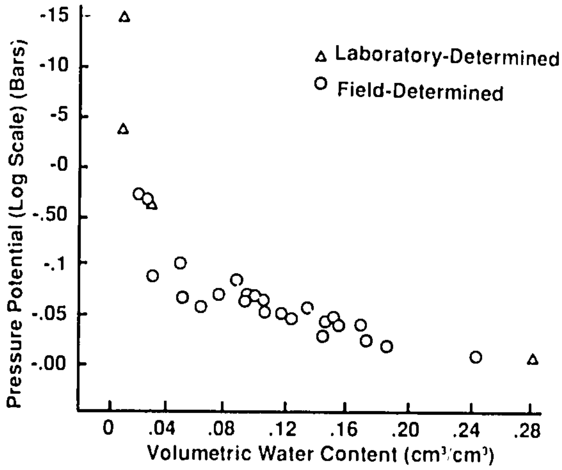


Figure 1. Pressure potential vs. soil water content for N'Dounga.

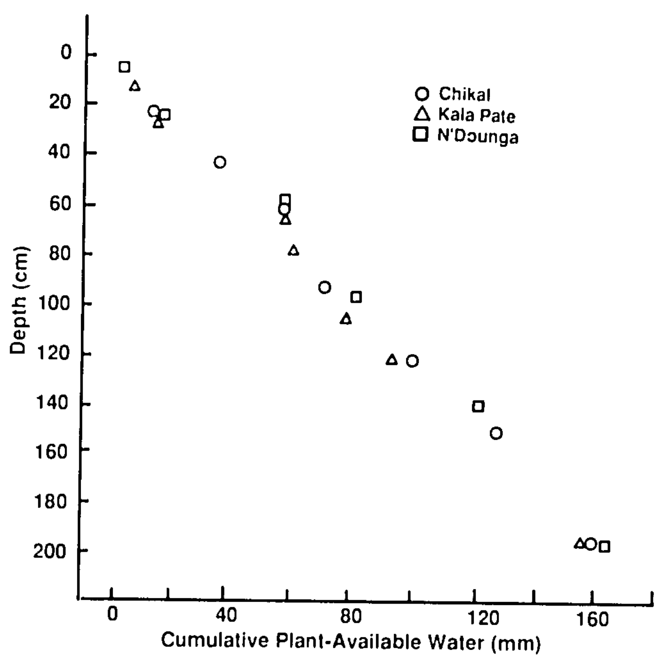


Figure 2. Plant available water (cumulative difference between field water retention capacity and water content at 15 bars) as a function of profile depth.

Water Balance of Bare and Cropped Fields

At each of the three sites, two 25 m x 25 m plots were established and rain gauges were installed. One of these plots was kept bare, while the other was sown in a local variety of millet. Within each plot, neutron probe access tubes were installed in five 2 m x 2 m randomly located mini-plots, two of which were additionally equipped with a set of tensiometers. On an approximate weekly basis during the growing season, and occasionally during the subsequent dry season, soil water content, soil water tension, and amount of rainfall were measured. From these measurements, direction of water movement and magnitude of water loss from the profile were calculated. In the cropped treatments this loss was due to evapotranspiration, whereas in the bare treatments it was due to a combination of drainage and evaporation.

Table 1 summarizes long-term results of the water balance study. These data indicate that yield is not necessarily dependent upon the amount of rainfall or, for that matter, the amount of water evapotranspired during the growing season. For example, although N'Dounga has only a slightly higher average clay content, it produced over two and one-half times the yield of Kala Paté, where 20% more rain fell in a very similar distribution. Chikal, where a dry year was experienced, obtained 75% of the production level of Kala Paté, with only 56% of the rainfall. This study also sheds light on the magnitude of evaporative loss from bare soils. During the month of July, 1985, 42%, 70%, and 57% of that month's rainfall were evaporated from bare treatments at N'Dounga, Kala Paté, and Chikal, respectively. These losses could have dramatic impact on seedling establishment, which usually takes place during July.

Evaluation of Low Input Technologies

Two techniques were examined. Briefly, they were: 1) the placement of a mulch of millet stalks on two of the five 2 m x 2 m mini-plots in each treatment at each site immediately after harvest as a potential means of reducing evaporative loss during the dry season; 2) bare fallowing during one rainy season in hopes of conserving moisture in the soil for the next.

The post-harvest application of millet stalks had no

Table 2. Post-harvest water loss from mini-plots.

Site	Dates Measured		Water Loss (mm)									
			Bare Treatment Mini-Plot #					Cropped Treatment Mini-Plot #				
	from	to	1	2	3	4	5	1	2	3	4	5
Chikal	10-16-85	3-24-86	49	60*	65*	55	61	10	3*	4*	11	6
Kala Paté	10-02-85	5-03-86	67	47	55*	52	67*	65*	61*	75	60	54
N'Dounga	9-25-85	4-10-86	69	66	68*	67	67	52	49	39*	44*	33

* Mini-Plots covered with mulch

measurable effect on soil water conservation at any time at any of the treatments (Table 2). Probable reasons are the high evaporative demand of the atmosphere during the dry season and the low moisture-retaining capacity of these soils.

Bare fallowing: As Table 1 indicates, water conserved during the growing season tends to be lost from the profile before the advent of the next growing season. Only N'Dounga showed a slight conservation of moisture, and none of this was in the upper 50 cm of the profile. Whether this moisture loss was downward due to hydraulic gradients or upward due to vapor movement is difficult to determine. This technique requires a) a good deal of labor, b) taking land out of production, and c) a sincere belief that the next rainy season will be a poor one. Therefore, its potential as a conservation technique is very low.

Implications

1. Although availability of soil moisture to plants is obviously of importance to millet production, it cannot alone explain the wide fluctuation in yield observed in this study. More research is needed to determine what other factors are at play.

2. In the absence of supplementary irrigation or water harvesting, and assuming that run-off is not a problem, soil water conservation efforts must be aimed at a) reducing water loss to drainage, b) increasing the ability of the soil to store water, or c) reducing evaporative loss to the atmosphere. Both a) and b) would require considerable investment of time, labor, and money. In light of the large evaporative loss measured in this study, more research should be directed towards seeking ways of reducing evaporation from these soils during the rainy season.

3. The data obtained in this study suggest that it would be extremely difficult to conserve soil water from one season to the next due to the low water retention of these soils and the high evaporative demand of the atmosphere. This in turn suggests that any excess moisture remaining in the profile at harvest might be better taken advantage of by immediately planting a suitable food or forage crop.

TECHNOLOGY FOR FOREST LANDS

There is no doubt that man's desperate struggle to secure food and fuel has accelerated the advance of the desert all along the Sahel. The advance alters climate and landscape, obliterates forests and farms. Desertification does not observe national boundaries, or yield to simple solutions.

Some of the factors contributing to desertification are related to soils. For example, if overgrazing removes the protective vegetation from an area, crusts form on the barren soil, sealing out rainfall and seeds. Soil temperatures rise, the microclimate changes, and the loss of forest at that site is permanent, unless man intervenes. As demand for resources increases, the forest declines, creating even greater demand.

The goal of the TropSoils' work reported here was to contribute assistance and expertise to institutions dealing with forest conservation in the Sahel. The research has concentrated on simple techniques for soil-water management and forest rejuvenation, and was designed to complement the collaborators' programs.

Soil and Water Management In Degraded Sahelian Soils

Robert G. Chase, Texas A&M University
Eric Boudouresque, University of Orleans
John Heermans, FLUP
Juan Seve, FLUP
Steve Dennison, CARE
Philip Serafini, ICRISAT

Forests are essential to the lives of Sahelian farmers and herders. The pressures of increasing population, and the demand for forage and fuel, have led to the serious degradation of Sahelian forests. Several experiments, conducted in collaboration with the Forest and Land Use Planning project (FLUP), have been designed to find practical means to stabilize and rejuvenate degraded forest and agricultural lands. The objective of the experiment reported here was to evaluate simple tillage and mulching treatments for their ability to regenerate vegetation in the Guesselbodi Forest near Niamey, Niger.

Table 1. Estimated biomass yields (kg/ha) from parcels established in 1983 (20 plots) and in 1984 six plots).

Treatments	Newly Established Plots 1983	Newly Established Plots 1984	Second Season Plots
Control	0 a*	0 a	0 a
Mulched	214 b	45 b	152 b
Tilled	440 c	96 b	32 a
Combination	961 c	78 b	307 c
Natural vegetated areas	891	195	195
S.E.	61	25	22
C.V.	136	229	161

* Means followed by the same letter are not significantly different (p = 0.05).

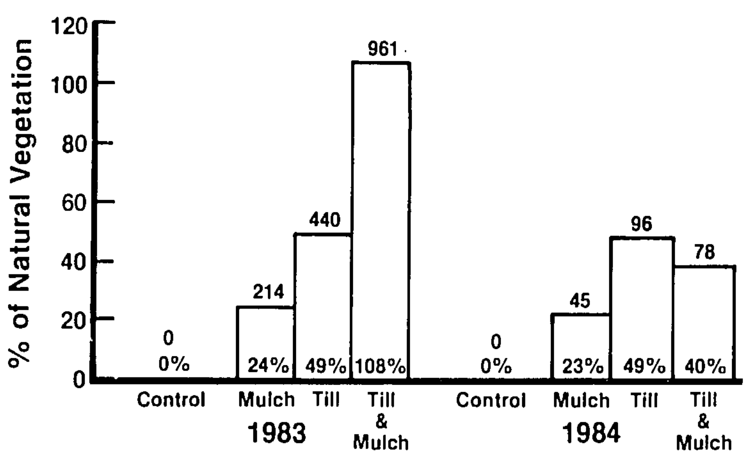


Figure 1. First-season biomass dry weight in plots begun in 1983 and in 1984, as a percentage of standing biomass in naturally vegetated forest areas. Actual biomass stand (kg/ha) is marked above each bar.

Methods

Twenty parcels, with four plots each, were established in May, 1983, on a barren, crusted soil, classified as Typic Paleustult, sandy-skeletal siliceous isohyperthermic. Ten parcels were protected from grazing and ten were exposed. These were not re-treated after their initial establishment. Six additional parcels were prepared in 1984, equally divided between protected and non-protected areas. In both years, neither fertilizers nor seeds of any kind were used. The four treatments imposed were a) control (unaltered, crusted, barren soil); b) mulch only (with tree branches to a cover of 20-25%, as determined by a solarimeter); c) hand tillage only (to 10-15 cm depth); and d) combination of tillage and mulch.

Soil moisture to 30 cm depth was measured at approximately 20-day intervals throughout the 1984 rainy season in all plots. Surveys of plant species and biomass produced in the plots and along fixed transects across the natural forest areas were made at the end of each rainy season.

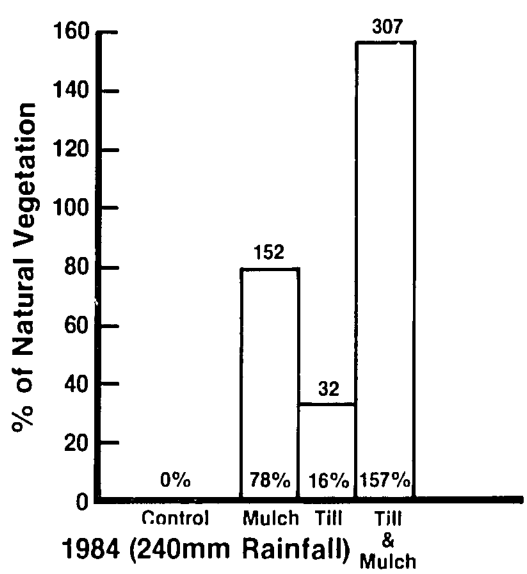


Figure 2. Second-season biomass dry weight in plots established in 1983 and harvested in Sept., 1984, as a percentage of standing biomass in naturally vegetated forest areas. Actual biomass stand (kg/ha) is marked above each bar.

Biomass Yield

The drought in 1984 (240-260 mm rainfall in the vicinity of Niamey), following a wetter season (540 mm in 1983), provided ideally contrasting environments with which to evaluate the effects of the drought on revegetation. The pronounced decrease in biomass production found in the first-season plots established in 1984, as compared with the biomass of the first-season plots from the previous year, is testimony to the severity of the drought in 1984 (Table 1).

A comparison of biomass stands in treated plots with those in adjacent vegetated areas of the living forest are a reasonable method to account for the differences in weather between years when comparing treatment performance between years. The mulch-plus-tillage plots established in 1983 performed well in that year compared with naturally vegetated areas. The same plots appear to have increased their relative biomass even further in 1984 than in 1983 when compared with the natural vegetation (Figures 1 and 2).

In the 1983 season, tillage-only was the second-best treatment. Its residual effect was greatly diminished in the 1984 season.

Soil Moisture

Soil moisture in plots established in 1984 showed the same pattern as was found in 1983. Tillage in newly treated plots was the most effective treatment for increasing surface soil moisture (Figure 3). In the second season, however, the mulching treatment had the greater effect in increasing soil moisture (Figure 4). This may be due in part to the ability of the mulch to promote deeper water percolation (Figure 5) and to decrease maximum surface soil temperatures (Figure 6).

The trend of decreasing productivity in the tilled soils and increasing productivity in the mulched soils continued in 1985. During this season, somewhat less rainfall was received than in 1983, but there was considerably more biomass production in the mulched, protected plots (Table 3). Plots exposed to grazing had a reduced standing biomass due primarily to grazing and animal movement.

Summary and Observations

In summary, tillage was not as effective in the reestablishment of vegetation on barren forest soils as was mulching with tree branches. This is important information for the implementation of soil-conservation practices in the Sahel because branches,

Table 2. Average soil surface temperatures at noon, August 20, 1984, in the revegetation plots.

	New (1984) Plots *°C	Older (1983) Plots *°C
Control	46.0 de**	47.9 e
Tilled	44.5 be	44.8 cde
Mulched		
Under branches	39.3 a	40.8 ab
Between branches	43.4 bcd	44.3 be
Combination		
Under branches	41.7 abc	39.4 a
Between branches	44.1 be	43.6 bcd

*Temperatures taken with an Everest IR Thermometer.
** Means followed by the same letter are not significantly different (p = 0.5) by the Duncan's Multiple Range Test.

Table 3. Mean biomass harvested from experimental plots at the end of two similar rainy seasons (1983 = 540 mm, 1985 = 480 mm). Plots were established in 1983 and undisturbed thereafter.

	1983 kg/ha	1985 kg/ha
Parcels Protected from Grazing		
Control	0 a	0 a
Hand Tillage	532 bc	80 a
Mulching	286 ab	1301 c
Combination	1036 d	1549 c
Parcels Exposed to Grazing		
Control	0 a	0 a
Hand Tillage	348 ab	61 a
Mulching	142 ab	323 ab
Combination	887 cd	630 b

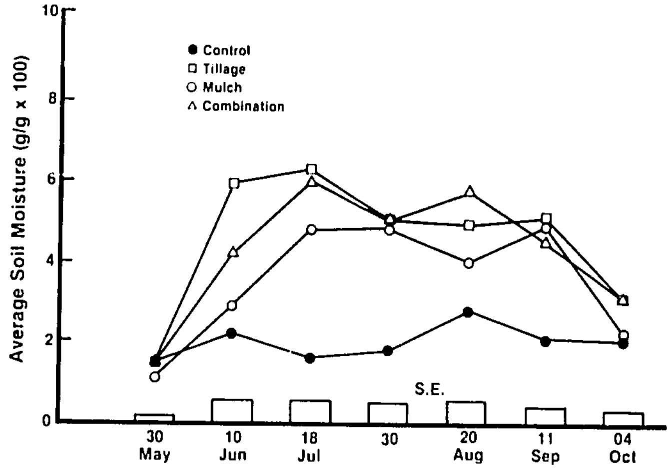


Figure 3. Average soil gravimetric water content (0-30 cm depth) during the 1984 season in plots initiated in 1984 inside a protective fence at the Guesselbodi Forest.

a waste product of commercial firewood harvesting, are readily available in areas being harvested and are easily placed on the surface of barren forest soils.

Several observations were made during the experiment:

1. The decrease of biomass production over time in the tilled plots may be due to several factors, including a reformation of the surface crust and a loss of debris that had collected in the vegetation from the previous year. Increased soil temperatures may increase the potential rate of evaporation from these soils.

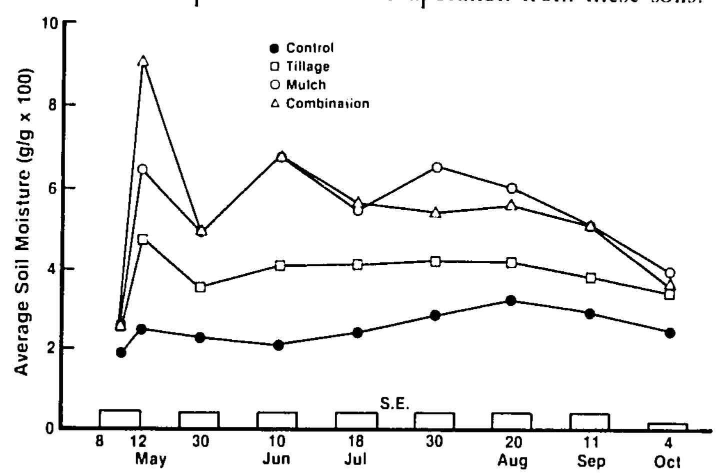


Figure 4. Average soil gravimetric water content (0-30 cm depth) during the 1984 season in plots initiated in 1983 inside a protective fence at the Guesselbodi Forest.

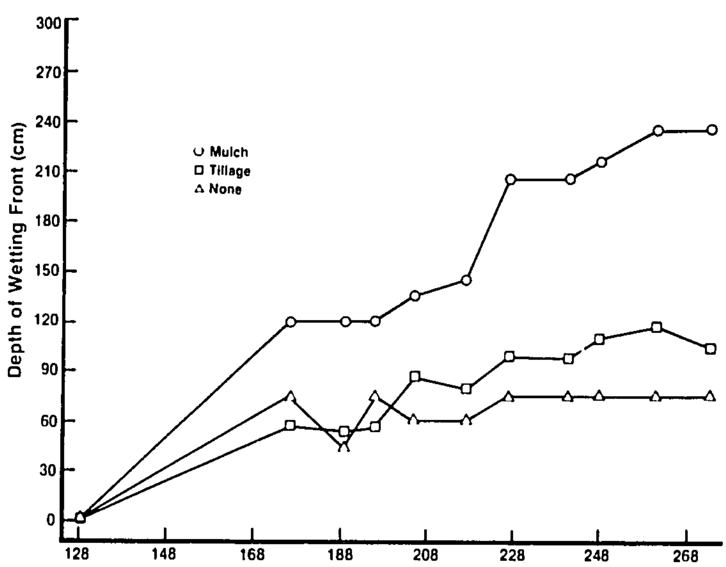


Figure 5. Effect of mulch and tillage on soil moisture.

2. The lack of storms during the 1984 drought not only reduced rainfall but also winds that blow sand, leaves and seeds into the mulch. The branch mulch stabilizes these transported materials, apparently providing an environment conducive to plant establishment.

3. The improvement in the production of biomass in the mulched plots with time may be due to a combination of factors, including the continued accumulation and stabilization of sand and leaf mulch held within the plots, termite activity opening stable macropores in the crusted soil, decreased soil surface temperatures and protection of the soil from rain impact.

4. The loss or recapture of a thin, easily eroded A horizon of sandy soil overlying the crusting, shallow, heavier-textured B horizon may be a major factor in supporting forest vegetation in this area. The proper management of this sandy layer could be important for successful forestry work in this type of environment.

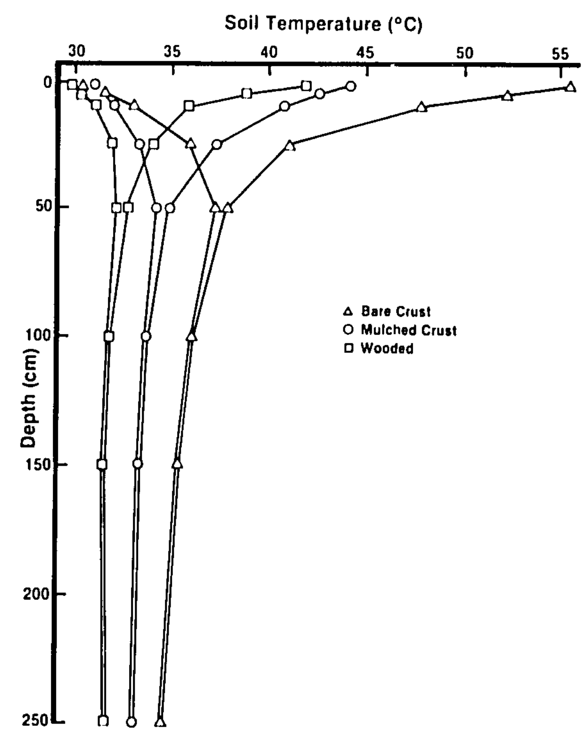


Figure 6. Maximum temperature fluctuations at all depths in three areas of Guesselbodi Forest on Oct. 11, 1985.

Agroclimatic Data Base

The overriding factor in characterizing the Sahel is climate. The variability of precipitation and the high annual evapotranspiration in relation to rainfall have significant effects on crop yields and growing season. For this reason, any new system of soil management for this environment would necessarily require a quantitative understanding of rainfall patterns and growing season, and of soil water balance.

Several of the studies reported in this section have begun to quantify rainfall patterns as they relate to agriculture in the Sahel, so that it might be possible to select planting dates and growing season for a location by considering rainfall probabilities. Because regional rainfall patterns also determine, to a great extent, the suitability of a site for specific uses, this information will also be valuable in land-use planning.

The data base combines information from the studies of rainfall patterns with data on soil water balance. Because the measurement of the different components of soil water balance is often impractical, modeling has been used to estimate these values, drawing primarily on climatic data. Results of these studies, combined with estimations of evaporation from bare soil and the effects of plant canopies on soil moisture, are supporting the technology-development projects discussed elsewhere in this report.

Quantification of Rainfall Characteristics, Patterns and Hydrology Of Representative Cropped Soils

Naraine Persaud, Texas A&M University

These related projects and experiments deal with rainfall and soil moisture in the Sahel of Niger. Because they are not yet complete, their progress is reported in brief.

Patterns and Probabilities of Rainfall

Many of the existing traditional practices of soil and crop management in Niger can be rationalized as adaptations to risk associated with various climate-based constraints to crop production. Thousands of years of cereal production under these constraints have produced a built-in sense of probability and semi-empirical methods of risk assessment among the farming communities. The objectives of this continuing study were 1) to quantify the risks associated with the variable and irregular north/south monsoonal rainfall gradient over Niger; 2) to detect less variable mesoscale patterns of monsoonal rainfall over Niger, based on analysis of long records of rainfall measurements; 3) to better define the start, midpoint and end of the rainy and growing season; 4) to determine if certain early season parameters can serve as indicators of overall seasonal or later-season behavior; and 5) to better define the pedoclimatic constraints to cereal production in Niger by pooling these results with hydrological data on various soil types.

Results

To date, computations are complete for work toward objectives one and two, and results are being compiled and interpreted. Computations are in progress for the remaining experiments. Because of the great quantity of data generated by these studies, only a few examples have been selected for this report. Table 1 shows an example of decadal probability results. Such analyses were done for seven- and 14-day periods, and for 43 stations in Niger. Table 2 shows an example of results of risk analysis associated with the length of the growing season at three locations in Niger. The growing period is defined here as that period when the rainfall exceeds one half of the potential evapotranspiration calculated by the Penman formula modified by the Food and Agriculture Organization (FAO). Such results have been compiled for 11 locations in Niger. Figure 1 shows the risk analysis for one location, Niamey.

Discussion

When these studies are complete, the results are expected to be useful to plant breeders in the introduc-

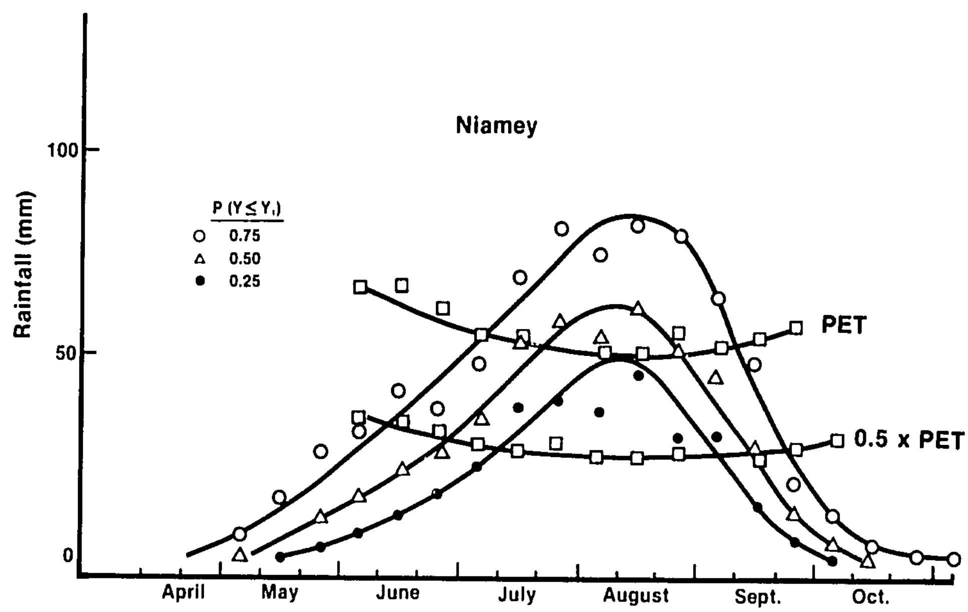


Figure 1. Equiprobable decadal rainfall totals and mean decadal Penman PET (1971-80) used to define the risk of crop failure at Niamey, Niger.

Table 1. Precipitation means and probabilities for seven-day periods at Niamey, Niger, based on 41 years of record. (Mean annual precipitation: 585.25 mm.)

Period Begins	Mean Precip.	Probability (%) of Receiving at Least the Following Amounts (mm) of Precipitation											
		2.5	5	10	15	20	30	40	50	60	80	100	120
MAR 13	0.05	0	0	0	0	0	0	0	0	0	0	0	0
MAR 20	0.93	9	4	4	2	0	0	0	0	0	0	0	0
MAR 27	0.26	4	2	0	0	0	0	0	0	0	0	0	0
APR 3	1.72	7	7	7	4	4	2	0	0	0	0	0	0
APR 10	0.58	4	4	2	2	0	0	0	0	0	0	0	0
APR 17	0.66	4	4	2	0	0	0	0	0	0	0	0	0
APR 24	2.39	14	9	7	7	2	2	2	0	0	0	0	0
MAY 1	3.38	24	17	9	4	4	2	2	0	0	0	0	0
MAY 8	4.96	31	29	17	9	4	4	2	0	0	0	0	0
MAY 15	6.55	41	31	29	21	14	0	0	0	0	0	0	0
MAY 22	14.09	73	58	39	21	19	14	12	9	4	0	0	0
MAY 29	12.49	63	51	29	29	26	17	9	2	2	0	0	0
JUN 5	18.39	73	63	53	48	36	24	14	9	2	0	0	0
JUNE 12	18.03	75	70	56	41	34	19	12	9	4	0	0	0
JUN 19	24.89	85	75	63	56	48	34	26	21	9	2	04	0
JUN 26	20.10	82	80	60	51	46	31	17	2	2	0	0	0
JUL 3	24.97	87	85	78	65	51	31	19	12	7	2	0	0
JUL 10	36.45	97	97	87	78	73	53	41	21	21	4	2	0
JUL 17	38.85	92	92	87	75	68	53	41	29	19	9	7	0
JUL 24	45.76	97	95	95	85	75	58	53	41	29	19	4	2
JUL 31	41.28	100	95	82	82	75	63	51	36	19	7	0	0
AUG 7	42.36	97	95	90	80	75	63	48	34	26	7	4	2
AUG 14	45.68	97	97	95	92	80	58	48	41	31	14	7	2
AUG21	42.27	92	92	90	87	80	60	51	34	21	9	2	2
AUG 28	40.47	95	92	80	73	63	48	36	24	19	9	7	2
SEP 4	34.73	97	90	78	73	70	48	31	19	12	9	4	0
SEP 11	25.80	87	70	63	60	48	34	29	14	14	0	0	0
SEP 18	15.46	73	65	51	39	26	17	12	9	0	0	0	0
SEP 25	8.09	51	43	31	24	14	7	0	0	0	0	0	0
OCT 2	5.94	36	31	19	17	14	4	0	0	0	0	0	0
OCT 9	2.57	19	12	9	4	2	2	2	0	0	0	0	0
OCT 16	1.99	14	9	7	2	2	2	0	0	0	0	0	0
OCT 23	1.52	17	14	4	0	0	0	0	0	0	0	0	0
OCT 30	0.52	4	4	2	2	0	0	0	0	0	0	0	0
NOV 6	0.27	2	2	2	0	0	0	0	0	0	0	0	0

Table 2. Growing period for different levels of probability ($x \geq 0.5$ PET)

Probability	Gaya			Niamey			Tahoua		
($x > 0.5$ PET)	Start	End	Days	Start	End	Days	Start	End	Days
0.25	5/23	10/3	133	6/12	9/22	104	6/29	9/13	76
0.50	6/9	9/28	111	6/26	9/14	80	7/13	9/2	52
0.75	6/25	9/21	88	7/10	9/5	57	7/31	8/17	17

tion or development of varieties suited to the environmental constraints and risks in Niger. Such information is essential to the successful management of small watersheds that abound in Niger. By allowing for a detailed, quantitative insight into the agroecology of dryland cereal production, these studies provide the basis for rational development or transfer of soil-water management concepts and practices. As an example, preliminary results have led to the concept of judicious biomass reduction to conserve water during growth of the millet crop, a technique which preliminary results indicate may have potential as a low-input, water-conservation practice.

Estimation of the Kinetic Energy of Rainstorms From Raindrop Size Measurements

The objectives of this study were 1) to measure raindrop size distribution during several rainstorms at various intensities; and 2) to use this information to deduce physical relationships between kinetic energy and intensity of tropical convecture rainstorms.

During the rainy season of 1985 a suitable low-cost apparatus was developed for raindrop size measurement. The flour-pellet methodology was evaluated with this apparatus during five rainstorms. A tipping bucket and a USWB dual trace-recording rain guage were used to measure rainfall intensity during these trials. The rainy season ended as these preliminary tests were completed. The tests resulted in a final methodology, and actual raindrop measurements were to be made during the next rainy season. Results of this study are expected to be universally applicable to erosion research on tropical soils.

Moisture Balance of Bare and Cropped Soils In Different Agroecological Zones of Niger

The objectives of this study are 1) to determine the infiltration rates and internal drainage characteristics of the selected profiles; 2) to measure soil moisture-loss patterns and the soil-moisture balance of profiles for bare and cropped conditions; 3) to determine the plant-available water capacity of various layers of the profiles; 4) to correlate soil physical characteristics such as texture and bulk density with available soil moisture at different values of soil-water potential; and 5) to develop or test simple procedures for estimating soil-moisture storage and balance in these profiles, based on observed soil properties and meteorological data.

To date, most of the field data for work toward the first three objectives have been collected, and some processing of the data has begun. Results of this study are essential to the development of practical soil-water management techniques and to the assessment of conditions during short-term seasonal drought. It is hypothesized that on the sandy soils of Niger the behavior of the zero plane of flux, which is being evaluated to meet objective two, is an important determinant of soil-moisture use by cereals under rainfed conditions.

Grouping of Soil Types in Niger According To Moisture Regime and Fertility Status

It is generally accepted that water and fertility are the principal soil constraints to crop production in Niger. This study, developed originally by collaborating scientists at INRAN, is designed to assist in the development of rational strategies for soil-water and fertility management. Its objectives were 1) to use multivariate-analysis methods to identify soil groupings based on soil moisture and/or fertility status; 2) to relate these groupings to soil-genesis factors; and 3) to pool these results with soil hydrological data and rainfall data to better define pedoclimatic constraints to cereal production in Niger.

Data have been assembled from laboratory analyses of several thousand soil samples taken at various depths in the profile from 25 locations in Niger. Analyses were done as part of the soil-characterization project conducted by INRAN and the FAO. The sampling locations have been grouped as follows, based on general landscape and geomorphological features and assumed soil genetic differences:

1. Soils developed on the middle course of the Niger River and overlying the continental divide.
2. Ancient and recent dune systems overlying the continental divide.
3. Soils from the alluvial deposits of the Goulbi N'Maradi.
4. Terraces of the Niger River.
5. Niger River floodplain.
6. Soils of the Maggia.

Micro-computer programs are being implemented for processing the information in this study.

Influence of Neem-Tree Windbreaks On Microclimate and the Growth And Yield of Cereals Between Rows

Naraine Persaud, Texas A&M University
Steve Long, CARE International
Mamadou Ouattara, INRAN/DRE
Mohamadou Gandah, INRAN/DRE

Tree windbreaks serve as a semi-permanent method for providing protection from the wind. By modifying the influence of hot, desicating winds in Niger, windbreaks also serve to reduce evapotranspiration and thus may conserve soil water and increase yields of cereals grown between the rows. It may be possible to harvest wood from these trees selectively, providing much-needed fuel without seriously impairing the windbreak's protective efficiency.

These studies are conducted in the Maggia of Niger, where CARE has planted neem windbreaks progressively since 1975. About 360 km of trees were planted in double rows 100 m apart, oriented approximately north/south across the long axis of a valley. Trees were spaced 4 m x 4 m within the double row.

TropSoils and INRAN research was designed to complement CARE's evaluation of the windbreaks' socioeconomic usefulness. The objectives of these joint studies are 1) to evaluate the effect of the tree windbreaks on meteorological variables such as windspeed profiles, wind direction, air temperature, humidity and evaporation; 2) to evaluate the effect of the windbreaks on the growth, development, yield and soil-water balance of millet and sorghum alley-cropped between rows of trees; and 3) to study the influence of wood-harvesting on the efficiency of the windbreaks.

Methods

Anemometers connected to automated data-logging apparatus were used to collect information on windspeed at 60-second intervals simultaneously at 108, 317, 572, 811 and 1151 cm above the ground, both between the tree rows and outside of their influence. Wind direction was also recorded outside the rows at 317 cm above the ground. The inside sensors were positioned for a period of several days midway between two adjacent double rows of trees. Wood was harvested from the row upwind of the sensors by four different methods:

Table 1. Mean value (m/s) of windspeed observed simultaneously at one-minute intervals for 84 hours at different heights outside and in the middle of neem windbreak rows for different harvesting methods.

	Mean Windspeeds m/s at the Following Heights in cm				
	108	317	572	811	1152
			Uncut Control		
Between Rows	1.27	1.57	1.90	2.23	2.70
Outside of Rows	2.48	2.89	3.09	3.32	3.60
			Complete Pollard (A)		
Between Rows	1,50	1.65	1.79	1.95	2.15
Outside of Rows	1.70	1.95	2.02	2.21	2.38
			One-row Pollard (B)		
Between Rows	1.99	2.21	2.44	2.72	3.06
Outside of Rows	2.90	3.27	3.46	3.68	3.93
			1-in-4 Pollard (C)		
Between Rows	2.36	2.61	2.86	3.17	3.66
Outside of Rows	3.31	3.73	3.94	4.22	4.49
			Partial Pollard (D)		
Between Rows	1.98	2.01	2.21	2.50	3.07
Outside of Rows	2.98	3.36	3.55	3.80	4.08

A) Complete pollard. All trees in 100 m of the double row were 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 eastern row were pollarded as in (A).

C) One-in-four pollard. One in every consecutive group of four trees in 100 m of a double row were pollarded as in (A), such that cut trees were never adjacent and there were always three uncut trees between cut trees in either row.

D) Partial pollard. Removal of the branches overhanging the alleys from both sides of the double crown formed by the trees for 100 m.

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 in a sample of 80 trees was 10.5 ± 1.6 m. Dates of the pairs-of-time series of windspeed observations were: uncut control, July 8-11; (A) June 24-27; (B) June 9-11; (C) June 19-22; and (D) June 15-18.

Windspeed Averages

The data-logger was used to compute and output half-hourly averages of the 60-second windspeed observations. For each harvesting method 169 pairs of averages were obtained. Table 1 presents a summary of these results and provides information on overall mean windspeed and windspeed profiles during the sampling periods. Observed windspeeds never exceeded 10 m/s, even at 1151 cm above the ground. The half-hourly means, when plotted against time, showed a marked, 12-hour periodicity with a minimum between 22:00 and 02:00 hours and a maximum between 10:00 and 14:00 hours, based on a 24-hour clock.

The 169 pairs of observations were grouped into eight categories using the half-hourly mean wind direction in intervals of 45 degrees, and ratios of inside-to-outside windspeed, calculated for each pair in the various categories. Winds were mostly from the southwest, west and northwest during the period of observation.

Table 2. 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
	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	0.83b	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	0.59a	0.64e	0.76d	45
	**	**	**	**	**	
	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
	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 1% level

Means not followed by same letter are significantly different at 5% level.

Effect of Harvesting Method

Results of a one-way analysis of variance and means separation are presented in Table 2. At each height sampled the effect of harvesting method on windspeed reduction depended on the wind direction. As expected, the complete pollard considerably lowered the protection from wind for all directions, especially for wind from the southwest. For most combinations of height and direction, wind reduction was as good with partial pollarding as 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.

Field-Plot Experiments

Field-plot experiments were conducted to study the influence of the trees on growth and yield of millet at several distances between rows (0.5, 2, 4, 6, 8 and 9.5 times the mean tree height of the windward row) and at two levels of fertilizer application (0 or 22.5 kg P_2O_5 and 45 kg N per hectare). Soil-water data were also collected in these plots. A local millet variety, GR-P1 (Guerguera), was planted at a density of 10,000 pockets per hectare. Ambient air temperature, precipitation and pan evaporation were monitored inside and outside the windbreak rows during the growing season, between May 21 and October 5, 1985.

Effects on Yields

Table 3 shows that protection by the windbreak rows significantly increased dry-matter production but did not effect grain yields or average grain weight per head. Fertilizer application increased grain yield and average head weight significantly, but did not affect dry-matter yields. Grain and dry-matter yields were significantly reduced near the windbreak rows (Table 4). Fertilizers increased grain yields regardless of distance from the windward row. Maximum daily air temperatures were 1-2 °C higher inside the windbreaks. Average reduction in pan evaporation due to the windbreaks was 1.5 mm/day.

Water-Use Efficiency

Soil water content was measured gravimetrically in the millet plots at intervals to a depth of 2 m at various distances from the windward row. Water-use efficiency, which was calculated as water used per kg grain produced (assuming no drainage beyond 2 m depth), was higher near the windbreak, although total yield was lower (Table 5).

Table 3. Effect of protection and fertilizers on millet grain 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
	ns	*	ns
Fertilized	487.5	2861.5	13.4
Non-fertilized	397.0	2741.5	11.1
	*	ns	*

*: Means are significantly different at 1% level
**: Means are significantly different at 5% level
ns: Means are not significantly different

Table 4. 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	12.1 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 5% level using Duncan's new multiple range test.

Table 5. Influen‹ › of distance from the windward row on water-use of millet, calculated using precipitation and soil-water observations.

Distance From Windward Row	kg Water Used per kg Grain
20	4047 a
50	5146 ab
70	5685 b
100	5805 b

Contributions to Texas Agriculture

The predominant soils of the semiarid tropics belong to the suborders Ustalf and Ustert. In the continental U.S., all Usterts and the vast majority of Ustalfs occur in Texas. Much of the basis for Texas agriculture is derived from the gene pools of the semi-arid regions of Africa, including sorghum and many of the pasture grasses. Texas and the semiarid regions of Africa also share in common many crop-production problems, including less than optimum rainfall, low fertility (particularly nitrogen and phosphorus), and soil crusting. Because of the agro-ecological similarity of the two regions, it is almost impossible to conduct research in West Africa that does not directly contribute to Texas agriculture. This report presents some of the areas in which this contribution has been, or is expected to be, substantial.

Pedology

TropSoils' pedology studies ("Soil Classification in the Semi-Arid Tropics," "Soil-Geomorphological-Hydrological Relationships of the Semi-Arid Tropics" and "Dust Inputs in the Sahel") are directly linked with the Texas Hatch Project, "Soil Genesis, Morphology and Classification of Texas and Related Soils." For example, the approach developed for verification, characterization, and publication of spatial variability of mapping units in the Soil Survey of the ICRISAT Sahelian Center, Niger, serves as a model for similar soil surveys in Texas and elsewhere in the U.S. The approach is ideally suited for large-scale surveys of experimental stations and is being used by the National Cooperative Soil Survey and also in soil surveys in developing counties.

Documenting the mechanisms of clay transport in sandy Sahelian soils, formation of soil crusts and argillic horizons, and the management implications of Sahelian soils are equally germane to Texas soils. Such research helps to elucidate the reasons for weak structural stability, infiltration responses, water retention, hard-setting surface horizons and wind and water erosion in sandy Ustalfs of Texas.

Enrichment of Teaching, Research

Teaching and research programs at TexasA&Mhave been enriched by the international relationships developed through TropSoils research. For example, research personnel had the opportunity to attend and participate in the ISSS Symposium on Water and Solute Movement in Heavy Clays, in Wageningen, The Netherlands in 1984, and the ISSS Soil Micromorphology Workshop in Paris, France, in 1985, in order to present research under TropSoils sponsorship. As a result of this professional interaction, the 1988 ISSS Subcommission B. Micromorphology Workshop will occur in San Antonio, Texas.

Studies of Vertisols

Cameroon Vertisols have many common properties with Texas Vertisols, but have developed in climatic regimes and from parent materials that yield remarkably different productivity, physical-chemical behavior, water movement and root-proliferation responses. In contrast to Texas analogues, subsoils of Cameroon Vertisols are so dense and compact they restrict water movement and root development. TropSoils research has significantly contributed to ICOMERT, an international committee on Vertisols, of which researchers in Texas have assumed major responsibility. The research in Cameroon will directly contribute to the modification of the classification of Vertisols in Soil Taxonomy and to the more effective grouping of soils with similar management responses and behavior. This is of direct benefit to Texas.

Dust Inputs From Deserts

Studies of dust inputs in the Sahel strongly interface with a similar program in Texas using the same methodology. It will be particularly constructive to determine the inputs of dust, and impacts on soils from deserts in the Saharan region of Africa versus dusts from the North American deserts. The program in Texas has three years of data to relate to the Sahelian work.

Water and Energy Balance

From the water-management standpoint, the research goal is to decrease evaporation, runoff and percolation losses, and to maximize the amount of water stored for use by the crop. Most of the published work on water and energy balances has been conducted under irrigated conditions or in humid climates where leaf area indices (LAI's) of plant canopies exceed 3.0. In semiarid environments such as the Sahel and West Texas, leaf area indices seldom exceed 2.0. It is thus difficult to extrapolate previously published work to the semiarid environment.

By understanding the water and energy balances in the semiarid environment, it will be possible to identify those strategies which offer the most promise for managing limited water resources. Results from studies in 1984 show that the evaporation of water from soil can be simulated with a model. Both the data and the model show that the local soils are self-mulching, in that evaporation losses decrease sharply two days following irrigation or precipitation. This suggests that soil-water evaporation suppressants should be in place at the time of the irrigation or rainfall to be effective.

Drought Tolerance and Water Use

Information on the nutrient requirements of plants receiving limited water is scant. TropSoils research into drought tolerance and water-use efficiencies in sorghum will develop principles and define mechanisms useful to Texas as well as to the semiarid tropics. For example, preliminary results from studies initiated in 1985 indicate that while sorghum lines differ somewhat in their water-use efficiency, these differences may not be great enough to make breeding for this trait feasible.

The studies have also shown that fertilizer can increase water-use efficiency in sorghum, if water supplies are adequate.

Publications, Texas A&M University

Bui, E. and L.P. Wilding. Pedogenesis and mineralogy of a Halaquept of Niger, West Africa, *Soil Sci. Soc. Am. J.* (In Review).

Bui, E. 1986. Relations between pedology, geomorphology, and stratigraphy in the Dallol Bosso of Niger, West Africa. Ph.D. Dissert. Texas A&M University, College Station.

Daniels, R.D. and L.P. Wilding. 1983. Report of soil/geomorphical relationships in area surrounding ICRISAT Sahelian Center. Dept. Soil and Crop Sci., Texas A&M University, College Station.

Hicks, S.K., Lascano, R.J., Wendt, C.W., and A. Onken, A.B. 1986. Use of hydraulic press for estimation of leaf water potential in grain sorghum (Sorghum bicolor L.). Agronomy Journal 78:749-751.

Isbell, V.R. and C.W. Wendt. 1984. Annual windbreak effects on cotton yield and development. New Mexico Journal of Science. 24:12.

Landeck, J.K. 1984. The moisture retention characteristics of four soils from Niger. MS Thesis, Texas A&M University, College Station.

Lascano, R.J., J.L. Hatfield, and C.H.M. van Bavel. 1986. Field calibration of neu.ron meters using a two-probe, gamma-density gauge. Soil Sci. 141:442-447.

Lascano, R.J. and C.H.M. van Bavel. 1986. Simulation and measurement of evaporation from a bare soil. *Soil Sci. Soc. Am. J.* 50:1127-1132.

Persaud, N., Chase, R.G., and Wendt, C.W. 1985. Low-input methods for soil-water-management in the Sahel. (Abstract). 77th Annual Meeting, American Society of Agronomy, Chicago, Illinois. December 1-6, 1985, pg. 37.

Van Bavel, C.H.M., R.J. Lascano, and J.M. Baker. 1985. Calibrating two-probe, gamma-gauge densitometers. Soil Sci. 140:393-395.

Waweru, Francis Mbote. 1984. Influence of annual windbreaks on the water relations, growth and yield of cotton and peanuts. M.S. Thesis, Texas A&M University, College Station.

Wendt, J.W. 1986. Pearl Millet (Pennisetum Typhoides) response to soil variability in sandy Ustalfs near Niamey, Niger, West Africa. M.S. Thesis. Texas A&M University, College Station.

West, L.T., L.P. Wilding, J.K. Landeck, and F.G. Calhoun. 1984. Soil Survey of the ICRISAT Sahelian Center, Niger, West Africa. Dept. of Soil and Crop Sci./TROPSOILS, Texas A&M University, College Station, pp. 66.

West, L.T., L.P. Wilding, and F.G. Calhoun. 1986. Argillic horizons in sandy soils of the Sahel, West Africa. In N. Federoff, L.M. Bresson, and M.A. Courty (eds). Proceedings of the 7th International Micromorphology Working Group, ISSS. Paris, France (In Press).

Wilding, L.P. and C.T. Hallmark. 1984. Development of structural and microfabric properties in shrinking and swelling clays. In J. Bouma and P.A.C. Raats (eds.). Proceedings of the ISSS Symposium on water and solute movement in heavy clay soils. ILRI Publ. #37, Wageningen, The Netherlands, pg. 1-22.

Yerima, B.P.K. 1986. Soil genesis. phosphorous, and micronutrients of selected Vertisols and associated Alfisols of northern Cameroon. Ph.D. Dissert. Texas A&M University, College Station.

Yerima, B.P.K., L.P. Wilding, F.G. Calhoun, and C.T. Hallmark. Volcanic ash-influenced Vertisols and associated Mollisols of El Salvador: Physical, chemical, and morphological properties. *Soil Sci. Soc. Am. J.* (In Press).