Annual Progress Report
Decision Aids for Integrated Soil Nutrient Management
February 11, 1999 - February 10, 2000

Executive Summary

Software release and evaluation - The initial version of the project's decision support software for diagnosing and correcting soil acidity, N and P constraints (NuMaSS version 1.0) was released in August 1999. Release of the software at the project's midterm was specifically intended to elicit user feedback. The software will be redesigned and improved, during the remaining 2 years of the project based on user suggestions for refinement. User evaluation and feedback on NuMaSS 1.0 was the central focus of a project workshop held on September 6-10 at the Philippine Rice Research Institute (PhilRice) in Maligaya. Both PhilRice and IRRI co-sponsored the workshop which was attended by 55 participants, including representatives from national agricultural research and extension services in Africa (Ethiopia, Gambia, Ghana, Mali, Senegal, South Africa, Tanzania and Zambia), Asia (Indonesia, Laos, Philippines and Vietnam) and Latin America (Bolivia, Brazil, Costa Rica, Ecuador and Venezuela).

Workshop participants were grouped according to the dominant agro-ecological zones in their respective countries: humid tropical, semiarid and wet/dry. Each group evaluated the software to determine components that worked and those that needed further improvements. Itemized recommendations for software improvements were presented and discussed during plenary workshop sessions. Many recommendations matched improvements scheduled for implementation during the coming years, whereas others new suggestions will improve the function and accuracy of the software. The *Nutrient Management Support System* (NuMaSS) was the name selected by participants for the software. Discussion groups also summarized similarities and differences among countries with respect to approaches used in diagnosing soil nutrient problems and recommending lime and fertilizers. These discussions outlined the primary challenges and constraints to improved soil nutrient management among the represented countries.

The workshop concluded with a field trip to one of the project's collaborative field testing and evaluation sites in Ilagan, Isabela Province. Approaches that could be used to field test and adapt NuMaSS to regional conditions within a country were demonstrated through ongoing trials with farmers in Ilagan. Based on results from these on-farm trials, PhilRice is considering potential options to extend the results to other upland regions in the Philippines.

Participants endorsed continued development of NuMaSS and are willing to contribute by providing data and testing software performance within their regions. Participants consider NuMaSS to be a useful tool and view the project as a forum to allow their interaction with an international group of soils scientists and agronomists.

Since the workshop, U.S. team-members met to review workshop participant feedback and determined programmatic and technical refinements to be implemented in the next version of NuMaSS. The next release will contain significant modifications and a simplified user interface.

Intensive testing sites - Ongoing field and laboratory research at the project's three collaborative testing sites (Huertar Norte, Costa Rica; Cinzana, Mali; and Ilagan, Costa Rica) began to provide critical information for knowledge gaps in NuMaSS. Work in the humid

tropical region of Costa Rica focused on development of the decision support system for tree crops, based on the region's peach palm system for production of heart-of-palm ('palmito'). Two-year field studies on decomposition and nutrient release from peach palm biomass pruned during bi-monthly palmito harvests enabled quantification of the magnitude of nutrient recycling which occurs within this tree crop system. Peach palm residues also promote downward movement of exchangeable bases in the acid Andisols cropped in the region, and may contribute to the crop's tolerance to acid soil conditions. In order to incorporate peach palm into nutrient diagnosis and prediction modules of NuMaSS, allometric equations were developed to predict biomass and nutrient accumulations for plantations of different ages. Collaborators in the Brazilian Amazon have contributed to the peach palm knowledge through their ongoing trials on acid, P deficient Oxisols. Travel to Bolivia identified an AID Mission development project which stands to benefit from the development of a peach palm nutrient management module in NuMaSS.

Grain yields for millet in acid, sandy Alfisols of Cinzana, Mali were increased significantly with NuMaSS recommended levels of fertilizer P. When compared as Ca sources for millet, Tilemsi phosphate rock and gypsum were more effective than Diamou calcitic lime in increasing yields. Soil P availability also posed a greater limitation than soil acidity on development of the symbiotic N_2 fixation system for cowpea. Farmers in the Cinzana region use composted materials (manure, crop residues and house wastes) as a primary source of nutrients for millet fields. On-farm trials were initiated to evaluate improvement of composting with supplementary additions of Tilemsi PR and urea. Results for the first year indicate that field applications of Tilemsi PR or composted Tilemsi PR were equally effective in increasing millet yields.

Nutrient management field experiments at Ilagan, Philippines have thus far included upland rice, peanut, and corn. NuMaSS recommendations of P and lime on peanut, and N, P and lime on maize were found to be near the levels needed for optimum yields in the regions Ultisols. Use of green manures on maize provided less than optimal yields without supplementary lime inputs, and was attributed to increased Mn solubility by the organic materials.

Thus far 39 farmers in the Ilagan region have collaborated in on-farm trials comparing their existing practices with nutrient recommendations by regional government agencies and by NuMaSS. On-farm corn trials included 3 farms on non-acid soils and 12 farms on acid soils, cropped with either traditional or hybrid varieties. Regional and NuMaSS nutrient recommendations performed equally across sites and increased yields over both the farmer practices and the zero fertilizer check treatments. Comparisons between regional and NuMaSS recommendations will be continued in subsequent crops, since NuMaSS will account for residual lime and fertilizer effects and regional recommendations are constant for every crop.

Enhancing the acidity, N and P knowledge base - U.S. project members and overseas collaborators continue to search published literature and assemble pertinent information for the NuMaSS knowledge base. Critical % Al saturation values and yield response curves to liming were defined for 10 corn and 7 soybean cultivars through a review of 15 published field trials on Inceptisols, Oxisols and Ultisols in Africa, Asia and Latin America. Inclusion of these data in NuMaSS expands user default options in crop cultivars and improves the prediction of conditions where liming would be economically feasible.

A review of N fertilization trials with corn throughout South America has established default mean values and suggested ranges for various coefficients used in estimating crop N recommendations in NuMaSS. Upon addition of this information, NuMaSS will provide users with suggested values for crop N accumulation, native soil N supply, legume cover crop N supply and fertilizer N efficiency for different regions within South America.

Fertilizer P recommendations require good estimates of a soils buffer coefficient - the change in soil available P per unit of applied fertilizer P. Algorithms for predicting P buffer coefficients in NuMaSS were refined to eliminate some discontinuous results encountered among soils with a certain range of clay contents. Laboratory investigations to devise short-term methods to estimate P buffer coefficients are beginning to provide favorable results. NuMaSS predictions of soil P buffer coefficients for 45 soils from Mali and Niger were quite similar to those obtained through laboratory P incubations. Laboratory estimates of P buffer coefficients among 62 soils in Central America suggest that amorphous Al might serve as a corollary measure in Andisols.

Introduction

The goal of this project is to integrate and disseminate decision aid tools that will reduce soil acidity and nutrient limitations to food production and quality. The tools will facilitate the diagnosis of soil nutrient constraints and help the user to select appropriate management practices for location-specific conditions.

The 5-year plan for project tasks are organized into two major categories: *developmental research* and *outreach activities*. Developmental research includes tasks to do the following:

merge the single-constraint decision support systems (DSS) for acidity, N and P into an integrated nutrient management system (NuMaSS);
synthesize, analyze and assemble knowledge required to overcome recognized information gaps in the existing information base for acidity, N and P;
test and refine NuMaSS; and
develop auxiliary tools to facilitate use of the integrated knowledge base by a variety of users.

Outreach activities involve two major types of collaborative effort: *intensive testing areas* and an *extensive evaluation network*. Intensive testing areas are a representative region in each of three agroecological zones (semi-arid, wet-dry and humid tropics) where there is significant potential for tools developed by this project to alleviate soil acidity, N and P management problems. These three regions provide real life situations where all developmental research by the multi-disciplinary team of 16 scientists from four U.S. universities (Cornell, Hawaii, N.C. State and Texas A&M) will be conducted jointly with national and international institute collaborators. The extensive evaluation network focuses on the evaluation of products under a variety of user conditions, once suitable performance is achieved at the intensive testing areas. Although major efforts in product evaluation will occur towards the end of the 5-year project, early and continued contact with network collaborators will help ensure global relevance in product design and knowledge assembly.

Report on project tasks or activities are grouped according to the outputs or products to which they contribute; outputs and/or products are then grouped according to the stated project objective that they collectively will achieve. Progress reports are also intended to reflect a starting point for the subsequent year's project workplan.

Objective 1: Develop an integrated computerized knowledge base for global use in diagnosing and recommending practical solutions to soil acidity and nutrient problems, which considers differences in resource availability and soil, climate, crop and management factors contributing to location-specific acidity and nutrient constraints.

Output 1 Integrated Nutrient Management Decision Support System (NuMaSS) Software - merge the three existing single-nutrient decision support system prototypes (acidity, nitrogen, and phosphorus) into a functional, fully integrated soil nutrient management DSS.

The three existing DSS's were programmed under different languages with different formats and structures. In order to produce a fully functioning integrated program, each individual DSS must be reprogrammed and combined with a common interface. Milestone events towards development of NuMaSS software, during the 5-year plan are as follows:

initial NuMaSS prototype developed with each DSS reprogrammed into a common language, computer interface, and using a common database;
intermediate NuMaSS prototype releases in years 3 and 4 with improved analytical tools and/or algorithms for integration across nutrients; integration is tested by users and necessary refinements are identified; and
final release of NuMaSS in year 5.

Lead Investigators and Contributors:

Deanna Osmond (NCSU) coordinates the NuMaSS software development effort, with inputs from Shaw Reid (N module), Jot Smyth (acidity module) and Russell Yost (P module) through their coordination roles for the individual DSS improvement tasks. Additional contributors to this output during year 2 are listed according to their respective institutions:

University of Hawaii - Xinmin Wang and Nguyen Hue
North Carolina State University - Pedro Luna, Dan Israel, Michael Wagger
Colorado State University - Dana Hoag
Understanding Systems, Inc., Raleigh, NC - Steve Pratt, Will Branch

Progress:

1. *Refinement of single-thread prototypes*

   Acidity module - (Jot Smyth, Nguyen Hue, Russell Yost and Will Branch) - the oldest of the three decision support systems, was the first to be re-coded for the integrated nutrient management decision support system (IntDSS) which has recently been renamed Nutrient Management Support System (NuMaSS). The recoding and validation were completed in Year 2. Validation of the acidity module in NuMaSS occurred in year 3 as part of the overall review of IntDSS, version 1.0. A units error was discovered and corrected in the economics section. Otherwise the program performed well. A few technical changes were suggested to deal with specific aspects of liming.

   N module - (Shaw Reid, Deanna Osmond, Dan Israel, Michael Wagger, Pedro Luna, Art Wollum and Will Branch)

   a. Programming - since the N module prototype was originally developed for temperate conditions with extensive state-specific soil and crop data, it had to be changed conceptually. In addition, all the code was rewritten. The basic premise in rewriting the N module was to

allow for flexibility of information. It is assumed that some users will have specific information whereas others will not and will be dependent on default values available through the data base development.

The revised Stanford equation is the basis for the nitrogen recommendation:

$$N_{fert} = ((Y_r * N_{cr}) - [(N_{soil}) + (N_{residue} * C_r) + (N_{manure} * C_m)])/(E_f)$$

ABBREVIATION	DEFINITION
N_{fert}	N fertilizer needed
E_f	Fertilizer efficiency
Y_r	Realistic yield, both vegetative and/or reproductive
N_{cr}	Concentration of nitrogen in the crop, both vegetative and/or reproductive (unitsN/unit dry wt)
N_{soil}	Nitrogen mineralized from soil organic matter during the growing season
$N_{residue}$	Nitrogen mineralized from the residues, including green manures
C_r	Proportion of N from the residue, including green manures, that the plant absorbs
N_{manure}	Nitrogen mineralized from the manure
C_m	Proportion of N from the manure that the plant absorbs

Realistic or target yield is derived from either a user input value or a default value. Default yield values are based on factors such as crop, variety, region, country, agricultural region and/or soil order.

Methods for determining the soil nitrogen (N_{soil}), which is the N derived from soil organic mater, residual fertilizer N, and atmospheric deposition, are outlined below in descending order of preference.

- best value of N_{soil} is a user-entered value;
- the second best estimate of N_{soil} is derived from the N content in the previous crop, if the previous crop was not fertilized and the previous crop is the same as the current crop; and
- the least precise measurement of N_{soil} is derived from soil test data, either %N, %OM, or %C.

Additional N inputs that need to be considered are residue and manure derived N, where

- $N_{residue}$ = amount of N mineralized from residue of the prior cropping year, if the crop was a green manure or legume that was left in the field, and current applications of residues. Information include type of green manure (at a minimum) and dry weight if it is available; and
- N_{manure} = amount of N derived from current and the previous year's application of manure. To calculate N contribution from residue, the following information will be required: type of animal, weight of manure, % N content (or default value), and moisture state (moist, dry).

We have conformed the N module to the structure outlined for the other two nutrient modules. However, the differentiation between diagnosis, prediction and economic evaluation are not as relevant to the N module as they are to the other two systems. The

integration process of the three models is a series of tradeoffs and so the N module is structured to meet integration needs.

When testing the N module, we found it to be very robust. Reviewers caught a programming error concerning legumes that has been fixed in NuMaSS Release 1.5. The other major concern was the amount of information required for the N module. Anticipated interface changes and additional data base information should obviate this concern.

b. Data Bases - in order to run the N module, variables are either supplied by the user or are pulled available as default tables. Building the default data tables has been very important to the successful running of the nitrogen portion of NuMaSS. Since the algorithms and programming of the N module were new for the integrated system, there was a iterative process between defining the fields in the data tables and the N module. The original data table format was set in late August of 1998. During the development of the N module, additional fields were added primarily to two of the tables (Crop Characteristics and Crop Yield) as additional data requirements became obvious.

The order in which the crop data has been collected is based on decisions made by our entire development team at the Hawaii meeting. In December 1997, the users identified 15 important crops. Because we were not sure we could collect sufficient information, we ordered the crops into three groups – essential (corn, peach palm, maize, millet, upland rice, sorghum); important (soybean, cowpea, Phaseolus bean, wheat, cassava); and somewhat important (sugar cane, coffee, cotton). Data has been collected in accordance with this order. Information required to populate these default tables are derived from literature reviews and current data. Pedro Luna has obtained crop default values for rice, corn, millet, sorghum, cowpeas and cover crops. Dan Israel has also worked on obtaining default values for sorghum and Michael Wagger has worked on values for cover crops. Default data for the manure table was collected by Deanna Osmond (See nitrogen section). Over 10,000 individual data entries have been entered from 53 cited references. For every cited reference, at least 2 other references have been reviewed. Most of this data has been gathered, reviewed and entered by Pedro Luna.

<u>P module</u> (Xinmin Wang and Russell Yost)

a. Incorporating the P module into NuMaSS 1.0 - we have finished incorporation of a P module based on PDSS2 into NuMaSS version 1.0. The structure of PDSS2 (a stand-alone version of the P module used to test additions of new information) was modified to fit the interface and structure of NuMaSS. Basically, four components have been implemented in the P module for the NuMaSS. The components for the P module are diagnosis, prediction, economic analysis, and recommendation. In the release of NuMaSS 1.0, the P module has some unnecessary features/bugs to be changed /corrected:

- program over-rode input yield values with default (lost input yield).
- Input buffer coefficient was over-ridden by default value (lost input data).
- Olsen soil test causes error.
- Database access errors occasionally occurred.

The reason that the P module chose to over-write values of crop yield is related to the fact that multiple records sometimes exist for the same crop in the same cropping regions. We are currently working on an algorithm to average data with multiple records. That input P buffer

coefficients were over-written by default values was partly related to the limitation of interface. We have requested that the interface provide more functions, which permit the P module to update the value only when it is necessary. These updates will be partially completed in the next release of NuMaSS. The last two errors have been modified and tested again and we expect fewer errors in the next release of NuMaSS. In the process of incorporating the P module into NuMaSS 1.0, an estimate of 10 - 20 percentage of our working time were spent on recoding/changing the P module due to the necessary data base changes needed to integrate the three modules into the integrated system.

b. P module programming and updating - The independent PDSS 2.0 software has been updated to PDSS version 2.11. This includes the following:

i. Add a peach palm (palmito) component into the system (PDSS2.0) - although peach palm is a perennial crop, the system treats palmito as it were annual crop because it is in the initial stage for peach palm development. The behavior of this initial stage is similar to annual crops. Some data that is used in this module follows.

Biomass data - of a fresh weight base values are 8,500 kg ha^{-1} for Costa Rica and 5,900 kg ha^{-1} for Brazil. The default value is the mean of these data. The change in yield with spacing and time is not implemented in this version because there is no spacing entry for this system (nor has it yet been discussed by the programming team). This feature may be included in the next version of the peach palm module.

P concentration - in palmito is 0.34% (dry weight base) for use in estimating P removals. The dry matter is 8.6% of fresh biomass. Together these values are used to estimate the P conversion factor which is used to estimate the removed P by the crop.

Soil P extractant - Modified Olsen, Mehlich 1, Mehlich 3, and Bray 1 extractants can now be used for peach palm.

Soil extractable P critical level - 15 mg kg^{-1} for Mehlich 1 (for the lag phase of growth) based on preliminary data from Brazil. Critical levels for the other methods are estimated from the following methods:

Modified Olsen = 5.09 + 0.485 * Mehlich 1

Mehlich 3 = 4.092 + 0.689 * Mehlich 1

Bray 1 = (Mehlich 1 + 1.119)/0.842

P buffer coefficient - the P buffer coefficient (PBC) is based on data from Costa Rica soils for modified Olsen. We have not developed a general model to estimate the PBC from soil properties alone. However, PBC are averaged for each soil order so the values of PBC are specific to soil order. The following PBC available data in this PDSS version:

Andisol: 0.1716

Inceptisol: 0.2206

Ultisol: 0.2554

whole soil: 0.2208 (as a default value, i.e. use this value if no soil order is selected)

ii. Add a new location to PDSS - a new site, Philippines (Sierra Madre uplands), has been added to the PDSS and the location Niger/Mali has been changed to Mali/Niger. The data which are dependent on the location have also been updated.

iii. Update user interface - soil extractable P critical levels and P buffer coefficients are not over-ridden in general after a user modifies these values. However, the default values for the

P critical level and PBC is be used when a user starts the program, or one of the following data is changed or modified: intended crop, soil clay content, and extractants for extractable P. The list of extractants for soil extractable P in the program is now dependent on the intended crop.

c. Test and improve predictions of P buffer coefficients - the P buffer coefficient, a ratio of the increase in extractable P to the amount of applied fertilizer P, is a source of considerable uncertainty in determining the amount of fertilizer needed to meet crop P requirements. Currently both PDSS 2.1 and NuMaSS 1.0 use soil clay content as a predictor of the P buffer coefficient for soils of similar mineralogy. However, it has not been satisfactory for soils with a wide range of soil mineralogies and relatively high clay content. We are trying to improve the prediction of buffer coefficients using soil characteristics associated with the process of P sorption, such as mineralogy, surface area, and aggregation (Wang et al., 2000). We have generated the values of PBC, which are specific to soil order, for palmito used in the PDSS 2.1.

2. *NuMaSS Completion and Release, Version 1.0* (Deanna Osmond, Jot Smyth, Shaw Reid, Russell Yost, Xinmin Wang, Will Branch and Steve Pratt) - although much of the integrated interface was completed in year 2, additional input boxes and pages were added on an as needed basis to support the individual nutrient modules that were being integrated into the overall system, especially the N module. In addition, it was necessary to add default value capability.

   Integration of the individual decision support systems (N module, acidity module, P module) have proceeded along different tracks but with the same outcome. The N and acidity modules continued to be integrated into the interface as single units of code. The single "unit" of code for the rule set is a first step in the modular design of the NuMaSS. Modularization of program code was used for several reasons: (a) to assure that other programmers will be able to understand the code and (b) as a safeguard to the fact that no single group is responsible for the implementation and future updates of all three nutrient models. The P module has been integrated as a self-contained component in the integrated interface (see P module integration).

   The individual modules were programmed as single-threads so that they could be tested and de-bugged before complete integration. Over 70 copies of the software (version 1.0) were sent to cooperating agronomists and scientist in Africa, Asia and Latin America. A workshop was held with a subset of our international partners (see Objective 3, Output 1). NuMaSS proved to be extremely robust for a first version. Most users were able to use the software without reading the instructions and with minimal assistance. In addition, relatively few program errors were found. The user concerns are listed below, some which are programmatic and some which are technical.

   <u>Recommendations made by reviewers for NuMaSS in general</u> -

   a. Programming

   - Zoom capability needed for maps
   - Delete input for soluble carbon
   - Use ranges to prevent gross errors in input
   - Rename input boxes

- Implement help section
- Provide table for minimum data set
- Implement feature to save input
- Allow user input of data
- Input for crops is case sensitive, if people type the crop as opposed to using the pull-down menu
- System should included a warning for values that are out of range
- Move cursor automatically from input box to input box

b. Technical Information

- New FAO classification should be included as an alternative option to USDA taxonomy
- Use more detailed rainfall information (make rainfall data more useful)
- Results obtained, in general, were reasonable
- IntDSS is intended for decision making professionals
- IntDSS can be improved by developing or introducing local knowledge that helps to take a more detailed decisions
- Previous crops limited, particularly for perennials
- Few varieties in system
- Textural class too restrictive
- Add fertilizer sources (14-14-14, 17-0-17)
- Economic analysis needs to allow more options and be consistent between the three systems
- Cropping systems need to be reviewed
- Break regions into agro-ecological zones
- If data can be calculated from other data, then those calculations should be entered automatically (e.g. ECEC)
- Ensure units are uniform

c. Other

- Ease improves with practice
- Good educational tool

<u>Recommendations for the N module</u> -

a. Programming

- Recommending nitrogen for legumes
- Could not calculate vegetative yield from harvest ratio and reproductive yield.
- If rerun N module, economic section should automatically be updated

b. Technical

- Reduce amount of detailed information
- Too dependent on accurate information (e.g. NUE)
- Wording in output needs to be more understandable
- P fertilizers are available for nitrogen recommendations
- Why two “or” in diagnosis intended crop
- Information material needed for NUE
- Better guidance from estimating N use efficiency (target yield, N soil)

Recommendations for the P module -

a. Programming

- Program over-rode input yield value with default (lost input yield)
- Input buffer coefficient was over-ridden by default (lost input data)
- Olsen soil test causes error
- Data base access errors occasionally occurred

b. Technical

- Include soil type/mineralogy (Equilibrium P and P-fixation index)
- Explain meaning of 0.1 band vs 0.2 band
- Include conversion between field P buffer coefficient
- Include other P fertilizer sources (14-14-14, 0-18-0, 16-20-0)
- Effect of age of residual P and variability on critical P
- Discussion of conflicting results, suggestion to repeat analysis
- Recommended rates are low relative to Brazil (recommended rates are 1/3 of what is actually needed)

Recommendations for acidity module -

a. Programming

- Economic analysis is off by 1000

b. Technical

- No correction for Ca and Mg deficiencies on very low CEC soils
- Need to consider lime as a "fertilizer" for some crops (e.g. peanuts)
- Gypsum should be included in the system as a source of Ca when we don't change pH (as for potato scab)
- Adjusts the potato critical Al saturation % due to risks of scab
- Lime recommendations in the wet/dry environments of Brazil are low relative to the amounts recommended locally
- Provide different lime placement options (broadcast vs banded)

The software has been revised to reflect some of these suggestions. The second prototype of the software has been released (NuMaSS 1.5). The software has undergone a name change from IntDSS to NuMaSS (Nutrient Management Support Software) based on suggested user input.

Due to user feedback, we have significantly modified and simplified the user interface. These changes will be reflected in NuMaSS (Version 2.0) to be released in the late fall of 2000. The Potash Phosphate Institute has agreed to let us use images on their recently released CD on 'Nutrient Deficiency Symptoms' to develop visual data for the diagnosis component of the decision support system.

3. *Maintenance of the project's web site*

The project's web site (http://intdss.soil.ncsu.edu) continues to serve as the primary conduit for communications on project activities among U.S. and overseas participants, as well as the general public. The site's calendar section alerted all members to pending deadlines and provided advanced notification of travel schedules throughout the year. Reports on each travel event, workplans, workshops, annual progress, baseline surveys and "white papers" were produced in Acrobat Reader file format (*.pdf) and posted on the website for

downloading by interested viewers. The FTP site on the project's server expedited the exchange of NuMaSS software files among programmers at Cornell, N.C. State and Hawaii universities. The FTP site allowed selected users access to download NuMaSS, 1.0 (formerly IntDSS, version 1.0). Following the workshop in the Philippines an e-mail listserver was also created to facilitate continued correspondence and consultation with collaborators.

4. *Environmental Concerns*

Effects of P (Russell Yost and Xinmin Wang) - this annual report describes some initial data related to environmental concerns with the application/accumulation of P in soils of the tropics. Although it is true that many of the soils of the tropics are P deficient, it is also true that many of them are high to extremely high in soil P. This apparent paradox occurs because P requirements are generally not being accurately assessed; consequently, it is not unusual for soil P levels to be high in several conditions. Often there is accumulation of P from fertilizer P (Pandutama, 1996) or from the application of manures and manure slurries from concentrated animal feeding operations. Environmental concerns include the observation that eutrophication of lakes and streams sometimes is more limited by P levels than by nitrate levels. In such cases, P in solution runoff from soils with high soil P levels can contribute to environment degradation through the eutrophication syndrome.

Results are reported here for samples of soils to which animal lagoon effluent has been applied for several years. Site 2 was located on a highly weathered soil, an Oxisol, with high P sorption characteristics. This site was sampled at two soil depths. Foliar samples were also taken. Three paddocks were sampled - the control, and two paddocks to which effluent had been applied. Each of the two effluent-receiving paddocks had sections to which both moderate and high levels of effluent had been applied. The portions of the paddocks receiving the moderate amounts of effluent had not received effluent since April 1999, or approximately 2 months. The portions of the paddocks receiving high levels were currently receiving effluent on a short rotation basis from overhead applicators.

The analysis of surface soil (0-20 cm) indicates that higher levels of P, Ca, Mg, electrical conductivity, and organic carbon were measured where effluent had been applied (Table 1). Most notably, however, was the substantially higher amounts of soil P where effluent had been applied. With these high levels of surface P there might be sufficient dissolved P in the runoff to cause problems downstream. The quantity of surface runoff will likely remain small because of the dense, vigorous, productive stand of pasture grass, which was clearly thriving on the regular effluent applications.

The impact of surface application was also assessed on the deeper (80-100 cm) part of the soil profile (Table 2). In general the 80-100 cm zone was very low in nutrients in both the control and where effluent had been heavily applied. Only potassium and electrical conductivity were present in moderate levels. For the other nutrients, even though there were significant increases in nutrients in the zone, the levels were still far below recommended levels for plant growth (Table 2, see FACS2 recommended levels). In particular, the low P level in the subsoil indicates that management options that would turnover the soil could reduce the high levels of surface P.

Results of foliar analysis of grass samples collected from site 2 indicated that there were no differences in nutrient content of the forage on the control site compared with that collected

from the sites where effluent was being applied. Not apparent in the foliar analysis was the substantially better grass growth where effluent had been applied. Nutrient levels were as follows (average) in percent - N: 4.16, P: 0.46, K: 2.95; Ca: 0.48, Mg: 0.24; Na: 13, and in mg kg^{-1} Mn: 103, Fe: 373, Cu: 18; Zn: 32, and B: 9.7.

Table 1. Results of sampling at Site #2, means of application rates (0-20 cm depth)

EFFLUENT APPLIED RATE	SAMPLE DEPTH	SOIL pH	MOD. TRUOG P	EXCHANGEABLE K	EXCHANGEABLE Ca	EXCHANGEABLE Mg	EC	ORG. C
	cm		---------- mg kg^{-1}	----------			mmhos/cm	%
None	0-20	[1]5.85a	87.5a	802a	1358a	377a	0.79a	4.03a
Moderate	0-20	6.70a	891b	940a	2570b	542b	0.88a	4.34a
High	0-20	6.95a	1055b	1476a	4013c	752b	1.57b	6.29b
Significance[1]		NS	0.055	NS	0.004	0.05	0.02	0.038
Recommendation[2]		6.0	30	250	1750	350	-	-

[1]Numbers followed by the same letter are not significantly different; those followed by a different letter are sig. at the 0.05 level. Higher letters in the alphabet indicate significantly higher results.
[2]University of Hawaii fertilizer recommendations for this site.

Table 2. Results of sampling at Site #2, means of application rates (100 cm depth).

EFFLUENT APPLIED RATE	SAMPLE DEPTH	SOIL pH	MOD. TRUOG P	EXCHANGEABLE K	EXCHANGEABLE Ca	EXCHANGEABLE Mg	EC	ORG. C
	cm		---------- mg kg^{-1}	----------			mmhos/cm	%
None	80-100	5.25a	4.45a	179a	155a	39a	0.28a	1.31a
Moderate	80-100	6.45b	11.2a	431a	304b	104b	0.88a	0.65b
High	80-100	6.30b	13.5a	531a	355b	128b	1.42b	0.57b
Significance		0.015	NS	0.01	0.044	0.06	0.001	0.05
Recommendation		6.0	30	250	1750	350	< 2.0	-

Written Units (Deanna Osmond) - information has been collected and units on the agricultural sources and affects of N and P are being written. Using N as an example, information has been collected on the N cycle, mode of transport, water quality limits, health affects, environmental affects, and agricultural sources. We have used multiple sources to collect this information. These informational units or "fact sheets" will be added to NuMaSS for release 2.0.

5. *Initial Prototype of Nutrient Management Guidance Module* (Deanna Osmond, Jot Smyth, Shaw Reid, Russell Yost and Dana Hoag) - a second two-day working meeting was held with

Dr. Dana Hoag, an agricultural economist at Colorado State University, to discuss integration of the three models within the *Guidance Section* of NuMaSS. Concurrence was reached between the four principle investigators and Dr. Hoag that the economic integration would proceed initially as a linear plateau model.

A data set on soil characteristics, crop yields, and commodity prices was collected for the Cerrado region of Brazil. This data set was forwarded to Dana who has been working with the information to determine if by using a linear plateau model he can determine the best mix of inputs. "Best mix" will depend on which of the three economic considerations the user selects: 1) needs to obtain a specific yield, 2) fertilizer or lime availability or 3) maximize profits. A preliminary algorithm has been suggested. This algorithm needs to be reviewed. Currently, the three nutrient DSS have very different input needs for the economic section. This is in part due to the nature of the material that is being applied, and in part differences in programming style. Currently, the acidity module is the most data intensive and the N module the least. Dr. Hoag is reviewing these data needs and will be suggesting which inputs are needed and which are not. During the review of IntDSS 1.0, users reported difficulty with some of the information that was asked. Sometimes users did not understand what was being asked and sometimes they simply did not have, nor could they find, the information that was being requested.

<u>External Funding and Support</u>

$5000 from State of Hawaii funds for work related to environmental concerns with P.

<u>Travel and Meetings Attended</u>

None

<u>Relevant Publications, Reports and Presentations at Meetings</u>

Luna, P., T.J. Smyth, D.L. Osmond, D.W. Israel. 2000. Collection and Evaluation of Literature on Crop Responses to N Application – The Case of Corn (Maize in South America). (http://intdss.soil.ncsu.edu/sm-crsp/Download/Documents/Corn_NDSS_0299.pdf)

Osmond, D.L. 1999. Presentation of an overview of IntDSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Osmond, D.L., T.J. Smyth, W.S. Reid, R.S. Yost, X. Wang, and W. Branch and S.H. Pratt. 1999. Integrated Nutrient Management Decision Support System (IntDSS), Version 1.0.

Osmond, D.L., T.J. Smyth, W.S. Reid, R.S. Yost, W. Branch and X. Wang. 1999. Integrated soil nutrient management decision support system (IntDSS), version 1.0 software installation and user's guide. Soil Management CRSP Technical Bulletin No. 99-02.

Reid, W.S. Presentation of NDSS as part of NuMaSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Smyth, T.J. 1999. Presentation of ADSS as part of NuMaSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Wang, X., J. Jackman, R. S. Yost, and B. A. Linquist, 2000. Predicting soil phosphorus buffer coefficients using potential sorption site density and soil aggregation (accepted). SSSAJ (2000).

Yost, R.S., M. DuPonte, J. Powley, L. Ching, C. Lee, and C. Smith. 2000. Assessing change in nutrient status under sustained application of animal manures on representative soils of the tropics. (Unpublished manuscript).

Yost, R.S. and X. Wang. 1999. Presentation of the P module of NuMaSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Output 2 Field evaluation and refinement of NuMaSS software - testing and refining the integrated decision support system under multiple environments and agricultural systems.

The process of developing the NuMaSS software is a continuous feedback loop among developmental research and outreach activities. Upon the synthesis of existing knowledge the team gathers to formulate options and refine developmental research needs. Prototypes are tested, and the team of U.S. scientists and collaborators critique/discuss/improve the prototypes. With each repetition of this cycle the product approaches desirable performance.

NuMaSS prototype testing and evaluation will initially focus on the intensive testing areas. Once decision support products and tools achieve suitable performance in intensive testing areas, they will be evaluated and tested under a variety of user conditions throughout the extensive evaluation network. Milestone events in field evaluation and refinement of NuMaSS software, during the 5-year plan are as follows:

team visits to Costa Rica, Mali and Philippines for selection of intensive testing sites in conjunction with host-country collaborators - year 1;
baseline assessment of social, economic and cultural conditions, infrastructure, soil resources and nutrient management needs for each intensive testing site - year 1;
refinement of the project's 5-year plan of research and outreach activities to ensure the particular nutrient constraints at each site are properly addressed - year 1;
developmental field research and testing/evaluation of NuMaSS at intensive testing sites - year 2 - 5
project impact assessment surveys at intensive testing sites - years 3 and 5; and
feedback on evaluation of NuMaSS software and auxiliary tools from extensive evaluation network - years 2, 4 and 5.

<u>Lead Investigators and Contributors</u>

Coordination of activities at each intensive testing site was assigned to a project team-member at one of the U.S. universities. These coordinators are Jot Smyth (NCSU) for Costa Rica, Lloyd Hossner (TAMU) for Mali and Russell Yost (UH) for the Philippines. Collaborating institutions and primary contacts for each site are as follows:

Center for Agricultural Research/University of Costa Rica - Alfredo Alvarado, Raphael Salas, and Eloy Molina

Institute d'Economie Rurale, Mali - Mamadou Doumbia and Aminata Sidibe (Sotuba Station); Adama Coulibaly, Oumar Coulibaly, and Zoumana Kouyate (Cinzana Station)

Philippine Rice Research Institute/IRRI - Teodula Corton (PhilRice) and Thomas George (IRRI)

All the project's U.S. team members contribute to intensive testing site activities through their individual tasks (see Objective 2, Outputs 1-3).

<u>Progress</u>

1. *Costa Rica*

   <u>Midterm survey</u> - (conducted under the supervision of Frank Smith, N.C. State Univ., and Alfredo Alvarado, UCR) Frank Smith traveled to Costa Rica to coordinate the mid-term evaluation of the project based on experiences at the Costa Rica site. In collaboration with local leaders, procedures and systems were developed to document progress toward project objectives. The trip report (available on the project web site) provides new information on

project activities and outcomes based on new field data on the evolution of the Costa Rica site. Meetings were held with stakeholder groups including farmers, farm organizations, fertilizer suppliers, researchers, government and non-government organizations, and extension specialists. The new information obtained is intended to assist with development of the DSS model and the subsequent technology transfer strategy through the project┤s extensive evaluation network.

The market conditions for palmito have change dramatically since the project site selection (Osmond, et.al., 1997) and the baseline study (Alvarado, et. al., 1998) (Figure 1). High prices for heart-of-palm ('palmito') fueled the rapid expansion of production in the period 1990-1997. Since 1997, however, prices have declined approximately 50% and the rural sector is facing a serious social problem. The National Production Council (CNP) estimates that 2000 farm families are suffering the effects of a total elimination of their principal source of income. The major fertilizer suppliers, FERTICA and ABOPAC, report only minimal sales of fertilizers to palmito producers. The majority of producers are minimizing costs of production by relying on the residual effects of previous fertilizer applications.

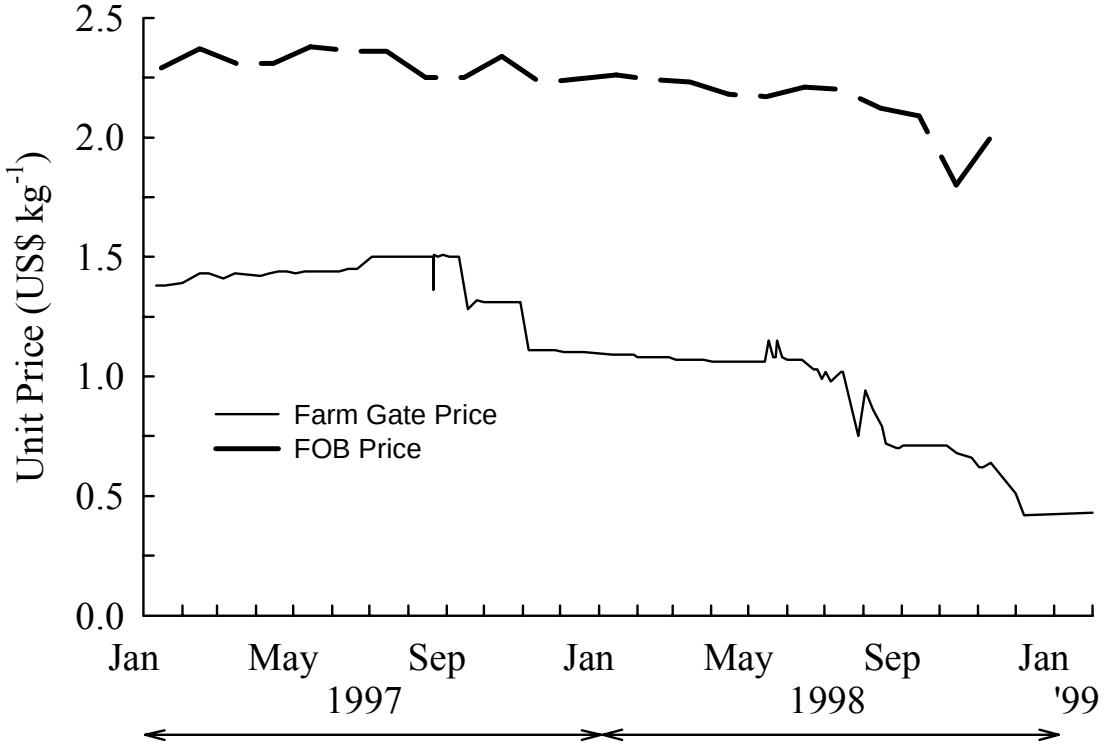

Figure 1. Comparison of prices paid for palmito by COOPROPALMITO to farmer cooperative members (farm gate price) with the export prices for processed palmito (FOB price) during the period of January 1997 - February 1999. Farm gate prices, in colones/palmito, were converted to US$/kg assuming 45 palmitos/box with 9.6 kg of palmito/box (CNP, 1999).

The current crisis in palmito markets emphasizes the importance of economic variables in decision-making. This work contributes to a more complete picture of farmer decisions under both boom and economic stress conditions. In 1998 exports of palmito grew 14.5% over 1997, reaching 12,000 metric tons with a total value of 24 million dollars and generating employment for 7000 persons. In 1998, 58% of the exports were sent to France and the balance to 23 other countries including the U.S. which received 1131 metric tons of palmito from Costa Rica (CNP, 1999). There is general consensus that the long-term solution depends on effective organization of production and marketing. The primary responsibilities will fall on growers and industries. Decision support aids will be extremely useful to achieve sustainable and efficient management of production in a context of changing market conditions.

The government has a limited role in ensuring fair and free markets and in providing institutional support for research, extension and education. The government is in the process of developing goals and strategies to reestablish and expand the market for palmito (CNP, 1999). Among points under consideration are the following:

1. Continued restructuring of existing debts in the palmito sector in cooperation with private banks.
2. Elimination of the import tax on packing materials used for processing and packing palmito as well as a selective sales tax on palmito in the local market.
3. Extension of social services to the distressed palmito sector.
4. Support for promotion of palmito and the work of the National Palmito Program.
5. Establishment of a system of grading the quality of various palmito products.

Additional collaboration will be needed between universities, research institutions, non-government organizations and industry for research in production, processing and marketing. Local researchers have expressed their satisfaction with the nature of the international collaboration and the opportunities to gain new knowledge and experience with research methods and procedures. Literature exchange facilitated by the project has benefitted students and other professionals.

<u>Ongoing laboratory, greenhouse and field investigations</u> -

a. Peach palm residue decomposition/nutrient release - (UCR supervision by Gabriela Soto with assistance from Michael Wagger, Pedro Luna and Jot Smyth) Gabriela Soto traveled to Raleigh in August 1999 to work on campus in analysis and interpretation of existing results. Using field data from decomposition studies, equations were developed to predict nutrient release from peach palm litter in heart-of-palm plantations.

The experiment was located in a 16-yr old commercial heart of palm plantation on the DEMASA, S. A. farm at Guápiles, Costa Rica. Mean annual temperature and rainfall are 25.5ºC and 3650 mm, respectively, and altitude is 210 m. Residue decomposition and nutrient release were evaluated for three different placement dates: July 31, 1998 (S1), September 24, 1998 (S2) and March 11, 1999 (S3), to account for the seasonal rainfall variation. During the 2-3 month dry season (S2) in the Sarapiqui region (with 50-75 mm rainfall month^{-1}), 'palmito' production drops by as much as 50%. As can be observed in Figure 2, the placement dates did not correspond with the expected rainfall peaks.

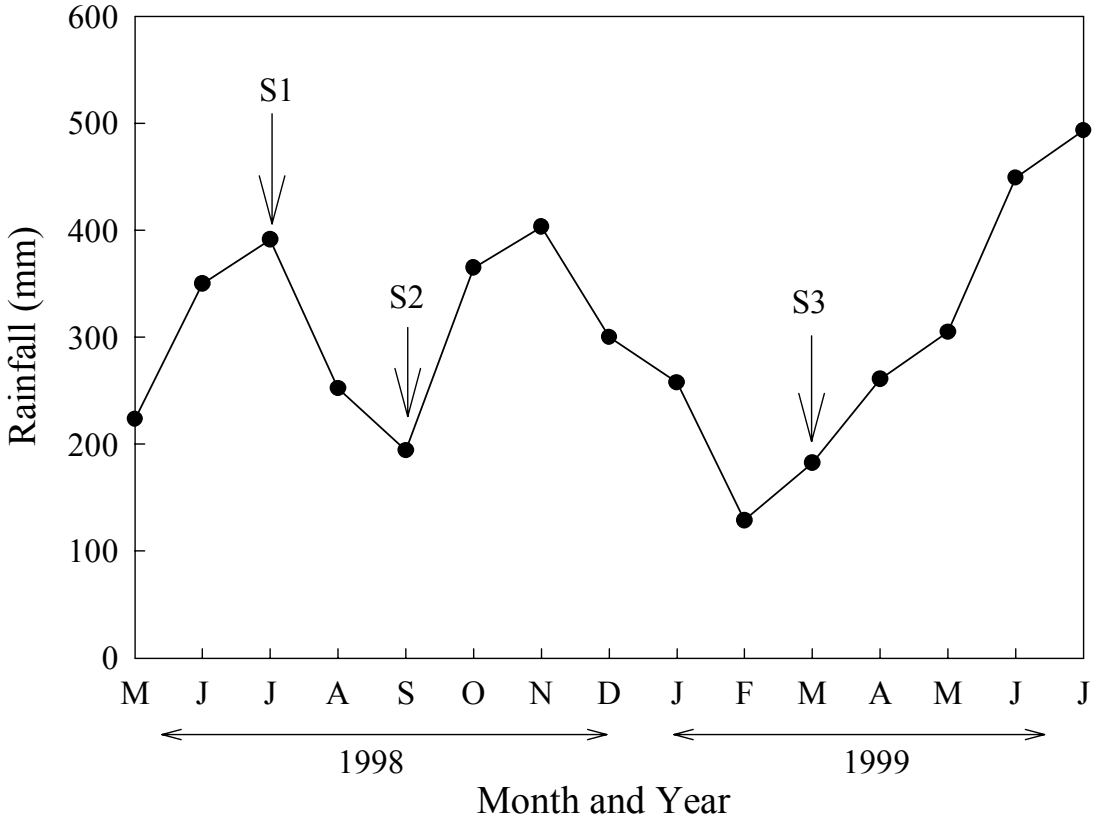

Figure 2. Monthly rainfall distribution during litter decomposition studies at Guapiles, Costa Rica. Arrows indicate times when each placement series was initiated.

To monitor residue decomposition at each seasonal placement, the third leaf of the five leaves cut during harvest was placed in 90 x 45 cm^2 fiber glass mesh bag, placed on the soil surface 2 m apart in the intrarow area. At the same time these samples were collected, 10 additional leaf samples were collected for nutrient (N, P, K, Ca, and Mg) determination. Lignin was also determined on these leaf samples by the acid-detergent method (Van Soest, 1968). Mesh bags were retrieved 1, 2, 4, 8, 16, 24, 32, 40 and 48 weeks after field placement. A total of 4 replicates were collected at each sampling date. At each retrieval date, the contents of each bag were dried at 70ºC, weighed and analyzed for N, P, K, Ca, and Mg. Dry matter accumulation was calculated on an ash-free weight basis by ashing samples at 550ºC to correct for soil contamination.

Percentage of original dry weight, N, P, K, Ca and Mg remaining at each retrieval date were regressed on time using the NLIN procedure of SAS (1997). The decreases with time generally followed an exponential trend, so several models were tested for fit to each response variable. A separate model was fit for each placement period. Selection of the best model for a particular response variable was based on the lower mean square error value. For the purpose of model comparison among placement periods, data from all periods were

pooled and a common selected model was fit to test the hypothesis that the curves for the three periods were the same.
Analysis of the third leaf cut at harvest during the three placement periods showed no significant variations in dry weight and nutrient content (Table 3). All nutrient concentrations are within the range of values previously reported in Costa Rica. Lignin content was only determined for the first placement period.

Table 3. Dry weight and nutrient and lignin content of the third leaf of heart of palm, cut at harvest times coinciding with the three placement periods for mesh bags at Guápiles, Costa Rica.

PLACEMENT PERIOD	DRY WEIGHT	FOLIAR ANALYSIS					
		N	P	K	Ca	Mg	LIGNIN
	g	%					
S1	110	2.18	0.18	1.24	0.29	0.17	6.2
S2	118	2.42	0.20	1.32	0.50	0.25	--
S3	108	2.81	0.22	1.44	0.35	0.18	--
Mean	112	2.47	0.20	1.33	0.38	0.20	--

This plantation has been established for 16 years, with an average production per plant of 4 stems per year (personal communication Ing. Félix Castro, farm manager, DEMASA). With a plant density of 5000 plants ha^{-1}, the annual production for this system is around 20,000 palmito stems. Using these plant density and harvest parameters,, an estimated 11.2 t ha^{-1} yr^{-1} of leaf residue remain in the field (Table 4). The nutrient content of this residue is considerable, averaging 276 kg N ha^{-1}, 22 kg P ha^{-1}, 149 kg K ha^{-1}, 43 kg Ca ha^{-1} and 23 kg Mg ha^{-1}.
Similar decomposition and nutrient release rates were observed for the three placement periods, thus allowing results for the three periods to be pooled into a single model. This result is not unexpected, even with different rainfall environments, since water availability was not deficient enough to limit decomposition. With the exception of K which was fitted to a single exponential model, an asymptotic model best described residue decomposition and nutrient release (Table 5). Relations for dry matter and litter N are shown in Figures 3 and 4, respectively. There was no significant difference between the different seasons studied . The general order for nutrient release was K > N > P > Mg > Ca. These results are similar to the ones observed in former SM-CRSP studies in Bolivia with two tropical legume cover crops.
It is important to emphasize that this study was conducted in a 16-year old plantation. Although Herrera (1989)notes that aboveground biomass and ‘palmito’ production reaches an equilibrium when plantations are 3-4 years old, Bogantes (personal communication) reported only two harvests per year per plant in a five year old system, as compared with 4 harvests a year reported by DEMASA personnel. Additional biomass data currently under collection

Table 4. Estimated total foliar biomass and nutrient content added to the field, based on harvesting 5000 plants ha^{-1} four times a year, in a 16-yr old peach palm plantation at Guápiles, Costa Rica.

RAINFALL PERIOD	LEAF DRY WEIGHT PER PLANT¶	LEAF DRY WEIGHT LAND AREA§	NUTRIENT CONTENT N	P	K	Ca	Mg
	g $plant^{-1}$	t ha^{-1} yr^{-1}	---------- kg ha^{-1} yr^{-1} ----------				
S1	549	11.0	239	20	136	32	19
S2	590	11.8	286	24	156	59	30
S3	538	10.8	302	24	155	38	19
Mean	559	11.2	276	22	149	43	23

¶ Based on 5 leaves at each plant harvest.
§ Based on 5000 plants ha^{-1} and 4 harvests $plant^{-1}$ yr^{-1}.

Table 5. Nonlinear equations for residue decomposition and nutrient release pooled across three placement intervals, from heart of palm leaves at Guápiles, Costa Rica.

PARAMETER	EQUATION¶		$S_{y.x}$§	TIME FOR 50% RELEASE
				weeks
Dry matter	Asymptotic	$y=18.2+81.8e^{-0.14t}$	56.3	6.6
N	Asymptotic	$y=18.2+81.9e^{-0.30t}$	77.9	3.2
P	Asymptotic	$y=17.9+82.1e^{-0.18t}$	111.5	5.4
K	Single exp.	$y=105.0e^{-0.28t}$	57.5	2.7
Ca	Asymptotic	$y=20.6+74.0e^{-0.08t}$	531.6	12.2
Mg	Asymptotic	$y=16.4+83.6e^{-0.17t}$	181.7	5.5

¶ unit for y are % of nutrient or dry weight remaining; units for t are weeks.
§ $S_{y.x}$ = mean square error.

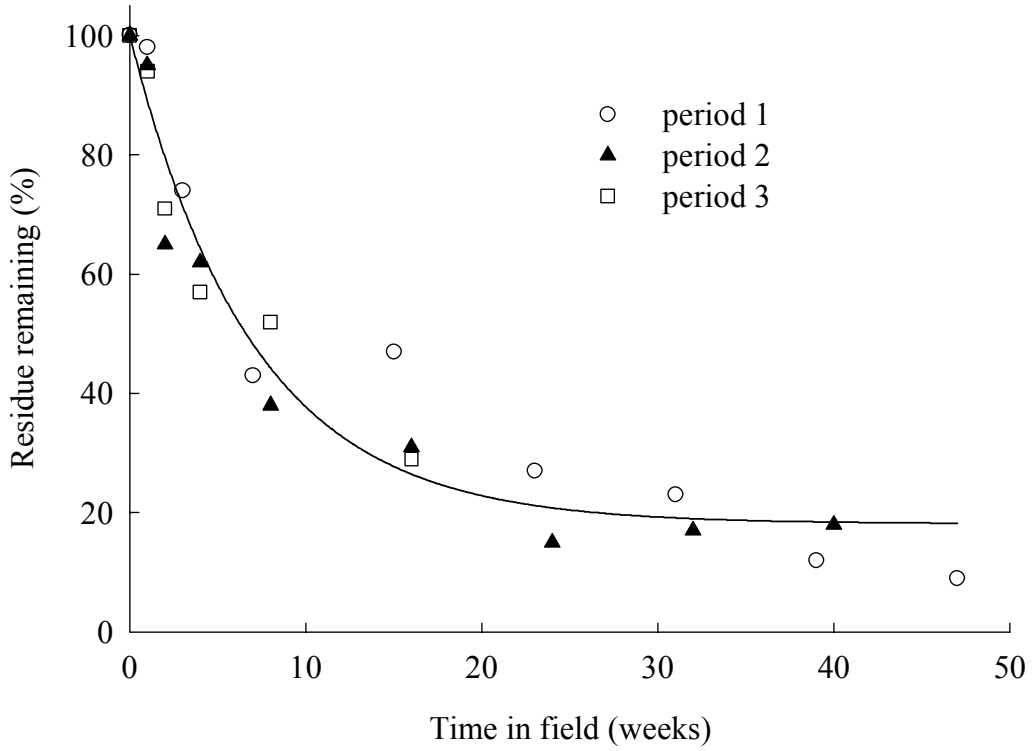

Figure 3. Peach palm leaf dry weight reduction in litter bags during different placement periods at Guapiles, Costa Rica.

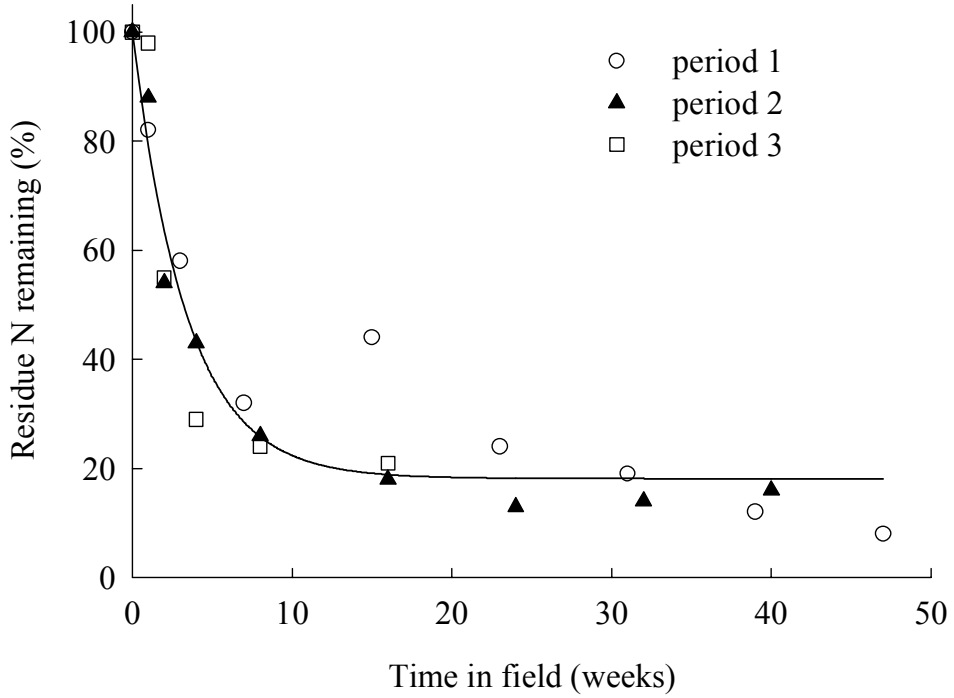

Figure 4. Nitrogen release from peach palm leaf residues during three placement periods at Guapiles, Costa Rica.

will help determine the equilibrium point mentioned by Herrera (1989), or the turning point in the exponential curve of plantation biomass production over time. Nutrient release rate of leaf residue from palmito harvests is expected to be similar in the initial years or in an "equilibrium" plantation, but the total derived from these tissue will vary strongly depending upon the harvest frequency.

b. Effect of peach palm litter on cation movement in Andisols - (UCR coordination by Lidieth Uribe with assistance from Nguyen Hue and Jot Smyth) This experiment at UCR complements detailed ongoing investigations which Hue is performing in laboratory facilities at the University of Hawaii (see report under Objective 2, output 1). The experiment was conducted in the greenhouse at the University of Costa Rica's Center for Agronomic Investigations. The soil was collected from the A horizon of an Andisol (pH 5.0, 1.17 cmol L^{-1} exchangeable acidity, 2.85 cmol L^{-1} Ca and 0.66 cmol L^{-1} Mg) and packed into PVC columns (60 cm length and 10.2 cm internal diameter) (Figure 5) with the following treatments applied to the soil surface:

i. lime as 2 t ha^{-1} $CaCO_3$,
ii. 10 t ha^{-1} peach palm residues,
iii. lime (2 t ha^{-1}) plus peach palm residues (10 t ha^{-1}), and
iv. control without lime our peach palm residues.

Figure 5. Setup of soil columns with device used for constant water supply.

There were four replicates of each treatment. After surface application of the treatments, soil columns were incubated for 2 weeks with moisture maintained at the equivalent of field water holding capacity.

A total of 39.2 cm of water was added to each column at a constant rate of 4.9 cm hr^{-1}. Water was added for 2 hrs/day for 4 consecutive days. A surface layer of 2 cm of quartz sand was added to each column to minimize treatment disturbance by water additions. Leachate passing through the columns was collected for 4 days for subsequent analysis. Columns were dismantled after 4 days and soil from the central 40-cm length of each column was divided into 10-cm segments. Soil from each segment was subjected to chemical analysis and used for a root growth bioassay.

An acid sensitive bean variety, 'Chirripo Rojo' was planted in soil from each column segment. However, variability in germination by this variety led to a second trial with the bean variety 'Negro Huasteco' after harvesting the initial bean variety. Plants were harvested after 11 days, roots were washed free of soil, air dried and stored at 4°C in 20% ethanol for subsequent measurement of root length. Digital images of roots were obtained with a desktop scanner after roots were stained with a red dye to enhance image contrast. Digital scan images are currently under interpretation for estimation of root length.

Movement of Ca applied on the surface of the 0-10 cm soil column segment down to the 10-20 cm soil depth was favored by the additions of lime to the soil column surface, either alone or in combination with peach palm residues (Table 6). However, Mg and K movement to the same soil depth were favored by the surface additions of peach palm residues, either along or in combination with 2 t lime ha^{-1}. Residue-enhanced movement was also evident at the 20-30 cm depth for K and the 30-40 cm depth for Ca and Mg. No significant changes were observed in soluble C, pH or exchangeable Al in any of the sub-surface column segments.

Chemical analysis of leachate collected during the 4-day period indicated no difference in dissolved C, pH or K levels (Table 7). However, leachate from columns receiving surface applications of residues or residues with lime had lower concentrations of Ca and Mg and lower electrical conductivities than columns used as the control or receiving lime alone. Approximately 50% of the Ca applied as lime moved below the 0-10cm depth. Possibly, all of the applied $CaCO_3$ was completely dissolved. Since soil pH did not change, no additional cation retention capacity was created in the surface soil segment (0-10cm), thus, allowing Ca^{2+} to move with the leaching water.

There were no differences in root fresh weight and top dry weight of bean cultivars grown in the different soil column segments (Table 6). Root length is still being determined from scanned digital images and will be reported in the future.

Table 6. Bean cultivar root fresh weight and top dry weight and chemical soil properties for each column segment after the leaching trial.

		ROOT FRESH WGHT.		NEGRO	SOL.		EXCHANGEABLE				EFF.	Al
DEPTH	**TREATMENT**	**CHIRRIPO**	**NEGRO**	**TOP WGHT**	**C**	**pH**	**Ca**	**Mg**	**K**	**Al**	**CEC**	**Satur.**
cm			----- g/pot -----		mg kg^{-1}			---------- cmol kg^{-1} ----------				%
10-20	Control	2.05	2.42	0.35	15	4.6	2.15	0.51	0.13	1.27	4.06	31
	Lime	2.12	2.36	0.35	19	4.7	3.11	0.53	0.11	0.96	4.71	21
	Residue	2.30	2.23	0.38	17	4.6	2.51	0.66	0.20	1.28	4.65	28
	L+R	2.02	2.32	0.39	17	4.6	3.46	0.86	0.22	1.21	5.75	21
	LSD 0.05:	ns	ns	ns	ns	ns	0.64	0.16	0.05	ns	0.79	8
20-30	Control	2.04	2.36	0.36	30	4.7	2.36	0.56	0.13	1.13	4.18	27
	Lime	2.30	2.33	0.39	20	4.6	2.53	0.59	0.13	1.27	4.52	28
	Residue	2.38	2.24	0.39	20	4.6	2.40	0.60	0.16	1.21	4.37	28
	L+R	2.19	2.39	0.39	18	4.6	2.68	0.67	0.20	1.25	4.80	26
	LSD 0.05:	ns	ns	ns	ns	ns	ns	ns	0.03	ns	ns	ns
30-40	Control	2.10	2.31	0.39	22	4.6	2.60	0.62	0.13	1.13	4.47	25
	Lime	2.26	2.44	0.41	18	4.6	2.61	0.62	0.13	1.21	4.56	27
	Residue	2.50	2.14	0.38	20	4.6	2.84	0.70	0.14	1.29	4.97	26
	L+R	2.51	2.41	0.39	19	4.7	2.90	0.70	0.14	1.28	5.02	26
	LSD 0.05:	ns	ns	ns	ns	ns	0.20	0.05	ns	ns	0.19	ns
40-50	Control	1.93	2.31	0.44	26	4.8	3.23	0.76	0.13	0.91	5.02	18
	Lime	2.30	2.31	0.38	22	4.7	3.13	0.76	0.21	0.99	5.09	20
	Residue	2.23	2.19	0.38	21	4.7	2.90	0.72	0.13	1.10	4.85	22
	L+R	2.07	2.48	0.38	25	4.7	3.21	0.81	0.15	0.96	5.12	19
	LSD 0.05:	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 7. Chemical composition of leachates collected after addition of 800 mL of water.

TREATMENT	DISSOLVED C	pH	K	Ca	Mg	EC
	mg L^{-1}		---------- mg L^{-1} ----------			MS cm^{-1}
Control	11.0	5.1	2.8	52.2	18.0	0.50
Lime	10.4	5.6	2.5	53.4	18.3	0.42
Residues	12.0	5.4	2.3	37.8	12.5	0.32
L + R	11.2	5.3	2.2	38.3	12.8	0.32
LSD 0.05:	ns	ns	ns	11.2	4.2	0.09

c. H/Al rhizotoxicity and Ca/Mg requirements for peach palm root growth - (supervised by Rafael Salas at UCR, with support from Nguyen Hue and Jot Smyth) the greenhouse and laboratory experiment is in the final phase of tissue analysis and data interpretation, but no report was provided for this year.

d. Biomass and nutrient accumulation with peach palm plantation age - (supervised by Eloy Molina at UCR and Antonio Bogantes at MAG, with support from Adrian Ares, Michael Wagger and Jot Smyth) this experiments seeks to fill part of the void in information on field export and recycling of biomass and accumulated nutrients through heart-of-palm harvests from mature peach palm plantations. The experiment was designed during Hue, Wagger and Smyth's visit to Costa Rica and 1998. Suitable fields of 4- and 8-year plantations were located at the Los Diamantes experiment station in January 1999; experimental setup began in April 1999.

The experiment contains six plots, each with 10 continuous plants, in both the 4- and 8-year plantations with the local 'Tucurrique' peach palm assession. Soil chemical data for composites samples from each plantation are shown in Table 8. Soils in both fields are mapped as Hapludands. 'Palmito' is harvested every 4 weeks across a period of 48 weeks. With each harvest the number of shoots are counted, cut into various components, weighed, and composite subsamples are taken from each plot for subsequent determination of moisture content and nutrient analyses on each plant component. Shoots are cut into leaves, rachis, petioles and stems (Figure 6). Stems are further divided into the commercial 'palmito' and what is locally called "field residue" and "industrial residue". Field residues comprises the outer stem sheaths and industrial residue comprises the base of the 'palmito'. With each harvest, excess tillers are also pruned from plants; fresh and dry weights of pruned tillers and their nutrient content were also determined by plot. Upon the final palmito harvest in week 48, plants in each plot with also be destructively sampled for aboveground biomass and nutrient content.

Biomass data has now been collected for the initial 28 weeks of sampling, whereas nutrient analysis has only been completed for the first 20 weeks. Number of harvested palmito, fresh

Table 8. Selected chemical soil properties at two depths in Hapludands for the 4- and 8-year peach palm plantations at 'Los Diamantes' experiment station, Guapiles, Costa Rica.

FIELD			KCl-EXTRACTABLE			OLSEN		ORG.
AGE	DEPTH	pH	Ca	Mg	Al	K	P	MAT.
years	cm		---------- $cmol_c$ L^{-1}			----------	mg L^{-1}	%
4	0-5	5.1	2.88	0.55	0.53	0.35	31.9	4.31
	5-20	5.3	2.99	0.50	0.32	0.27	22.8	3.87
8	0-5	4.9	2.68	0.59	0.55	0.32	12.2	12.95
	5-20	5.1	3.23	0.46	0.23	0.26	9.3	11.17

and dry weights of shoot components and pruned tillers averaged across the 8 initial harvests

Figure 6. Harvested palmito shoot subdivided into stem, rachis and leaves with petioles. Prunned tillers are in bottom right.

in each field are shown in Table 9. All data are presented on a hectare basis. High standard deviations for mean values reflect the absence of any harvested palmito for plants within a plot among the 6 replicates at several of the 8 sampling dates in both plantations. Palmito shoots are harvested when they reach a given size, based on stem diameter or stage of development for a given leaf number. Dry weights of palmitos and the ratios between total dry weight and palmito weight were greater for the 8-year than for the 4-year plantation. In both plantations the palmito biomass exported from the field corresponds to less than 10% of the harvested material and pruned tillers.

Average concentrations of macronutrients in harvested and pruned peach palm components are shown in Table 10. Distribution of nutrient uptake in harvested shoot components, based on mean values for the six initial sampling dates, indicated that most of the N (68%) was in the harvested leaves (Figure 7). Phosphorus and K are more evenly distributed than N among

plant components, with leaves accounting for about 30% of these nutrients. Upon completion of this experiment in April 2000, the data base will be incorporated into NuMaSS.

Table 10. Average macronutrient concentrations for harvested and pruned plant components during the six initial sampling dates in 4- and 8-year peach palm fields at Los Diamantes experiment station, Guapiles, Costa Rica.

FIELD AGE	PLANT COMPONENT	N	P	Ca	Mg	K	S
years		----------	----------	---------- %	----------	----------	----------
4	Palmito	2.53	0.62	0.43	0.45	3.22	0.28
	Leaves	2.35	0.23	0.42	0.23	1.25	0.22
	Rachis	0.48	0.25	0.22	0.11	1.51	0.07
	Petiole	0.38	0.25	0.22	0.14	1.66	0.06
	Field Residues	0.63	0.28	0.36	0.19	1.72	0.15
	Industrial Residues	0.65	0.25	0.31	0.17	1.59	0.14
	Pruned Tillers	1.66	0.24	0.28	0.16	2.12	0.20
8	Palmito	2.84	0.59	0.41	0.42	2.70	0.31
	Leaves	2.73	0.23	0.46	0.27	1.06	0.32
	Rachis	0.59	0.19	0.24	0.13	1.27	0.07
	Petiole	0.53	0.19	0.25	0.11	1.20	0.08
	Field Residues	0.81	0.24	0.38	0.22	1.25	0.21
	Industrial Residues	0.70	0.21	0.34	0.18	1.26	0.16
	Pruned Tillers	1.95	0.24	0.34	0.22	1.93	0.23

Table 9. Harvested palmito and fresh and dry weights of shoot components and pruned tillers averaged across the 8 initial harvest in 4- and 8-year peach palm plantations at Los Diamantes experiment station, Guapiles, Costa Rica. All data are expressed on a hectare basis. (Number of observations for each mean value =48)

FIELD AGE	HARVESTED PALMITOS	WEIGHT TYPE	PALMITO	LEAVES	RACHIS	PETIOLES	RESIDUES[b] FIELD	RESIDUES[b] INDUST.	PRUNED TILLERS	TOTAL
	no. ha^{-1}		---------- kg ha^{-1} ----------							
4	885±963	Fresh	514±587[a]	1006±1097	518±619	718±753	1130±1394	423±565	96±207	4402±4736
		Dry	59±71	372±402	137±162	168±177	177±220	71±96	20±44	1003±1066
8	1198±1762	Fresh	561±757	1528±2426	923±1699	782±1128	2829±6246	528±846	510±1421	7651±12833
		Dry	55±67	503±837	226±410	203±270	383±854	79±126	68±180	1516±2481

[a] Values following the ± are standard deviations of the mean.

[b] Field and industrial residues from the palmito stem.

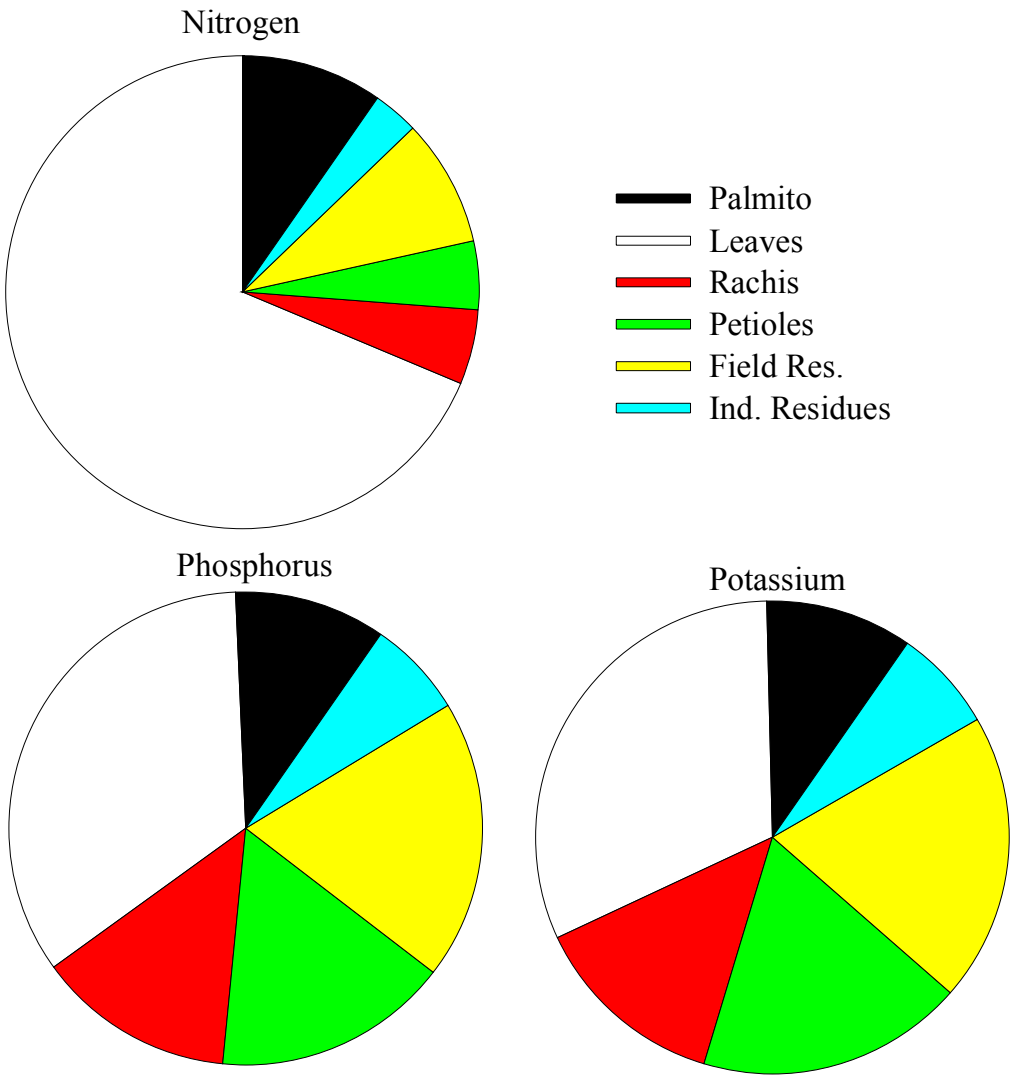

Figure 7. Distribution of total accumulated N (20.7 kg ha^{-1}), P (4.2 kg ha^{-1}) and K (24.4 kg ha^{-1}) in harvested shoot components for the 4-year peach palm plantation. Values are averaged across the six initial sampling dates.

e. N fertilization field trial - (supervised by Eloy Molina and Gabriela Soto at UCR and Antonio Bogantes at MAG, with support from Adrian Ares, Shaw Reid and Jot Smyth) fertilizer N is one of the major inputs for farmers growing peach palm for palmito production; previous surveys and reports from Costa Rica indicate annual applications as high as 400 kg N ha^{-1}, although there are no field trials or diagnostic plant indicators which have been calibrated for fertilizer N recommendations. The site for the experiment was selected in April 1999 on Hapludands at the 'Los Diamantes' experiment station near Guapiles. The field is 5-years-old with a traditional 2x1m spacing among plants. Due to poor prior management of plant shoots, the field was cut with a powersaw at soil surface level in

November 1998. This radical plantation treatment is often practiced in the region and allows rapid regrowth to an established root system. Since last April, Molina and Bogantes have provided standard management and fertilization (except N) of the plantation to develop uniformity in number of tillers per plant.

The two-year experiment with three replicates will be initiated in January 2000 with treatments and experimental protocol built on the knowledge base developed from other project activities in Costa Rica. Annual fertilizer N rates, as NH_4NO_3, will be 0, 50, 100, 200 and 400 kg ha^{-1}, band-applied to the surface in equal split applications every two months. One additional treatment, with 100 kg N ha^{-1} as urea, will provide comparison among the two main fertilizer N sources used in Costa Rica. Crop residues, upon each 'palmito' harvest, will be left in the field for all of the treatments described above. In an additional zero-N treatment, however, crop residues will be removed from the field upon each harvest. Comparisons between zero-N treatments, with and without maintenance of crop residues, will enable assessments of soil N contributions both from native soil reserves and from recycled crop residues.

'Palmito' and pruned crop residues will be harvested, counted, weighed and subsampled for nutrient analysis once per month. Diagnostic leaf tissue will be sampled and analyzed once every 3 months; at the same time growth measurements will be taken to predict crop growth response to N via allometric equations. Once every 12 months, above-ground components of two peach palm plants in each replicate will be destructively sampled, weighed and analyzed for nutrients.

Soil in each treatment replicate will be sampled and analyzed for KCl-extractable NH_4- and NO_3-N at three depths (0-5, 5-20 and 20-40 cm) at the start of the experiment, after the third split N application and, thereafter, every N application. Microbial biomass will be measured at 8 and 45 days after N applications in 0-5cm soil samples for treatments receiving 0, 200 and 400 kg N ha^{-1}. Suction lysimeters will be installed in two replicates each of treatments receiving 0, 200 and 400 kg N ha^{-1}; samples will be drawn and analyzed for nutrients at 7, 25 and 45 days after each N application.

f. Growth and nutritional response of peach palm to P additions - (supervised by Eloy Molina, Rafael Salas and Jimmy Boniche at UCR, with support from Adrian Ares and Russell Yost) the objective of this experiment is to determine growth response of peach palm to P additions and both soil and foliar critical P levels. The site for the on-farm experiment is located within the farm "Agropecuaria Río Frijoles" in Caño Negro, San Carlos, at about 200 m elevation. Mean annual rainfall is about 4000 mm. The soil has clay contents ranging between 29 to 57 % with pH ranging between 4.2 and 4.4 (Table 11). Soil extractable P by the modified Olsen method averaged 2.7 mg kg^{-1} at 0-5 cm depth and 1.6 mg kg^{-1} at 5-20 cm depth. In addition to low P values, a preliminary survey showed that foliar P levels were also low (0.15 % for most plants and 0.13 % for plants with symptoms of deficiency) compared with the tentative foliar P critical levels proposed for Costa Rica.

The experiment started August 1999 and is proceeding as scheduled. There are six treatments in four replicates arranged in a randomized complete block design. Each plot contains 100 plants at a 2x0.5 m spacing. Treatments include a control with no added P, and P additions to raise soil P levels to 5, 10 and 20 mg kg^{-1} based on laboratory estimates of P buffer

Table 11. Baseline soil data for the experimental site at San Carlos, Costa Rica.

REP	DEPTH	pH	Ca	Mg	K	ACIDITY	ECEC	P	Cu	Fe	Mn	Zn	OM	CLAY
	cm		---------- $cmol_+ L^{-1}$ ----------					---------- $mg L^{-1}$ ----------					------- % -------	
1	0-5	4.4	9.95	2.69	0.26	2.38	15.28	2.5	12.5	22	46	2.0	3.5	50
	5-20	4.3	8.08	2.90	0.15	2.93	14.06	1.3	15.0	29	55	2.1	4.0	52
2	0-5	4.3	8.29	2.33	0.24	6.71	17.57	2.8	15.1	35	51	2.4	5.1	30
	5-20	4.4	8.78	2.92	0.14	2.52	14.36	1.4	16.2	32	54	2.5	4.2	30
3	0-5	4.3	9.13	2.76	0.23	3.37	15.49	2.5	17.8	41	69	2.9	5.3	51
	5-20	4.4	8.75	3.04	0.13	3.24	15.16	1.4	16.6	33	53	2.3	3.9	49
4	0-5	4.2	8.54	2.63	0.38	2.38	13.93	3.1	15.5	34	66	2.7	5.7	56
	5-20	4.2	8.05	2.58	0.18	2.11	12.92	2.5	14.3	31	57	2.1	4.0	57

coefficients. Two additional treatments contain P additions to supply crop requirements, assuming 25 and 75% nutrient uptake efficiency. Additional blanket nutrient applications include 250 kg N ha^{-1}, 125 kg K ha^{-1}, 36 kg Mg ha^{-1} and 60 kg S ha^{-1}.

Foliar P content on the 3rd pinnate (adult) leaf and the 6th leaf will be determined at 0 (before P additions) 3, 6, 9, 12, 15, 18 and 24 months. Litter P content will be determined on selected samplings. Depending on availability of funds, roots will be occasionally sampled for nutrient content and mycorrhizae infection. Stem basal diameter, height, number of leaves and yield of palmito are determined monthly. Soil P, by the Modified Olsen and Mehlich-III methods will be determined at the same dates as for leaf analyses on samples collected at 0-5 and 5-20 cm depths. Labile, moderately labile and moderately resistant organic P are determined by extractions with 0.5 M $NaHCO_3$, 1.0 M H_2SO_4 and 0.5 M NaOH to determine the diagnostic value of these pools.

Data analysis will begin in early 2000. Preliminary observations suggest that the stand is responding positively to P additions. This experiment represents the first experiment in which P additions to peach palm were based on soil P buffer coefficients.

g. Allometric equations, biomass and nutrient accumulation through time for peach palm - (supervised by Adrian Ares with assistance of Eloy Molina and Jimmy Boniche at UCR) in order to incorporate a peach palm component in NuMaSS, procedures must be developed and calibrated to calculate biomass and nutrient accumulation for plantations of different ages. Allometric equations for peach palm were generated by harvesting 25 plant units (locally called "cepas") in a 10-year old stand on an Andisol in Guapiles, Costa Rica. For the period 1964-98, mean annual rainfall was 4577 mm and mean air temperature about 24.4° C in the nearby Agricultural Station Los Diamantes at 249 m.a.s.l. Stem basal diameter, number of leaves, total height and height to the fork were recorded for each shoot. The shoots were separated into stem, petiole and foliage (rachis plus leaflets) and these portions were weighed in the field. Subsamples of each fraction were randomly collected for determining dry weights.

Nonlinear multiplicative models were used for estimating total shoot and component (foliage, petiole and stem) biomass. The basic equations were:

[1] $Y = b\, X_1^{c}\, \varepsilon$

[2] $Y = b\, X_1^{c}\, X_2^{d}\, \varepsilon$

where Y = total or component biomass; X_i = plant dimension variable; b, c and d = model parameters; and ε = error term. The nonlinear equations were transformed into linear regression equations by taking the logarithm of both sides of the equation. The equations were then corrected for logarithmic bias by calculating a correction factor (CF).

Results showed that stem basal diameter was the best predictor of total, foliage, petiole and stem biomass followed by height to the fork. Univariate models explained between 69 to 92% of the variance in biomass. Number of leaves per shoot was a poor predictor of biomass. A model combining stem basal diameter and height to the fork did not increase significantly the percentage of variance explained by the allometric model (Table 12).

Table 12. Allometric equations to estimate biomass of peach palm shoots as a function of stem basal diameter (D) and height to the fork (H) in univariate ($Y = b X^c$) and bivariate ($Y = bX^cX^d$) models.

VARIABLE	INTERCEPT	SLOPE © or d)	RESID. M. SQ.[a]	r^2	EXPO-NENTIAL[b]	CF	CORRECTED EXPONENTIAL
			---------- Total dry weight (n = 145) ----------				
D	2.034	2.342	0.094	0.92	7.645	1.048	8.011
H	-2.970	2.102	0.179	0.85	0.051	1.094	0.056
D and	0.642	1.800	0.085	0.93	1.900	1.043	1.982
H		0.545					
			---------- Foliage dry weight (n = 129) ----------				
D	1.477	2.328	0.118	0.87	4.380	1.061	4.647
H	-3.343	2.055	0.200	0.78	0.035	1.105	0.039
D and	0.107	1.820	0.110	0.88	1.113	1.057	1.176
H		0.526					
			---------- Petiole dry weight (n = 129) ----------				
D	0.938	1.953	0.170	0.76	2.555	1.089	2.782
H	-3.157	1.736	0.221	0.69	0.042	1.117	0.047
D and	-0.381	1.464	0.163	0.78	0.683	1.085	0.741
H		0.507					
			---------- Stem dry weight (n = 130) ----------				
D	0.306	2.560	0.114	0.89	1.358	1.059	1.438
H	-5.123	2.290	0.197	0.82	0.006	1.104	0.006
D and	-1.500	1.892	0.099	0.91	0.223	1.051	0.234
H		0.693					

[a] Residual mean square (MSE)

[b] (b = exp (slope))

Stem basal diameter and height to the fork were measured on all plants within 0.02-ha plots in peach palm stands in the Atlantic region. The stands were either on Andisols or Ultisols. Stands on Andisols were 5, 7, 10, 15 and 20 years-old while stands of age 1, 2, 4, 9 and 20 were measured on Ultisols. Data on biomass accumulation until age 137 days were available from a previous study in the same area. Additional stands will be measured soon to complete an age series from 1 to 20 years. Foliar samples (3rd and 6th leaves, petioles and stems) and soil samples (at 0-5 and 5-20 cm depth) were collected in each stand and they are being analyzed at the UCR laboratory. Results indicate that total stand biomass seems to stabilize at about 6 t ha^{-1} which translates to 10-12 kg P ha^{-1} sequestered in the areal biomass (Figure 8). There was no obvious differences in biomass accumulation between stands on Ultisols and on Andisols and, therefore, data were pooled in a single function. The range in average weight of shoots was small (0.24-0.32 g) suggesting little competition between shoots within plants.

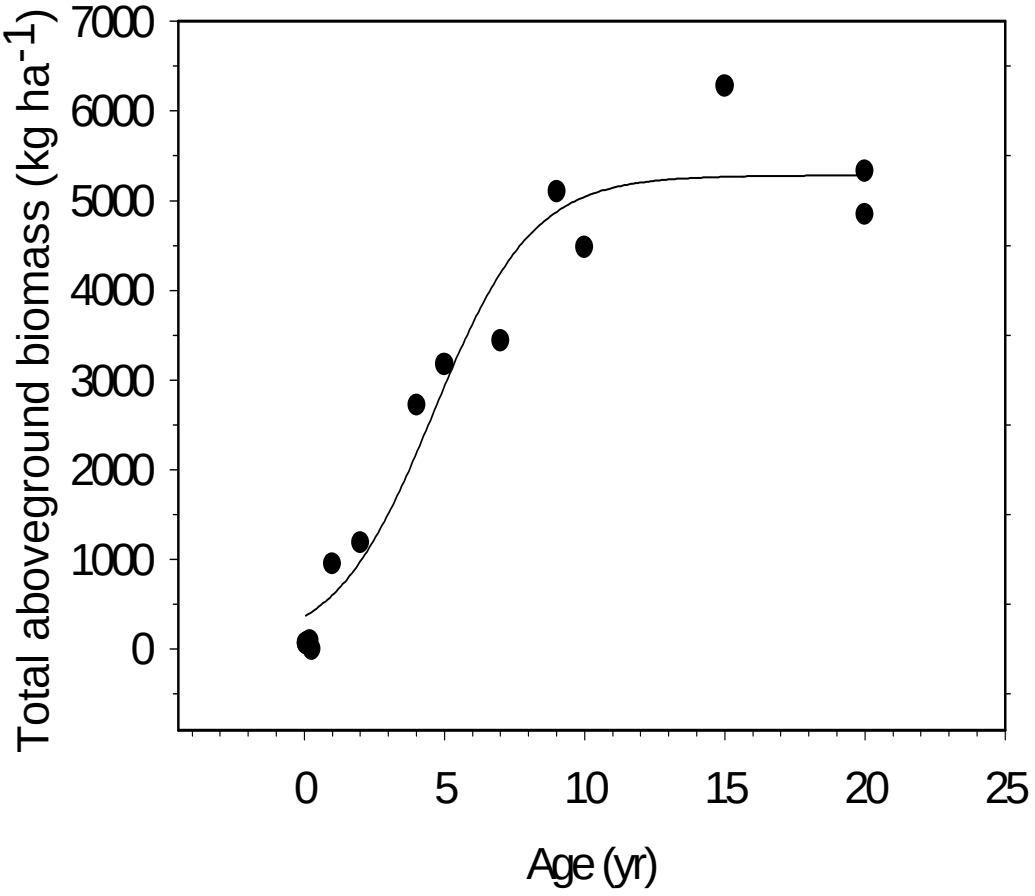

Figure 8. Biomass accumulation through time in peach palm stands in the Atlantic region of Costa Rica.

Most of the sampled stands had relatively low density (3100-4100 plants ha^{-1}) because these densities were traditionally used in Costa Rica stands. In new plantations, however, densities of 10, 000 plants ha^{-1} are not uncommon. In these plantations, stand biomass stabilization is likely reached at an earlier age than in low-density stands. Thus, there may be two main patterns of biomass accumulation depending of stand density.

2. *Mali*

Midterm survey - (conducted under the supervision of Frank Smith, N.C. State Univ., Lloyd Hossner, Texas A&M Univ., and Mamadou Doumbia, IER) Smith and Hossner traveled to Mali in June to initiate the mid-term survey, which included interviews with farmers, agri-businesses and various government agencies in both the Cinzana region and Bamako. Completion of the survey report is still dependent upon receiving statistical and price data which IER collaborators agreed to collect and send to Frank Smith. Once the survey is completed a report will be posted on the projects website.

Ongoing field experiments -

a. Core trials to evaluate and adjust NuMaSS predictions in Cinzana Alfisols - (conducted on-site by M. Doumbia, A. Coulibaly, Z. Kouyate, A. Sidibe with support from F. Hons, A. Juo, D. Israel, and S. Reid) two replicated experiments with incomplete factorials of lime, N and P applications are being conducted at Cinzana. Millet and cowpea are rotated between the experiments each year, thus enabling the comparison of the two crops within years and the legume-grass rotation effect between years. To keep track of each trial, the experiment planted to millet in 1998 is referred to as the "millet core experiment", and the "cowpea core experiment" refers to the trail planted to cowpea in 1998. In both 1998 and 1999 the millet cultivar was Sanioba 03 and the cowpea cultivar was Sutiva 2. *Bradyrhizobium* inoculant for cowpea was only available in the 1999 season. During this year IER collaborators have provided preliminary yield, plant and soil data for the 1998 season and yield data for the 1999 season.

Each trial was designed to contain three rates of N, P and lime with the highest rate corresponding to the NuMaSS predictions for the targeted crops based on surface soil chemical analyses. The intermediate rates of N, P and lime would correspond to half of the NuMaSS predictions and would test how well the software recommendations approached nutrient needs for optimum yields. Actual rates of N, P and lime applied to each experiment in the initial 1998 season are shown in Table 13. No fertilizer N was applied to either experiment because it was not available in the region. For the cowpea core experiment this only affected two treatments (Table 16) wherein crop response with and without fertilization would be used to assess biological N_2 fixation. In the millet core experiment, however, millet response to applied P and lime may have been limited by insufficient N supply from native soil reserves (Table 15).

In the 1999 season fertilizer N was applied as originally planned to the ensuing cowpea and millet crops (Table 14), but P applications negated the designed gradient in available soil P for both experiments. Fertilizer P was applied to all treatments based on NuMaSS predictions to raise Bray-1 soil test P levels to that for optimum yield (i.e. P2 treatments). Thus, zero-P treatments (P0) and intermediate P treatments (P1) received amounts of fertilizer P to obtain the same Bray-1 soil test P levels as the high P treatment (P2). Residual soil P levels for most of the high P treatments (P2) were above or near the level recommended by NuMaSS for optimum yield and, therefore, received no fertilizer P. No lime was applied in the 1999 season because pH of limed treatments remained above a value of 5.0.

Table 13. Application rates of N, P (as triple superphosphate) and lime (as Diamou calcitic lime) to treatments in the cowpea and millet core experiments prior to planting in the 1998 season.

TREATMENT LEVELS[a]	AMOUNTS APPLIED	
	COWPEA EXPERIMENT	MILLET EXPERIMENT
	---------- kg ha^{-1} ----------	
N0	0	0
N1	0	0
N2	0	0
P0	0	0
P1	8.3	6.5
P2	16.5	13.0
L0	0	0
L1	900	900
L2	1810	1810

[a] 0 = no applied fertilizer or lime; 1 = 50% of the level recommended by NuMaSS; 2 = 100% of the amount recommended by NuMaSS.

Table 14. Application rates of N (as urea) and P (as triple superphosphate) to treatments in the cowpea (cropped to millet) and millet (cropped to cowpea) core experiments prior to planting in the 1999 season. No lime was applied to either experiment in this season.

COWPEA CORE EXPERIMENT			MILLET CORE EXPERIMENT		
TREATMENT	N	P	TREATMENT	N	P
	----- kg ha^{-1} -----			----- kg ha^{-1} -----	
N0P0L0	0	9.0	N0P0L0	0	8.3
N2P0L2	71	5.7	N0P0L2	0	7.0
N2P1L2	71	6.4	N0P1L2	0	8.0
N2P2L2	71	0	N0P2L2	0	7.2
N2P2L0	71	0	N0P2L0	0	7.2
N2P2L1	71	9.0	N0P2L1	0	5.7
N2P1L1	71	3.6	N0P1L1	0	3.0
N0P2L2	0	0.5	N2P2L2	71	2.0
N1P2L2	35.5	6.1	N0P2L2	0	0
N0P2L2[a]	0	1.7	N1P1L1	35.5	3.4
N1P1L1	35.5	1.5			

In the absence of fertilizer N, millet yields in the 1998 season were significantly higher than for the control treatment (N0P0L0) when P was applied at the highest level in the presence of lime (Table 15). There was no detectable yield advantage to applications of more than 0.9 t ha^{-1} of lime. There were no significant differences among treatments in N and P concentrations of millet plant components. Neither cowpea yields nor plant N and P concentrations were affected by P and lime treatments in the 1998 season (Table 16).

In the 1999 season there was a significant reduction in cowpea grain yield when fertilizer N was applied at the rate of 35.5 kg ha^{-1} (Table 15). Similarity in yields among all other treatments is probably related to the erroneous adjustment of soil available P in all treatments to that corresponding the high P level (P2) prior to planting this crop. Nevertheless these data suggest no yield advantage with cowpea to the residual effects of lime applied in the previous season, when P supply is adequate.

Millet yields in the 1999 season, following cowpea in the previous season and upon adjusting P supply to the highest level for all treatments, were not affected by N and lime treatments (Table 16). However, significantly greater millet yields were obtained for the sole treatment where stover from the previous crop was maintained, rather than exported, from the field.

Maintenance of soil pH values above 5.0 in most limed plots, at harvest of both crops in the 1998 season, was the basis for the decision to not apply additional lime prior to planting crops in the 1999 season (Table 17). The effect of the applications of calcitic Diamou lime on surface soil (0-15cm) Ca levels is evident in both experiments. Bray 1-extractable soil P levels in all millet treatments which yielded more than 1.8 t ha^{-1} (Table 15) were > 7.4 mg kg^{-1} as compared with 6.0 mg kg^{-1} in the control treatment.

Table 15. Millet grain yield and N and P contents of plant tissues in the 1998 season, and subsequent cowpea yield in the 1999 season for lime, N and P treatments in the "millet" core experiment in Haplustalfs at the Cinzana Station, IER, Mali.

MILLET - 1998 SEASON								COWPEA - 1999 SEASON	
TREAT-	GRAIN	LEAF		STALK		GRAIN		TREAT-	GRAIN
MENT	YIELD	N	P	N	P	N	P	MENT	YIELD
	kg ha^{-1}	---------- % ----------							kg ha^{-1}
N0P0L0[a]	1208 c	1.21	0.33	0.40	0.15	1.38	0.62	N0P2L0	526 a
N0P0L2	1542 bc	1.07	0.28	0.33	0.09	1.34	0.72	N0P2L2	403 ab
N0P1L2	1523 bc	1.07	0.29	0.31	0.10	1.40	0.67	N0P2L2	539 a
N0P2L2	2310 a	1.11	0.32	0.40	0.20	1.31	0.69	N0P2L2	433 ab
N0P2L0	1477 bc	0.09	0.26	0.37	0.12	1.30	0.68	N0P2L0	394 ab
N0P2L1	1977 ab	0.90	0.27	0.36	0.14	1.35	0.72	N0P2L1	456 ab
N0P1L1	1546 bc	0.81	0.26	0.39	0.20	1.33	0.66	N0P2L1	446 ab
N0P2L2	1824 ab	0.89	0.28	0.31	0.11	1.30	0.71	N2P2L2	446 ab
N0P2L2	1884 ab	0.92	0.28	0.52	0.19	1.27	0.74	N0P2L2[c]	337 ab
N0P1L1	1519 bc	0.93	0.29	0.40	0.18	1.26	0.70	N1P2L1	380 b
Mean	1681	0.90	0.29	0.38	0.15	1.32	0.69		436
CV (%)	18	15	14	24	37	7	9		21

[a] Level 0 = no application of N, P or lime; Level 1 = 50% of amounts recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during the 1999 season soil P was erroneously adjusted to Level 2 in all treatments. Lime was only applied in the 1998 season.

[c] The only treatment inoculated with a mixture of two efficient *Bradyrhizobium* strains from Zimbabwe, when planted to cowpea.

Dan Israel traveled to Mali at cowpea flowering stage in both the 1998 and 1999 seasons to assist in assessment of N fixation in the core experiments. Measurements of nodule number and weight were taken on one hill of plants each from two rows in all plot replicates of selected treatments (Table 18). Plants were well nodulated in the 1998 season, indicating a favorable level of infective bradyrhizobia indigenous to the soil. Most nodules in both seasons were reddish brown to pink in the infected zone which indicated some level of N fixation activity.

Table 16. Cowpea grain yield and N and P contents of plant tissues in the 1998 season, and subsequent millet yield in the 1999 season for lime, N and P treatments in the "cowpea" core experiment in Haplustalfs at the Cinzana Station, IER, Mali.

COWPEA - 1998 SEASON					MILLET - 1999 SEASON	
TREAT-MENT	GRAIN YIELD	STOVER N	STOVER P	GRAIN N	TREAT-MENT	GRAIN YIELD
	kg ha^{-1}	---------- % ----------				kg ha^{-1}
N0P0L0[a]	649	1.98	0.37	3.89	N0P2L0	1123 b
N0P0L2	564	2.30	0.45	4.00	N2P2L2	1469 ab
N0P1L2	606	2.35	0.49	4.06	N2P2L2	1392 ab
N0P2L2	746	1.89	0.44	4.23	N2P2L2	1586 ab
N0P2L0	777	2.02	0.44	4.38	N2P2L0	1534 ab
N0P2L1	658	2.22	0.42	4.60	N2P2L1	1491 ab
N0P1L1	574	2.05	0.39	4.52	N2P2L1	1509 ab
N0P2L2	678	2.10	0.47	4.13	N0P2L2	1383 ab
N0P2L2	790	2.00	0.47	3.87	N1P2L2	1457 ab
N0P2L2[b]	1129	1.90	0.37	4.95	N0P2L2[b]	1759 a
N0P1L1	559	1.99	0.44	3.89	N1P2L1	1247 b
Mean	702	2.07	0.43	4.23		1450
CV (%)	42	20	23	15		17

[a] Level 0 = no application of N, P or lime; Level 1 = 50% of amounts recommended by NuMaSS; Level 2 = 100% of amounts recommended by NuMaSS; during the 1999 season soil P was erroneously adjusted to Level 2 in all treatments. Lime was only applied prior to planting in the 1998 season. Fertilizer N was not applied to selected cowpea treatments, as originally planned.

[b] The only treatment where cowpea stover, when planted in the experiment, is left as residue in the field.

In the 1998 season nodule number and mass in treatments without fertilizer P were significantly lower than in the N0P2L2 treatment (Table 18). However nodule number and mass were similar for the N0P2L0 and the N0P2L2 treatments. These results indicate that P availability, at this location, is more limiting to the development of the symbiotic system than soil acidity. Although only significant at the 0.06 probability level, whole plant dry weight in the N0P0L2 treatment was 28% less than that for the N0P2L2 treatment.

In the 1999 season P and residual lime application had no significant effect on nodule number or mass (Table 18). Nodule color in the central cortex indicated the presence of some

Table 17. Soil chemical properties after crop harvest in the 1998 season for the "millet" and "cowpea" experiments as influenced by N, P and lime treatments.

MILLET - 1998 SEASON					COWPEA - 1998 SEASON				
TREAT-	pH in	BRAY 1	EXCH.		TREAT-	pH in	BRAY 1	EXCH.	
MENT	H_2O	P	Ca	Mg	MENT	H_2O	P	Ca	Mg
		mg kg^{-1}	$cmol_c$ kg^{-1}				mg kg^{-1}	$cmol_c$ kg^{-1}	
N0P0L0[a]	4.7	6.0	0.62	0.41	N0P0L0	4.7	4.4	0.44	0.17
N0P0L2	5.0	5.7	1.04	0.48	N0P0L2	5.6	5.8	1.29	0.05
N0P1L2	5.0	5.5	0.80	0.39	N0P1L2	5.3	6.8	0.78	0.10
N0P2L2	5.6	7.6	1.72	0.58	N0P2L2	4.9	10.3	1.04	0.16
N0P2L0	4.9	6.6	0.63	0.44	N0P2L0	5.6	9.9	0.49	0.08
N0P2L1	5.2	7.4	1.76	0.44	N0P2L1	4.9	6.2	0.58	0.13
N0P1L1	5.2	8.4	1.24	0.51	N0P1L1	4.9	6.6	0.59	0.06
N0P2L2	5.4	9.3	1.50	1.19	N0P2L2	5.2	11.2	0.69	0.06
N0P2L2	5.3	11.2	1.12	0.49	N0P2L2	5.6	6.4	1.19	0.10
--	--	--	--	--	N0P2L2[b]	5.5	8.7	0.93	0.17
N0P1L1	5.4	8.3	1.18	0.55	N0P1L1	5.3	8.2	0.69	0.09
CV (%)	13	28	71	113		13	50	74	112

[b] The only treatment where cowpea stover, when planted in the experiment, is left as residue in the field.

functional N fixation. Although non-significant, there was a higher mean nodule number with the inoculation. Multiple hills were sampled in border rows of the N0P2L2 treatments with and without inoculation, to determine if the introduction of the efficient *Bradyrhizobium* strains decreased the variation in nodulation traits (Table 19). Inoculation resulted in a small reduction in variation of nodule number and mass, relative to plants without inoculation, but coefficients of variation for these measurements were still very high (67 and 58%, respectively). There was no direct method available on-site to determine whether inoculant strains competed effectively with indigenous organisms for nodule formation. Unless crop N accumulation data (when completed) conflicts with field nodule measurements, these results indicate that soils in the core experiments have bradyrhizobial populations that effectively infect and fix N with cowpea.

Table 18. Influence of P and lime (and inoculation in 1999) on nodulation of cowpea in the 1998 and 1999 crop seasons for core experiments at Cinzana, Mali.

TREAT-MENT	NODULE NUMBER '98	NODULE NUMBER '99	NODULE FRESH WEIGHT '98	NODULE FRESH WEIGHT '99	WHOLE PLANT DRY WEIGHT 1998
	----- no./hill -----		---------- g/hill ----------		
N0P0L0[a]	50	28	1.29	0.99	20.0
N0P0L2	56	35	1.78	1.06	23.3
N0P1L2	98	34	2.13	1.23	27.6
N0P2L2	107	36	3.48	1.31	32.3
N0P2L0	95	23	2.88	0.69	28.7
N0P2L1	84	40	2.80	0.94	28.1
N0P1L1	93	25	3.27	0.70	23.7
N0P2L2[b]	--	46	--	1.19	--
$LSD_{0.05}$	37	NS	0.96	NS	NS

[a] For 1999 season no lime was applied; during the 1999 season soil P was erroneously adjusted to Level 2 in all treatments.
[b] The only treatment inoculated with a mixture of two efficient *Bradyrhizobium* strains from Zimbabwe in the 1999 season; no inoculant was available in the 1998 season.

Table 19. Variation in cowpea nodulation in plots with high P and lime in the 1999 season, with and without inoculation of a mixture of *Bradyrhizobium* isolates from Zimbabwe.

TREAT-MENT	INOCU-LANT	HILLS SAMPLED	NODULE NUMBER MEAN	NODULE NUMBER SD	NODULE NUMBER CV	NODULE FRESH WEIGHT MEAN	NODULE FRESH WEIGHT SD	NODULE FRESH WEIGHT CV
			no/hill		%	g/hill		%
N0P2L2	yes	32	33	22	67	0.88	0.51	58
N0P2L2	no	27	22	17	77	0.89	0.90	101

b. Comparison of Ca sources and Ca-Mg movement in Cinzana soils - (conducted on-site by A. Coulibaly with support from L. Hossner and A. Juo) kaolinitic Alfisols occupy large agricultural regions in sub-Saharan Africa. Rapid acidification of these poorly buffered soils following N fertilization and cropping has been a primary cause of soil degradation. Experiments to compare Ca sources and quantify Ca and Mg movement on a sandy soil at the summit and a clayey soil at the toeslope of a Cinzana toposequence have completed their second cropping season with millet. Treatments for both experiments consist of a control (without added Ca) and the factorial combination of three Ca sources (Tilemsi phosphate

rock, gypsum and Diamou calcitic lime) applied at 3 different rates. IER collaborators describe application rates as those corresponding to 0.5, 1 and 2 times the lime requirement based on exchangeable acidity. Presumably, the gypsum and Tilemsi PR are applied at rates equivalent in Ca content to those of the Diamou lime-based lime requirements. There are three replicates for each treatment in both experiments. Calcium sources were only applied before the 1998 millet crop. In the 1999 season, all plots received 100 kg ha^{-1} of a local cereal fertilizer blend (15-15-15); preliminary reports give no indication whether N, P and/or K was applied in the 1998 season and, if so, how much. Soil samples were collected at four depth increments (0-15, 15-30, 30-60 and 60-90 cm) in all plots of both experiments prior to application of Ca treatments in 1998 and after harvesting millet in 1998 and 1999. Currently, however, soil analysis has only been completed for samples collected after the 1998 crop at the 0-15cm depth.

Grain yield and soil pH, Ca and Mg data for selected treatment mean comparisons are shown in Table 20. In the 1998 seasons millet yield, averaged across all treatments, was higher in the sandy soil than in the clayey soil despite an acid pH and less soil Ca and Mg in the former. In the 1999 season yields were higher in the clayey soil and contrast with previous experiments comparing sandy and clayey soils in the toposequence on the Cinzana Station. Superior yields in sandy soils are often attributed to better oxidized conditions than in clayey soils, but direct effects of differential clay content on soil P availability can hopefully be assessed upon completion of pending soil analyses. Superior millet yield in the 1999 season in both soils is consistent with an earlier planting data and better rainfall distribution than in the 1998 season.

Among Ca sources, ranking of millet yields in both years followed the same trend: Tilemsi PR > gypsum > Diamou calcitic lime (Table 20). Millet yields with Tilemsi PR exceeded yields for the limed treatments by at least 18% in both years. Yield response among rates of applied Ca decreased in 1999 and may be indicative of a short-lived residual effect to the applications made only before planting in 1998. In 1998 a 29% yield increase was observed between the control (no applied Ca) and the highest rate (2 x LR), whereas in 1999 yields were only increased up to the intermediate rate (1 x LR) and only exceeded the control by 4%.

c. Effects of crop residues, rotations and green manures on soil/plant N dynamics - (conducted on site by Z. Kouyate, S. Blanton-Knewtson, A. Sidibe and M. Doumbia with support from F. Hons, L. Hossner and D. Israel) field studies were conducted on two soils at the Cinzana Research Station, a toe-slope loam and a mid-slope loamy sand. Five crop system were evaluated: (1) continuous cereal with residue removed from the field, (2) continuous cereal with residue returned to the field every second year, (3) cereal rotated with cowpea, (4) cereal rotated with a sesbania (*Sesbania rostrata*) green manure crop, and (5) cereal rotated with a dolichos (*Dolichos lablab*) green manure crop. Sorghum was the cereal crop grown on the loam soil and millet was the cereal crop grown on the loamy sand soil. Although sorghum has a higher grain production capacity, millet yields are higher on the loamy sand soil.

Table 20. Comparisons of selected treatment effects among Ca sources and rates in two Cinzana soils on millet yields in the 1998 and 1999 seasons, and selected surface soil (0-15 cm) chemical properties for samples taken after the 1998 crop.

TREATMENT	GRAIN YIELD			EXCHANGEABLE	
MEANS	'98	'99	pH in H_20	Ca	Mg
	---------- kg ha^{-1} ----------			----- $cmol_c$ kg^{-1} -----	
SOILS					
Sandy	2132	4408	4.5	0.75	0.50
Clayey	1590	4837	5.9	9.17	2.24
Ca SOURCE					
Tilemsi PR	2153	4991	5.1	4.50	1.37
Lime	1675	4225	5.4	5.00	1.33
Gypsum	1862	4358	4.9	4.80	1.41
Ca RATE					
Control	1635	4589	5.0	4.30	1.31
0.5 x LR	1823	4636	5.3	5.00	1.31
1.0 x LR	1871	4760	5.2	4.80	1.28
2.0 x LR	2104	4505	5.2	5.00	1.44
CV (%)	39	26	19	54	37

Averaged across all years of the experiments, the cereal rotation with cowpea increased annual yields by approximately 20% in both soils despite the fact that cowpea seed and plant materials were removed from the field. Rotations with sesbania and dolichos green manure crops increased cereal yields in both soils. Grain and stover yields increased 30-50% when compared to the continuous cereal crop.

Soil N concentrations were low in all crop rotation treatments. Total N ranged from 450-700 mg kg^{-1} in the loam soil and from 180-210 mg kg^{-1} for the loamy sand soil. In the loam soil NH_4-N ranged from 1-10 and NO_3-N ranged from 0.5-30 mg kg^{-1}. Respective ranges of NH_4-N and NO_3-N for the loamy sand soil were 0.5-10 and 0.5-7.0 mg kg^{-1}. Both NH_4-N and NO_3-N increased in the 0-10 cm soil depth at the onset of the rainy season. Inorganic N levels in the soil decreased as plant biomass increased and little difference was measured between the different cropping systems. Nitrogen budgets are currently being calculated from the long term field data.

d. On-farm trials to develop millet yield and nutrient input/output budgets, and evaluate compost efficiency and nutrient composition - (conducted by M. Doumbia with support from L. Hossner, F. Hons, S. Reid and R. Yost) trials are being conducted with the cooperation of

local farmers. Nutrient budgets are being developed by measuring nutrient inputs of fertilizer/compost and using plant analysis and production data to calculate nutrient exports. The primary system being monitored is the Tilemsi PR-household waste system. During the dry season in 1998 the effects of PR and N supplements on compost quality were evaluated during composting of different mixtures of organic materials (manure, crop residues, house wastes) at the Sotuba Research Station, Mr. Saouty Toure's farm in Cinzana and Mr. Lassine Djire's house at Dougouba. Composting was conducted from February 1998 to May 1999 with weekly applications of water mixtures at a ratio of 1 t of organic materials : 100 kg Tilemsi PR : 12 kg urea. Selected chemical properties of the composted materials are summarized in Table 21. Variation among composted materials was high, so that adding Tilemsi PR or urea did not significantly alter their composition. However, there were evident trends for increased N and P contents upon inclusion of "compost extenders".

Table 21. Selected mean chemical properties of composted materials from Sotuba Research Station, Cinzana and Dougouba.

COMPOST	TOTAL CONTENT					C/N
TREATMENT	N	P	K	Ca	Mg	RATIO
	---------- % ----------					
Organic materials (OM)	1.94	0.75	2.87	1.20	1.17	30
OM + Tilemsi PR	1.53	2.17	2.26	1.66	0.59	45
OM + PR + urea	2.30	2.76	1.78	3.06	0.55	24
CV (%)	35	56	23	69	76	36

In the 1999 cropping season on-farm trials with millet compared the composted materials with Tilemsi PR (Table 21; OM+Tilemsi PR) to existing farmer practices (check) and application of Tilemsi PR alone (Table 22). In these trials there was no yield advantage to composting with PR as opposed to conventional application of PR alone. However, millet yields in Dougouba were significantly increased upon the addition of P as Tilemsi PR.

In 1999 on-farm trials were conducted in the regions of Sotuba (sorghum and maize), Cinzana (millet) and Dougouba (millet) to compare regional N, P and lime recommendations from NuMaSS to existing commodity-based recommendations by IER. A control treatment, without nutrient or lime inputs was also included in each trial. Yield data for these trials are shown in Table 23.

In all locations except Cinzana yields for NuMaSS-based recommendations were significantly greater than yields for the control, but there were no differences between NuMaSS- and IER research-based recommendations. Reasons for millet yield depression with the NuMaSS recommendation in Cinzana can, hopefully, be explained with soil and plant data (when completed). Fertilizer N recommendations in NuMaSS are based on a targeted yield, which was only achieved or exceeded in one of the millet trials in Dougouba.

Table 22. Millet yields as influence by applications of Tilemsi PR and composted Tilemsi PR in on-farm trials in Cinzana and Dougouba.

TREATMENT	RATE APPLIED	MILLET GRAIN YIELD CINZANA	MILLET GRAIN YIELD DOUGOUBA
	---------- kg ha^{-1} ----------		
Control	--	980 a	675 b
Tilemsi PR	300	1285 a	2000 a
Composted Tilemsi PR	5000	1360 a	1875 a
CV (%)		28	19

Table 23. On-farm comparisons of sorghum, maize and millet yields as influenced by recommendations from IER research programs and NuMaSS during the 1999 season.

TREAT-MENT	FERTILIZER & LIME[a] SOURCE	FERTILIZER & LIME[a] RATE	GRAIN YIELD SOTUBA SORGHUM	GRAIN YIELD SOTUBA MAIZE	GRAIN YIELD DOUGOUBA MILLET-1	GRAIN YIELD DOUGOUBA MILLET-2	GRAIN YIELD CINZANA MILLET
			---------- kg ha^{-1} ----------				
Control	--	--	700 b	414 b	440 b	880 b	535 ab
IER	DAP	100	1047 ab	1582 a	1110 a	1180 ab	570 a
	Urea	50-100					
NuMaSS	Lime	1360					
	TSP	125	1451 a	1624 a	810 a	1240 a	285 b
	Urea	100					
CV (%)			33	47	28	20	39
NuMaSS Target Yield			1500	2000	1000	1000	1000

[a] DAP = diammonium phosphate; TSP = triple superphosphate.

As with other core sites, on-farm trials to compare regional- and NuMaSS-based recommendations need to be conducted for several seasons. Whereas regional recommendations may not change between seasons, future NuMaSS recommendations of N, P and lime for the same on-farm sites may decrease as the system will account for residual fertilizer and lime effects carried over from prior season applications.

3. *Philippines*

Midterm survey - (conducted under the supervision of James Friday, Thomas George and Frank Smith) Friday and Smith traveled to Philippines for purposes of supporting activities associated with the planned mid-term evaluation of the project at the intensive testing site at Barangay Centro San Antonio, Ilagan, Isabela. The survey included extensive field interviews with farmers, agricultural suppliers, researchers, extension agents, marketing entities and potential partner institutions. In addition to collection of original data at the research site, efforts were made to gather pertinent information and data from secondary sources including government offices. In-country travel provided opportunities for the team to observe the variations in local farming systems. A summary of the conclusions from our mid-term assessment of the field site in San Antonio, Ilagan, Isabela, Philippines are as follows:

• The farming systems contain diversified elements, but corn and rice are the backbone of the system. There is little technical backstopping for corn or upland rice.

• Soil-based problems such as acidity, low fertility, and erosion receive little attention from either the professionals or the farmers in the area (Table 24). The practice of liming is known only in theory to the professionals and unknown to the farmers.

• Markets for capital, inputs and products drive on-farm activity but lack of transparency in pricing invites abuse and inefficiencies.

• While most farmers plant corn and rice, different farmers use different cultivars, apply different amounts of fertilizer and pesticides. Group interviews did not pick up this variability in farming practices among farmers but individual interviews did.

• Farmers are open to innovations. They frequently change cultivars, modify fertilizer and pesticide use, and experiment with new crops. They are eager participants in experimental trials.

• Farmers are very interested in the results of the on-farm experiments and the core experiment. They are eager to apply the knowledge gained to their own farms. A field day at the core experiment site hosted by the project researchers and DA-CVIARC (Philippine Department of Agriculture) staff would be extremely valuable in teaching farmers about liming and fertilization.

• On-farm decision-making relies on the farmers' own experience and advice of family and friends. Farmers did not report being able to get technical advice from professionals with government agencies.

• Given the need for information, a computer decision support system would be very beneficial. However, while a limited number of local researchers and perhaps private sector commercial growers and businesses could use such as system, the Municipal Agricultural Office and the extension agents are not ready to use a computer-based system. One opportunity is to train the local researchers with the DA-CVIARC in using DSS software, and allow them to work with and train the municipal agricultural extension agents. Another opportunity is to install DSS software directly into the village's own computer and allow both agricultural extension agents and local farmers and businesspeople to experiment with it.

• While there is a great opportunity for a DSS software, wide acceptance and use of the software by the practitioners would depend on the Department of Agriculture Research and the Municipal Extension Systems accepting it as a tool by policy at the regional and national

levels and providing the needed support. It cannot be assumed that the intended users are eagerly waiting for the arrival of the software. It may be that the software can be programed to generate graphs or figures that are useful without the dependence on computers. Some clever hand-held tools and decision-aids such as the PhilRice color chart for assessing N status in rice might be an example of tools and products that would be very helpful.

Table 24. Farmer responses regarding problems related to growing corn.

	FARMER REPLIES	
PROBLEM	**FREQUENCY (N=43)**	**% OF TOTAL**
Pests, including insects and rats	17	40
Weather, including typhoons, drought and flooding	14	33
Financial, including costs of seed, fertilizer, pesticides, equipment and labor	10	23
Soil, including erosion and low fertility	5	12
Weeds	4	9
Diseases	3	7
Selection of crop varieties	1	2

Ongoing core field experiment to test NuMaSS predictions and development management alternatives - (supervised by Theodula Corton and Josefina Lasquite at PhilRice with support from Thomas George at IRRI and Russell Yost) the factorial field trial with upland cropping systems tests yield predictions and parameters in NuMaSS and develops crop and amendment combinations for outreach testing throughout the region. Field experiments were conducted for rice, peanut and corn during the period September 1998 to September 1999. Rice yield was lower than the targeted value of 3.5 t ha^{-1} (Table 25) and there was no response to added N, P and lime. Experimental variability was high (cv = 21.3%) as commonly occurs in the first crop after application of large amounts of lime and fertilizers. Furthermore the crop suffered damage during the vegetative stage by two successive typhoons. Continuous rain for more than one week delayed the topdressing of N during the panicle initiation stage which is the most critical for increasing N fertilizer use efficiency. Soil analysis shows that the soil pH increased to more than 5.5 from the initial pH value of <4.2 (Table 26). Aluminum saturation decreased to 0 from 40-54% initially. Soil extractable P (Olsen method) was <7 ppm where P fertilizer was not added and >7 ppm with application of 15 to 60 kg P ha^{-1} except in two cases where it was only 5 ppm. Applied lime moved down to 15-30 cm depth as shown by the lower Al saturation (8 - 13%) with lime treatment compared with 29 - 51% without lime (Table 27). However the soil pH at 15-30 cm depth remained below 5.

Table 25. Grain yield of upland rice (IR 55423) as affected by lime, N, and P at the core experiment in San Antonio, Ilagan, Isabela, Philippines.

TREATMENT[a]	YIELD[b]
	t ha^{-1}
$N_0P_0L_0$	1.13 B
$N_2P_2L_0$	1.68 AB
$N_0P_2L_2$	1.92 A
$N_2P_0L_2$	1.64 AB
$N_1P_2L_2$	1.95 A
$N_2P_2L_2$	1.75 AB
$N_3P_2L_2$	2.00 A
$N_2P_1L_2$	1.69 AB
$N_3P_3L_2$	1.77 AB
$N_1P_1L_2$	1.73 AB
$N_2P_2L_1$	1.64 AB
$N_2P_2L_2$ (50/50 $CaCO_3/CaSO_4$)	1.74 AB
$N_2P_2L_0$ (+ 5 t/ha Green Manure)	1.62 AB
$N_2P_2L_1$ (+ 5 t/ha Green Manure)	1.88 A

[a] N1 = 40, N_2 = 80, N_3 = 120 kg/ha; P_1 = 15, P_2 = 30, P_3 = 60 kg/ha; L_1 = 3, L_2 = 6 t/ha.
[b]Means followed by the same letter are not significantly different.

The peanut crop gave a relatively good yield compared with the regional yield average of 1.3 t ha^{-1} (Table 28). The highest yield was with treatment $N_0P_3L_2$ (2026 kg ha^{-1}) and the lowest was with $N_1P_0L_1$ (1507 kg ha^{-1}). During the visit of Dr. Nguyen Hue in January 1999, when the peanut crop was at 10 days after sowing (DAS), symptoms of Mn toxicity were observed. Symptoms of yellowing of the leaf margin then wilting and dying of tips was pointed out. Analysis of the first fully mature leaf in the $N_0P_0L_0$ treatment showed 550-686 ppm Mn while the $N_3P_2L_2$ treatment had 155-156 ppm Mn at 10 DAS. At flowering stage (Table 29) the leaf sample analysis showed that only the $N_0P_0L_0$ treatment had >500 ppm Mn. At harvest, the analysis of shoots showed four treatments where Mn was higher than 500 ppm (Table 30):

Table 26. Soil analysis (0-15cm depth) collected after harvest of the rice crop planted in an acid upland area in Barangay San Antonio, Ilagan, Isabela, Philippines. 1998 wet season.

TREATMENT[a]	pH	OC	NH_4-N	NO_3-N	OLSEN P	K	Ca	Mg	ACIDITY	Al	ECEC	Al SAT.
		%	---------- mg kg^{-1} ----------						---------- $cmol_c$ kg^{-1} ----------			%
$N_0P_0L_0$	4.2	1.81	8.2	6.9	6.8	74	231	47	2.21	1.57	3.94	40
$N_2P_2L_0$	4.2	1.79	9.8	7.7	8.5	93	261	41	2.34	2.15	4.22	54
$N_0P_2L_2$	6.9	1.64	10.0	8.3	8.8	69	1888	39	0.00	0.00	9.95	0
$N_2P_0L_2$	6.7	1.40	8.8	6.3	4.8	62	1988	34	0.01	0.00	10.39	0
$N_1P_2L_2$	6.8	1.71	9.4	8.5	11.3	80	2029	47	0.01	0.01	10.76	0
$N_2P_2L_2$	6.8	1.57	8.8	8.3	5.8	58	2133	35	0.00	0.00	11.11	0
$N_3P_2L_2$	6.8	1.82	10.1	9.2	9.4	69	2197	31	0.00	0.00	11.43	0
$N_2P_1L_2$	6.7	1.60	9.5	8.0	10.5	88	1999	38	0.00	0.00	11.29	0
$N_3P_3L_2$	6.7	1.60	9.6	8.3	11.0	62	2105	32	0.00	0.00	10.94	0
$N_1P_1L_2$	6.6	1.56	8.7	7.1	5.2	59	2163	39	0.01	0.00	11.31	0
$N_2P_2L_1$	5.7	1.56	10.0	5.9	7.7	84	1710	44	0.00	0.00	9.13	0
$N_2P_2L_2$ (50/50 $CaCO_3$/$CaSO_4$)	5.4	1.70	10.6	7.6	8.9	62	1419	16	0.21	0.02	7.60	0
$N_2P_2L_0$ (+5 t/ha Green Manure)	4.3	1.88	11.3	9.3	8.8	96	239	63	1.85	1.61	3.81	41
$N_2P_2L_1$ (+5 t/ha Green Manure)	5.5	1.69	8.9	7.8	7.1	108	1610	52	0.00	0.00	8.76	0

[a] N1 = 40, N_2 = 80, N_3 = 120 kg/ha; P_1 = 15, P_2 = 30, P_3 = 60 kg/ha; L_1 = 3, L_2 = 6 t/ha.

Table 27. Soil analysis at three sub-surface depths after harvest of the upland rice crop planted in an acid upland area in Barangay San Antonio, Ilagan, Isabela, Philippines. 1998 wet season.

TREATMENT	DEPTH	pH	NH_4-N	NO_3-N	K	Ca	Mg	ACIDITY	Al	ECEC	Al SAT.
	cm		---------- mg kg^{-1}	----------				---------- $cmol_c$ kg^{-1}	----------		%
$N_0P_0L_0$	15-30	4.2	10.4	4.8	51	397	70	1.96	2.38	4.66	51
$N_2P_2L_0$		4.2	5.7	5.2	69	428	78	2.10	2.06	5.06	43
$N_0P_2L_2$		4.7	9.8	8.3	51	1085	60	0.68	0.71	6.73	12
$N_3P_2L_2$		4.8	7.0	8.9	52	1178	107	0.55	0.59	7.46	10
$N_3P_3L_2$		4.7	9.5	8.0	41	1177	65	0.53	0.44	7.06	8
$N_2P_2L_1$		4.5	8.0	6.2	55	970	68	0.96	0.66	6.52	13
$N_2P_2L_2$ (50:50 $CaCO_3/CaSO_4$)		4.2	9.3	5.0	51	1000	37	1.05	0.74	6.49	11
$N_2P_2L_0$ (+5 t/ha Green Manure)		4.2	10.6	6.7	61	654	99	1.63	1.63	5.89	29
$N_2P_2L_1$ (+5 t/ha Green Manure)		4.4	6.4	5.7	62	856	92	0.66	0.45	5.87	8
$N_0P_0L_0$	30-60	4.3	10.3	2.7	33	518	92	2.11	1.96	5.55	36
$N_2P_2L_0$		4.2	5.7	5.7	56	552	95	1.67	1.39	5.36	26
$N_0P_2L_2$		4.3	10.3	8.6	32	698	82	0.77	0.65	5.02	13
$N_3P_2L_2$		4.3	7.1	5.8	38	701	91	1.03	1.09	5.38	21
$N_3P_3L_2$		4.5	8.0	7.2	36	771	78	0.90	0.91	5.50	17
$N_2P_2L_1$		4.3	8.2	6.5	35	641	84	1.28	1.25	5.28	31
$N_2P_2L_2$ (50:50 $CaCO_3/CaSO_4$)		4.3	5.0	3.2	41	991	83	0.85	0.78	6.60	12
$N_2P_2L_0$ (+5 t/ha Green Manure)		4.3	8.3	4.4	41	711	1265	1.21	1.11	15.41	14

TREATMENT	DEPTH	pH	NH_4-N	NO_3-N	K	Ca	Mg	ACIDITY	Al	ECEC	Al SAT.
	cm		---------- mg kg^{-1}	----------				---------- $cmol_c$ kg^{-1}		----------	%
$N_2P_2L_1$ (+5 t/ha Green Manure)		4.3	7.3	8.0	38	696	101	0.87	0.59	5.29	11
$N_0P_0L_0$	60-90	4.3	11.6	15.9	25	555	94	1.08	1.37	4.70	31
$N_2P_2L_0$		4.3	4.3	14.9	36	574	104	1.69	1.42	5.52	25
$N_0P_2L_2$		4.2	10.9	23.5	22	678	106	1.67	1.52	6.00	26
$N_3P_2L_2$		4.5	11.4	24.1	25	608	108	1.16	1.47	5.16	28
$N_3P_3L_2$		4.3	5.3	19.0	26	614	101	0.75	0.68	4.72	13
$N_2P_2L_1$		4.2	7.8	19.4	30	547	92	1.19	1.30	4.76	32
$N_2P_2L_2$ (50:50 $CaCO_3$/$CaSO_4$)		4.3	3.9	7.3	30	767	123	1.00	1.04	5.93	17
$N_2P_2L_0$ (+5 t/ha Green Manure)		4.3	7.6	12.0	29	764	131	0.83	1.03	5.82	17
$N_2P_2L_1$ (+5 t/ha Green Manure)		4.3	4.6	9.9	38	641	93	1.24	0.97	5.31	19

[a] N1 = 40, N_2 = 80, N_3 = 120 kg/ha; P_1 = 15, P_2 = 30, P_3 = 60 kg/ha; L_1 = 3, L_2 = 6 t/ha.

Table 28. Yield of peanut (BPI Pn9) as affected by lime, N, and P at the core experiment in San Antonio, Ilagan, Isabela, Philippines.

Treatment[a]	**Yield**[b]
	kg ha^{-1}
$N_0P_0L_0$	442 D
$N_0P_1L_1$	1691 ABC
$N_0P_2L_1$	1793 ABC
$N_0P_3L_1$	1777 ABC
$N_0P_1L_2$	1825 ABC
$N_0P_2L_2$	1633 BC
$N_0P_3L_2$	2026 A
$N_1P_0L_1$	1507 C
$N_1P_1L_1$	1797 ABC
$N_1P_2L_1$	1756 ABC
$N_1P_3L_1$	1822 ABC
$N_3{}^*P_2L_2$	1797 ABC
$N_0P_2L_2$ (50/50 $CaCO_3/CaSO_4$)	1711 ABC
$N_0P_2L_0$ (+5 t/ha Green Manure)	1769 ABC
$N_0P_2L_1$ (+5 t/ha Green Manure)	1992 AB
$N_0{}^*P_2L_2$ (non-fixing reference)	661 D

[a]N_1 = 30, N_3 = 120 kg/ha (All plots were inoculated except the non-fixing reference treatment); P_1 = 30, P_2 = 60, P_3 = 120 kg/ha; L_1 = 4, L_2 = 8 t/ha.
[b]Means followed by the same letter are not significantly different.

$N_0P_0L_0$ with 708 ppm, $N_1P_0L_1$ with 568 ppm, $N_1P_2L_1$ with 542 ppm, and $N_0P_2L_0$ + green manure with 701 ppm.

A significant increase in yield was observed at the highest P rate (120 kg P ha^{-1}) (Figure 9). This could be a case of amendment effect of P addition, as suggested by R. Fox, which may be associated with secondary benefits of the high rates of P, such as improved CEC, improved N mineralization, and the improved Ca status. The high rate of lime could have also neutralized the Mn toxicity.

Table 29. Analysis of peanut (cv. BPI Pn9) leaf sample at flowering stage, during the 1999 dry season (San Antonio, Isabela, Ilagan, Philippines).

TREATMENT	N	P	K	Fe	Mn	Zn	Ca	Mg
	---------- % ----------			---------- ppm ----------				
$N_0P_0L_0$	3.48	0.06	0.18	6933	668	68	2361	364
$N_0P_1L_1$	3.58	0.08	0.18	2355	229	52	4090	1097
$N_0P_2L_1$	3.67	0.08	0.14	1798	217	46	3655	387
$N_0P_3L_1$	3.67	0.09	0.18	1891	280	46	3961	1042
$N_0P_1L_2$	3.46	0.08	0.14	2104	261	53	5179	416
$N_0P_2L_2$	3.48	0.08	0.17	1935	208	73	4655	438
$N_0P_3L_2$	3.83	0.09	0.17	1653	221	46	5025	431
$N_1P_0L_1$	3.34	0.06	0.19	3785	317	73	5742	1066
$N_1P_1L_1$	3.58	0.08	0.15	2231	334	49	4364	406
$N_1P_2L_1$	3.51	0.08	0.18	1557	312	47	4002	1105
$N_1P_3L_1$	3.57	0.09	0.18	1653	207	50	4210	387
$N_3^*P_2L_2$	3.60	0.08	0.18	1884	269	48	4606	422
$N_0P_2L_2$ (50/50 $CaCO_3/CaSO_4$)	3.69	0.08	0.16	1571	321	49	6323	963
$N_0P_2L_0$ (+5 t/ha Green Manure)	3.71	0.08	0.21	2032	469	55	2292	373
$N_0P_2L_1$ (+5 t/ha Green Manure)	3.63	0.08	0.19	1805	200	42	3525	442
$N_0^*P_2L_2$ (non-fixing reference)	2.23	0.07	0.10	15730	496	88	20175	999

[a]N_1 = 30, N_3 = 120 kg/ha (All plots were inoculated except the non-fixing reference treatment); P_1 = 30, P_2 = 60, P_3 = 120 kg/ha; L_1 = 4, L_2 = 8 t/ha.

Comparing the Mehlich 1 extractable P with the target residual soil P, they are similar at lower P fertilizer rate (Figure 10). The differences increase at higher P rates (120 kg P/ha). More Mehlich 1 P was extracted at the high level of lime (8 t ha^{-1}) than at 4 t ha^{-1}. In Figure 11, the Mehlich 1 extractable P seemed to plateau in terms of yield between 6.5 to 12.9, but at 20.4 ppm P the grain yield increased as discussed above.

The soil analysis for the 0-15 cm depth collected after harvest of peanut showed that the pH increased to more than 5 with application of lime (Table 31). The Al saturation was also reduced from 55% to < 3%. The application of 5 t ha^{-1} green manure, however, did not show a liming effect because pH was still <5 and Al saturation was 45%. Manganese was relatively high (120-145 mg Mn kg^{-1}) without lime treatment. Though it decreased with addition of 8 t ha^{-1} lime, it was still at 103-105 mg Mn kg^{-1}. Soil Zn was low and below the critical level (<1.5 mg kg^{-1}). At the 15-30 depth, the soil pH was < 4.5 and Ca did not seem to have moved down to neutralize subsoil acidity.

Table 30. Analysis of peanut (cv. BPI Pn9) shoot sample at harvest. (1999 dry season, San Antonio, Ilagan, Isabela, Philippines).

TREATMENT[a]	N	P	K	Cu	Fe	Mn	Zn	Ca	Mg
	---------- % ----------			---------- ppm ----------					
$N_0P_0L_0$	1.76	0.03	1.19	28	5040	708	54	3946	370
$N_0P_1L_1$	1.71	0.03	1.26	15	3236	409	39	5571	1620
$N_0P_2L_1$	1.88	0.04	1.08	21	4597	446	23	6514	372
$N_0P_3L_1$	1.79	0.04	1.29	18	2855	372	29	6011	804
$N_0P_1L_2$	1.83	0.04	1.44	19	3442	459	23	6046	960
$N_0P_2L_2$	1.98	0.04	1.10	25	6359	437	34	5800	342
$N_0P_3L_2$	1.72	0.04	1.07	19	3012	373	16	7208	901
$N_1P_0L_1$	1.71	0.03	1.49	26	5924	568	39	6795	443
$N_1P_1L_1$	1.80	0.03	1.48	18	1991	482	22	6479	259
$N_1P_2L_1$	1.82	0.04	1.24	17	4194	542	27	5331	954
$N_1P_3L_1$	1.76	0.04	1.05	19	4323	370	32	5680	993
$N_3^*P_2L_2$	1.94	0.04	1.06	18	4496	447	35	6583	336
$N_0P_2L_2$ (50/50 $CaCO_3/CaSO_4$)	1.97	0.04	1.18	16	3249	384	26	7156	430
$N_0P_2L_0$ (+5 t/ha Green Manure)	2.10	0.04	1.52	24	2808	701	32	4087	300
$N_0P_2L_1$ (+5 t/ha Green Manure)	1.89	0.04	1.78	23	2156	359	23	6407	301
$N_0^*P_2L_2$ (non-fixing reference)	1.41	0.04	1.24	20	2060	338	27	21476	1411

[a]N_1 = 30, N_3 = 120 kg/ha (All plots were inoculated except the non-fixing reference treatment); P_1 = 30, P_2 = 60, P_3 = 120 kg/ha; L_1 = 4, L_2 = 8 t/ha.

For the maize crop, there appears to be a plateau on yield (Figure 12). However, the Mehlich 1 P increased linearly with applied P fertilizer. Comparing Mehlich 1 P with target residual P, the critical level of 4-5 mg P kg^{-1} seems acceptable although the NuMaSS-estimated critical value for 34% clay was 7 mg P kg^{-1} (Figure 13). There was a response to lime from L0 to Ll (Figure 14), probably because the Al saturation decreased from 56 to 2%. However, at L2 there was a decrease in yield. Considering the pH at L2 the decreased yield may have been due to overliming. The soil pH after harvest was greater than 6 at the highest lime rate (L2 or 6 t ha^{-1}). A possible imbalance of micronutrients such as Zn, which was already low, may have limited yield (Ritchey et al., 1986).

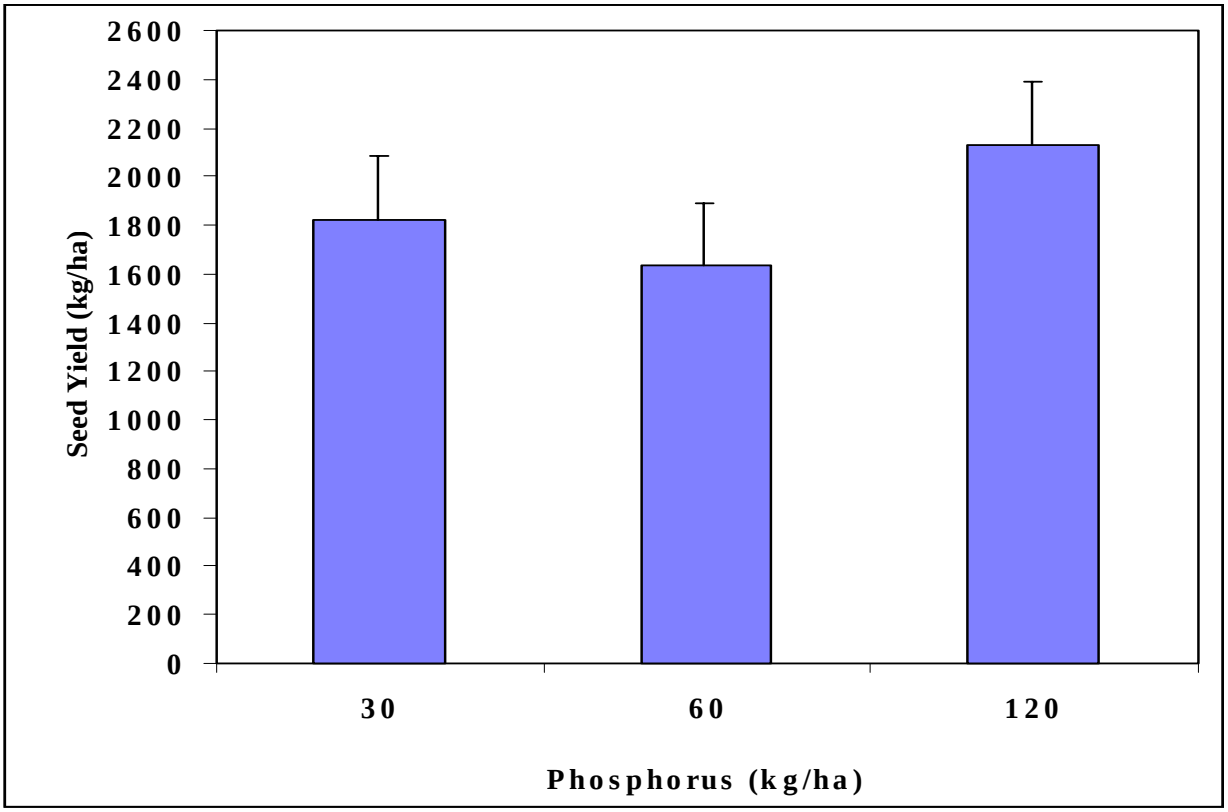

Figure 9. Response of peanut (BPI Pn9) to phosphorus and lime in an acid, upland soil of Ilagan, Isabela, Philippines.

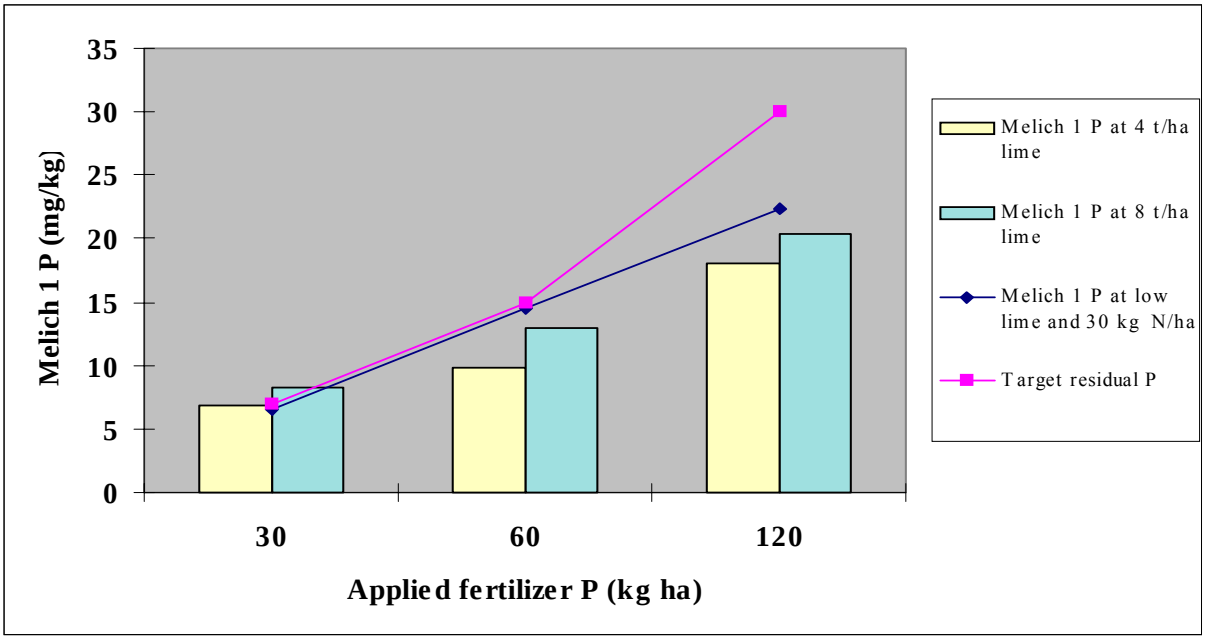

Figure 10. Extractable P (Mehlich 1) and target residual P after harvest of peanut (BPI Pn9), grown in an acid, upland soil of Ilagan, Isabela, Philippines.

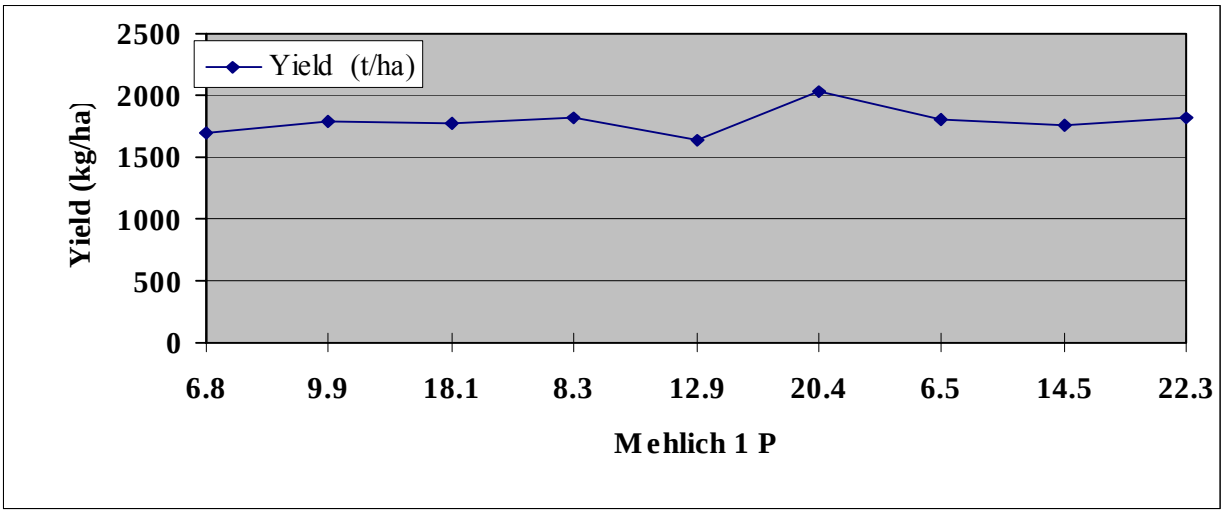

Figure 11. Relationship of Mehlich 1 P and peanut yield, Ilagan, Isabela, Philippines

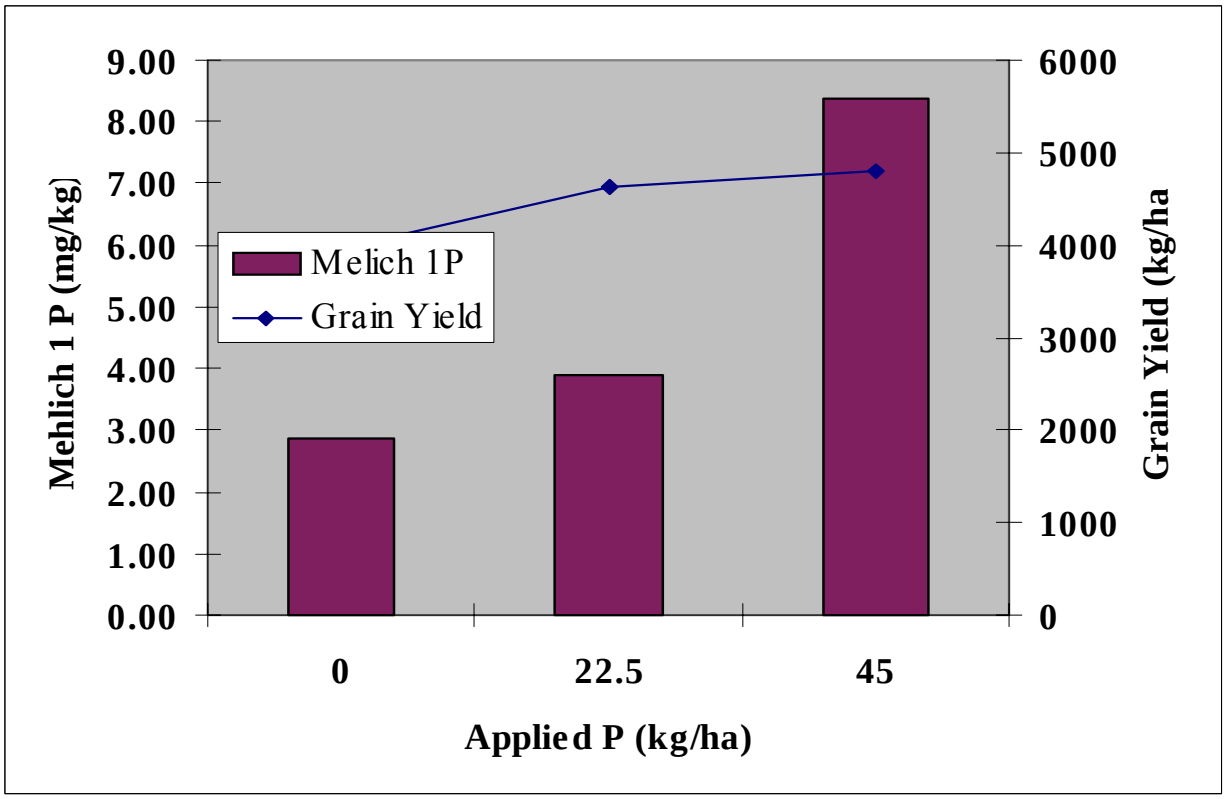

Figure 12. Phosphorus response of corn (Hybrid AG8362) grown in acid, upland soil of Ilagan, Isabela, Philippines.

Table 31. Soil analysis for samples (0-15cm) collected after harvest of the peanut crop planted in an acid upland area in Barangay San Antonio, Ilagan, Isabela, Philippines. 1999 dry season.

		P							EFF.	Al				
TREATMENT[a]	**pH**	**OLSEN**	**MEH.**	**K**	**Ca**	**Mg**	**ACIDITY**	**Al**	**CEC**	**SAT.**	**Mn**	**Zn**	**Fe**	**Cu**
		---------- mg kg^{-1} ----------					----- $cmol_c$ kg^{-1} -----			%	---------- mg kg^{-1} ----------			
$N_0P_0L_0$	4.1	3.5	2.7	68	294	65	2.88	2.64	5.07	55	120	1.0	65	1.5
$N_0P_1L_1$	5.1	6.1	6.8	65	1784	71	0.09	0.05	9.77	1	75	0.8	50	1.6
$N_0P_2L_1$	5.2	8.3	9.9	77	1800	84	0.14	0.11	10.04	1	105	0.7	48	1.6
$N_0P_3L_1$	5.0	14.4	18.1	64	1473	83	0.18	0.15	8.40	3	99	0.9	58	1.8
$N_0P_1L_2$	6.3	6.8	8.3	70	2981	59	0.02	0.01	15.60	0	84	0.7	36	1.5
$N_0P_2L_2$	6.0	8.5	12.9	62	2734	63	0.03	0.02	14.38	0	85	0.6	35	1.5
$N_0P_3L_2$	6.2	13.8	20.4	57	2932	63	0.02	0.02	15.35	0	90	0.7	36	1.6
$N_1P_0L_1$	5.1	4.0	2.9	69	1561	54	0.33	0.27	8.77	3	97	0.6	46	1.4
$N_1P_1L_1$	5.0	6.8	6.5	66	1550	60	0.26	0.17	8.68	2	106	0.8	55	1.9
$N_1P_2L_1$	5.2	11.1	14.5	61	1591	56	0.13	0.09	8.71	1	104	0.8	56	1.8
$N_1P_3L_1$	5.2	17.1	22.3	69	1835	63	0.09	0.06	9.97	1	103	0.7	51	1.8
$N_3^*P_2L_2$	6.0	7.5	11.0	66	2725	56	0.04	0.02	14.30	0	88	0.7	40	1.4
$N_0P_2L_2$ (50/50 $CaCO_3/CaSO_4$)	5.4	9.8	10.9	60	2182	27	0.06	0.04	11.34	0	94	0.6	46	1.5
$N_0P_2L_0$ (+5 t/ha Green Manure)	4.1	10.2	11.6	115	407	68	2.57	2.34	5.46	45	145	1.2	74	2.0
$N_0P_2L_1$ (+5 t/ha Green Manure)	5.3	8.2	10.1	124	1868	89	0.09	0.05	10.48	1	116	1.0	50	1.7
$N_0^*P_2L_2$ (non-fixing reference)	6.1	9.2	12.9	85	2907	82	0.04	0.02	15.48	0	87	0.8	38	1.4

[a]N_1 = 30, N_3 = 120 kg/ha (All plots were inoculated except the non-fixing reference treatment); P_1 = 30, P_2 = 60, P_3 = 120 kg/ha; L_1 = 4, L_2 = 8 t/ha. Green manure (3% N) was applied one week before planting.

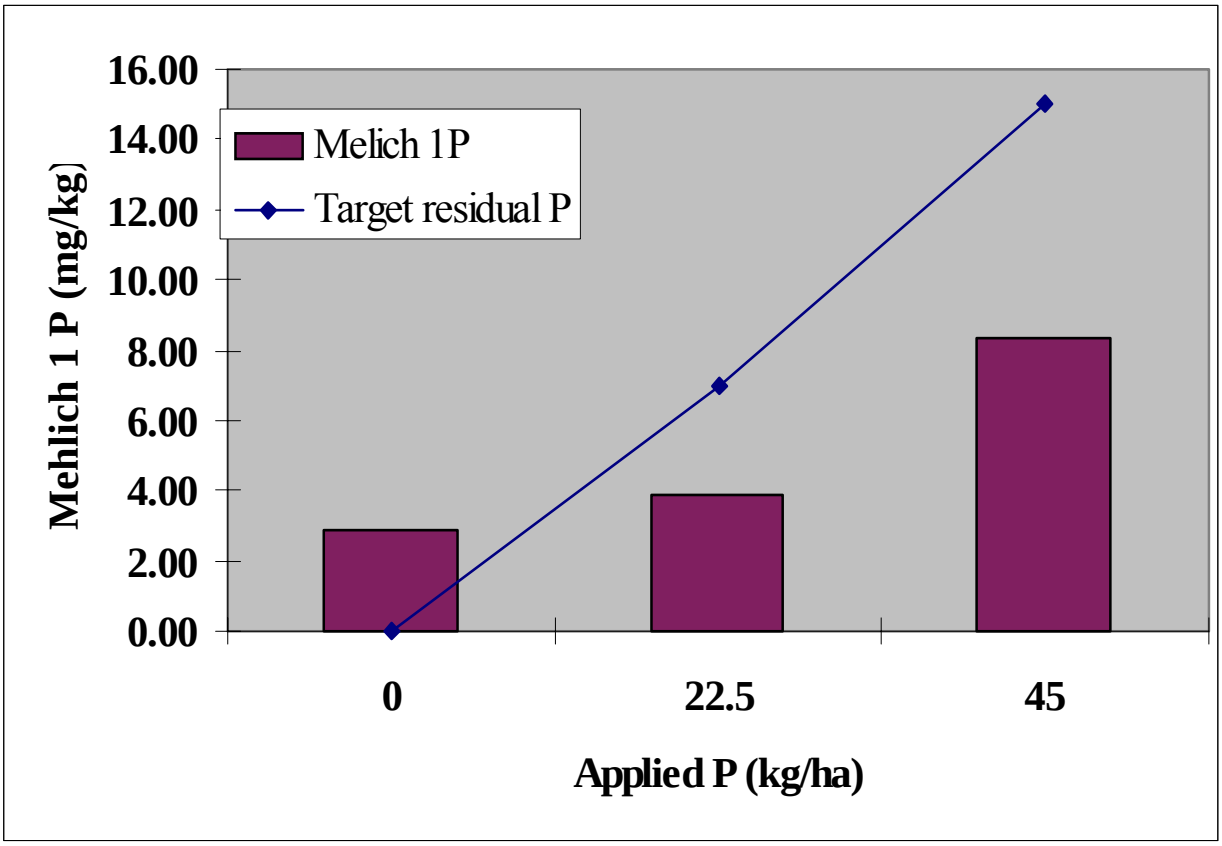

Figure 13. Mehlich 1 extractable soil P from harvest after corn (Hybrid AG8362) and target residual soil P for each rate of applied P as predicted from PDSS2.

A field day, attended by farmers, extension technicians, and DA-Ilagan Experiment Station staff was held on September 3, 1999. A hundred farmers were present and they were shown the difference in N, lime, and P treatments. Farm mechanization equipment was also demonstrated in farmers' fields. Farmers were amazed at how the hybrid corn grew robustly in a place where they could not grow good crops before our experiment was established. Although the farmers pointed out that high input was applied, it was explained to them that the soils were marginal and with time after building up the fertility of the soil, the input of lime and P will eventually decrease.

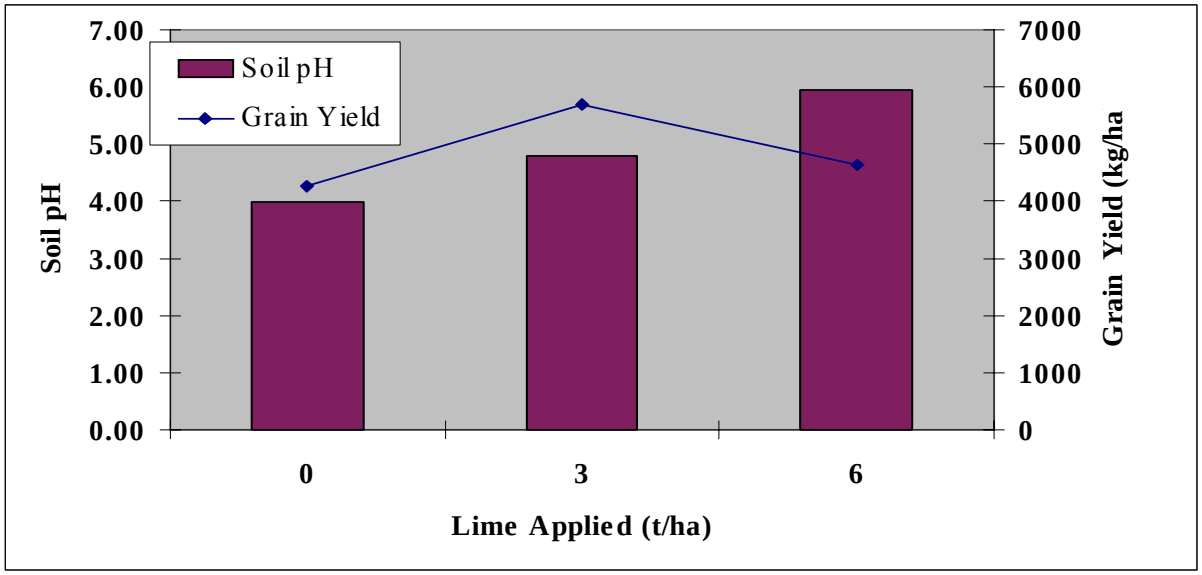

Figure 14. Response of corn (Hybrid AG8362) to residual lime applied to the previous rice crop, Ilagan, Isabela, The Philippines.

Table 32. Yield of maize (Hybrid AG8362) as affected by lime, nitrogen, and phosphorus at the core experiment in San Antonio, Ilagan, Isabela, Philippines.

TREATMENT[a]	YIELD[b]
	kg ha^{-1}
$N_0P_0L_0$	1663 J
$N_2P_2L_0$	4275 H
$N_0P_2L_2$	4650 FG
$N_2P_0L_2$	3971 I
$N_1P_2L_2$	5084 ED
$N_2P_2L_2$	4623 G
$N_3P_2L_2$	5377 C
$N_2P_1L_2$	4791 FG
$N_3P_3L_2$	6209 A
$N_1P_1L_2$	4540 G
$N_2P_2L_1$	5688 B
$N_2P_2L_2$ (50/50 $CaCO_3/CaSO_4$)	5261 CD
$N_2P_2L_0$ (+5 t/ha Green Manure)	4879 EF
$N_2P_2L_1$ (+5 t/ha Green Manure)	5489 BC

[a] N_1 = 100, N_2 = 200, N_3 = 300 kg ha^{-1}; P_1 = 22.5, P_2 = 45, P_3 = 90 kg ha^{-1}; Lime was applied in the previous rice crop; [b]Means followed by the same letter are not significantly different.

On-farm tests of diagnosis of nutrient constrains and nutrient recommendations - (supervised by Thomas George at IRRI, Teodula Corton and Josephina Lasquite at PhilRice, and Danilo Tumamao at DA-Ilagan Exp. Station, with support from Russell Yost) these trials test NuMaSS to determine whether it optimally diagnoses and detects nutrient-responsive conditions on farms. The on-farm testing protocol was revised and expanded to enable documentation of farmer perspectives in the potential usability of a computerized decision support system. Farmer cooperators were selected based on criteria that included off-farm income, slope, soil acidity and crop (upland rice and maize). Cooperator farmers are being surveyed periodically for documenting changes in their nutrient diagnosis and crop management practices. On-farm trials with nutrient treatments were superimposed on cooperators' crop.

A total of 58 farmers have been contacted to date which resulted in 8 upland rice farmers participating in 1998, 15 corn cooperators in 1999 wet season and 16 upland rice cooperators in 1999 late wet season. A survey was conducted of all contacted farmers. The treatments were: 1) farmer practice, 2) no fertilizer check, 3) regional fertilizer recommendation, and 4) NuMaSS recommendations of N, P and lime. Corn yield data collection had been completed and 1999 upland rice yield data collection is in progress.

The survey of the on-farm trial farmers indicated that 16 of the 58 farmers were aware of one or more agricultural agencies operating in the area. However, only 4 of the 58 farmers directly consulted the technicians from the Municipal Agricultural Office, the local extension agency. About 52% of the on-farm trial farmers indicated that they have heard of at least one farm technology, but most were related to new seeds and government-mandated programs such as biological control of corn insects pests. Ten farmers indicated that they have heard about the decision aid project from co-farmers before project staff contacted them. Most cooperator farmers described soil by color, never in terms of nutrients problems. They characterized their crops as good or bad or green or yellow. Majority of farmers considers availability and affordability of fertilizers in their decision to use. Type of fertilizer is not really a consideration but experience from previous crop is always considered. Few considered technician recommendations in their fertilizer use. Farmers were found to be eager participants in the on farm trials and were encouraged by the results that they see in on-farm trials and core experiments. Farmers' diagnosis and problem solving approaches are different from technicians and researchers.

On-farm corn trials included 3 farms in non-acid soils and 10 farms in acid soils where hybrid corn varieties were grown. The other two farms included were planted to the native glutinous corn variety. Average yields are presented in Table 33. It is obvious that nutrient applications substantially increased corn yields over both the zero fertilizer check and farmer practice across all farms. However, the yields for regional and NuMaSS recommendations were at par. A direct comparison within first season of cropping between regional and NuMaSS recommendations is prone to misinterpretation. First, the regional recommendation included various commercial organic fertilizers, which may have affected the yield in more ways than the three nutrient problems that NuMaSS recommendations were intended to correct. Second, NuMaSS recommendations included larger corrective amounts of lime and P applications whose residual effects are likely to last for a few more future crops. Therefore,

future NuMaSS treatments would require fewer amounts of lime and P compared to the regional recommendation. At the minimum, a three year yield comparison would be required to establish whether NuMaSS recommendations are more profitable in the long-term.

Table 33. Corn yield in on-farm trials at San Antonio, Ilagan, Philippines.

	CULTIVAR AND SOIL TYPE			
TREATMENT	NATIVE IN ACID SOIL	HYBRID IN ACID SOIL	HYBRID IN NON-ACID SOIL	ALL FARMS
	grain yield, kg ha^{-1}			
Farmer practice	1070	3612	5871	3725
No fertilizer	636	2149	5049	2554
Regional recommendation[a]	3332	4566	5815	4852
NuMaSS recommendation[b]	2629	4530	6838	4738

[a] included application of commercial organic fertilizers.
[b] included only N, P and lime.

External Funding and Support

- Costa Rica - support in kind from the Univ. Costa Rica in terms of salaries, laboratories and soil/plant analyses, transportation and administrative services are estimated by our collaborators to be $80,000. Support in kind from DEMASA, in terms of salaries, experiment maintenance, and field supplies/materials are estimated to be $20,000. A similar $20,000 is estimated to be provided in kind from the Ministry of Agriculture, via the Los Diamantes Experiment Station. Local farmer support for the on-farm P fertilization trial is conservatively estimated at $5,000. Total support to the project by collaborators in Costa Rica is conservatively estimated at $125,000.
- Mali - indirect expenses provied by IER-Mali for salaries of collaborators, field equipment, laboratory facilities and transportation are conservatively estimated at $100,000.
- Philippines - PhilRice support in personnel, laboratories and analyses, transportation and administrative services are estimated at $80,000. Support in salaries, field assistance from collaborators at the Ilagan Experiment Station are estimated at $15,000. Contributions from IRRI in transporation, and personnel assistance in establishing and maintaining field experiments and on-farm demonstrations are estimated at $10,000. Farmer assistance in conducting and maintaining on-farm trials in the Ilagan region are estimated at $10,000. Total support to the project by collaborators in Philippines is conservatively estimated at $115,000.

Travel and Meetings Attended

- Nguyen Hue - travel to Philippines to initiate evaluations of lime, gypsum and organic input treatments in field trials at San Antonio. January 17-23.
- Jocelyn Bajita - travel to Hawaii to begin graduate studies at the Univ. of Hawaii on decision aids for nutrient management in the Philippines. February 20.

- Teodula Corton - travel to Univ. of Hawaii to work with collaborators on matters related to project field trials in San Antonio, Philippines. March 7-31.
- Adrian Ares - travel to Costa Rica and Brazil to work with collaborators on P experiments with peach palm in Costa Rica and assimilate pertinent knowledge for NuMaSS on tree crops in Brazil. March 14-27.
- Jot Smyth - present a paper on NuMaSS at PCCMCA meetings in Guatemala, work with collaborator in Honduras on field, greenhouse and laboratory P experiment data, and provide technical backstopping to UCR collaborators in Costa Rica. April 13-22.
- Frank Smith - travel to Costa Rica to assist collaborators in the project's mid-term socio-economic survey. June 1-10.
- Lloyd Hossner, Frank Hons and Frank Smith - travel to Mali to assist collaborators in on-farm compost/nutrient management trials, assess progress of nutrient interaction trials, provide backstopping assistance to ongoing project activities and conduct project's mid-term socio-economic survey. June 20-July 14.
- James Friday and Frank Smith - travel to Philippines to conduct mid-term impact assessment of the project's activities at Barangay San Antonio. July 18-August 3.
- Gabriela Soto - travel to Raleigh to work with collaborators on data for field trial in Costa Rica on peach palm residue decomposition/nutrient release. August 17 - September 2.
- Dan Israel - travel to Mali to assist collaborators in assessment of cowpea BNF among lime, P and N treatments in ongoing field trials. August 21-27.
- Jot Smyth and Russell Yost - travel to Bolivia to assess/assist in tree crop programs, visit to CIAT, Cali to explore potential collaboration, and technical backstopping assistance to ongoing activities in Costa Rica. November 28 - December 15.

Relevant Publications, Reports and Presentations at Meetings

Ares, A. 1999. "Decision support systems for integrated nutrient management in agroecosystems." Seminar at Instituto Nacional de Pesquisas da Amazônia, March 16 1999, Manaus, Brazil.

Ares, A. 1999. "Nutrient diagnosis and fertilization responses in perennial tree crops for the humid tropics: the case of peach palm (*Bactris gasipaes*) in Costa Rica, Brazil and Hawaii." Seminar at the University of Hawaii, May 12, Honolulu.

Ares, A. 1999. Report on trip to Brazil and Costa Rica. Decision Aids for Integrated Soil Nutrients Project. 10p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Adrian_Brazil_CRica_99Rept.pdf)

Blanton-Knewtson, S.J., L.R. Hossner, Z. Kouyate and M. Doumbia. 1999. Effect of Sahel rainy season on inorganic soil nitrogen availability. 91st Annual Meeting. Amer. Soc. Agron., Oct. 31-Nov. 4, 1999, Salt Lake City, UT.

Deenik J, Ares A. and Yost RS. 1999. Fertilization responses and nutrient diagnostic methods for peach palm (*Bactris gasipaes*). Nutrient Cycling in Agroecosystems 55 (4): 1-13.

George, T., J. Quiton, V. Manoharan, T. Corton, and R. Yost. 1999. Adaptation of the Nutrient Management Support System (NuMaSS) in Asia. Paper presented at International Symposium on "Systems research for optimizing future land use, SysNet'99", International Rice Research Institute, Los Baños, Laguna, Philippines, October 11-13, 1999.

George, T. et al. 1999. SM-CRSP Project Decision Aids for Integrated Nutrient Management: Mid-Term Evaluation. Paper presented at the Decision Aids Workshop, 6-11 September, PhilRice, Philippines.

George, T., J.B. Friday and F. Smith. 1999. Mid-term review report: Philippines. Decision Aids for Integrated Soil Nutrients Project. 27p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Documents/Philippines_MidTerm_Rept.pdf)

George *et al*. 1999. SM-CRSP Project Decision Aids for Integrated Nutrient Management: On-Farm Testing. Paper presented at the Decision Aids Workshop, 6-11 September, PhilRice, Philippines.

George, T., R. Magbanua, B. Tubana, J. Quiton, A. Almendras, W. Khatib, F. Cox and R. Yost. 1999. Estimating buffer coefficients for the phosphorus decision support system using field and laboratory measurements. Comm. Soil Sci. and Plant Anal. *In Press*.

Hue, N. 1999. Trip report to the Philippines. Decision Aids for Integrated Soil Nutrients Project. 7p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hue_Phil_0199.pdf)

Hossner, L., F. M. Hons and F.J. Smith. 1999. Report on trip to Mali. Decision Aids for Integrated Soil Nutrients Project. 7p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hossner_Hons_Smith_MaliRept_0699.prn.pdf)

Smith, F., A. Alvarado and J. Smyth. 1999. Mid-term review report: Costa Rica. Decision Aids for Integrated Soil Nutrients Project. 13p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/CRica_Midterm_Assessment.pdf)

Smyth, T.J. 1999. Report on trip to Guatemala, Honduras and Costa Rica. Decision Aids for Integrated Soil Nutrients Project. 16p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Smyth_CAmerica_0499Rept.pdf)

Soto, G. 1999. Trip report to North Carolina. Decision Aids for Integrated Soil Nutrients Project. 13p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Gabriela_Rept_0899.pdf)

Yost R, Ares A., Bajita J and Wang, X. 1999. Diagnosing nutrient deficiencies. Proceedings Workshop on Integrated Nutrient Management, The Philippines.

Objective 2: Improve the diagnosis and recommendations for acidity and nutrient problems by identifying and resolving knowledge gaps through extensive literature reviews and, when necessary, developmental research.

Output 1 Enhancing the knowledge base for the acidity decision support system - collecting, developing and synthesizing soil, plant and management information to improve the diagnosis and recommendations of location-specific problems related to the soil acidity syndrome.

The current knowledge base on acidity in NuMaSS does not predict the rate of movement of basic cations into acid subsoils from surface-applied liming materials. This limits our ability to recommend management strategies for alleviating acidity constraints below the depth of lime incorporation, or properly accounting for the economic value of improved crop rooting depth as lime reaction products move into the subsoil. The introduction and movement of Ca and Mg into subsoils is a major consideration for sustained productive use of the acid, sandy soils in the African Sahel. The acidity knowledge base needs to be expanded to evaluate soil conditions with limited Ca and/or excess Mn. The consequences of using lime materials low in Mg on soil Mg availability also need to be added to the acidity module knowledge base.

Funding for all activities for improving the acidity module knowledge base is provided through the end of the year 3, but completion dates extend through year 4. Investigations related to basic cation (lime) movement were funded during years 1 and 2, but information continues to be collected in subsequent years. Investigations related to Ca and Mg deficiencies and/or Mn toxicity continue through year 3 in the Sahel and year 4 elsewhere.

Lead Investigators and Contributors

Jot Smyth (N.C. State) provides overall coordination to activities related to the acidity module. Investigations on basic cation movement prediction parameters are under the direction of David Bouldin (Cornell) and Anthony Juo (Texas A&M) directs field and lab work on this task in the Sahel. Nguyen Hue (Hawaii) and Smyth provide direction to lab, greenhouse and field investigations in Costa Rica and the Philippines related to diagnosis of Ca and Mg deficiencies, Mn toxicity, and lime equivalence of organic inputs. All team members are involved in efforts to review and assemble pertinent knowledge in the published and “grey” literature. Additional contributors to this output during year 3 are listed according to their respective institutions:

University of Costa Rica/Costa Rica - Alfredo Alvarado, Rafael Salas, Lidieth Uribe and Eloy Molina

Institue d’Economie Rurale/Mali - Mamdou Doumbia (Sotuba Station); Zoumana Kouyate and Adama Coulibaly (Cinzana Station)

Texas A&M University - Yuji Nino and Rick Wesch, graduate students

IITA/Nigeria - G. Tiau

Organization of Tropical Studies/Costa Rica - O. Gonzales and A. Vargas

Progress

1. *Variation in critical Al saturation values among published liming trials with corn and soybean* - the acidity module in NuMaSS currently provides default critical Al saturation values of 30% for corn and 15% for soybean. The only deviation from these default critical levels is a value of 20% Al saturation for soybean cultivar ‘Orba’, based on previous research by the SM-CRSP in Sitiung, Sumatra. When Al saturation percent exceeds the default critical

values, NuMaSS currently predicts that relative grain yield declines at a constant rate of 1.35% for corn and 1.12% for soybean with each increment in Al saturation up to 100%. As part of the continuing effort to assemble pertinent information for diagnosis of acidity and liming recommendations, Smyth evaluated linear-plateau relations between relative grain yield and % Al saturation for 17 published liming experiments with corn and soybean (Table 34). Each experiment contained multiple rates of applied lime and were either conducted for several cropping seasons or at different locations within the same season. When experiments contained different locations or multiple cultivars analysis was performed to determine whether soils and cultivars could be pooled and represented by single relations. Linear-plateau regressions were developed using the NLIN procedure in SAS.

Table 34. Author and reference source for liming experiments with corn and soybean evaluated for relations between grain yield and % Al saturation.

ID No.	AUTHOR & SOURCE
1	Abruña, Pearson & Perez-Escobar. 1975. pp. 261-282. *In* Bornemisza & Alvarado (eds.) Soil Management in Tropical America. N.C. State Univ., Raleigh.
2	Aitken, Dickson & Moody. 1998. Aust. J. Agric. Res. 49:639-647; Aitken, Moody & Dickson. 1998. Aust. J. Agric. Res. 49:627-637.
3	Alley. 1981. Agron. J. 73:687-689.
4	Smyth & Cravo. 1992. Agron. J. 84:843-850; Cravo & Smyth. 1997. R. Bras. Ci. Solo 21:607-616.
5	EMBRAPA. 1978. Relatório técnico anual do Centro de Pesquisa Agropecuária dos Cerrados 1976-1977. EMBRAPA-CPAC, Brasilia, Brazil.
6	EMBRAPA. 1982. Relatório técnico anual do Centro de Pesquisa Agropecuária dos Cerrados 1980-1981. EMBRAPA-CPAC, Brasilia, Brazil.
7	Farina & Channon. 1991. Plant Soil 134:127-135.
8	Fox. 1979. Soil Sci. 127:330-334.
9	Friesen, Juo & Miller. 1982. Soil Sci. Soc. Am. J. 46:1184-1189.
10	Gill. 1979. Ph.D. Thesis, N.C. State Univ., Raleigh.
11	Lathwell. 1979. Cornell Int. Agric. Bull. No. 35. Cornell Univ., Ithaca.
12	Martini, Kochhann, Siqueira & Borkert. 1974. Soil Sci. Soc. Am. Proc. 38:616-620.
13	Miranda. 1993. R. Bras. Ci. Solo 17:75-82.
14	van Raij, Camargo, Mascarenhas, Hiroce, Feitosa, Nery & Laun. 1977. R. Bras. Ci. Solo 1:28-31.
15	Wade, Kamprath, Heryadi, Al-jabri, Joniarta & Agus. 1987. pp. 125-131. *In* Caudle & McCants (eds.) TropSoils Technical Report 1985-1986. N.C. State Univ., Raleigh.

Critical Al saturation values among the 10 liming trials with corn ranged from 0 - 43% (Table 35). Critical values of 0 Al saturation % denote situations were there was a linear decline in relative grain yield across the entire range of soil acidity among the lime treatments. In three

of the experiments containing multiple locations (Table 34; ID no. 2, 3 & 7) relations between relative yield and % Al saturation were similar across sites. In some cases, differences in critical Al saturation values among experiments can be attributed to cultivars; composite varieties or hybrids used for trials in Peru, Puerto Rico and Indonesia are know to have been selected in regions predominated by calcareous soils. Variation in linear regression slopes was greater than 3 fold among the experiments.

Table 35. Linear-plateau regression coefficients for liming trials with corn in Africa, Asia, Latin America and U.S. relating % relative grain yield to % Al saturation.

COUNTRY	REGION	SOIL ORDER	CRITICAL Al SAT.	LINEAR SLOPE	YIELD PLATEAU	CULTIVAR	ID No.
			%		%		
Brazil	W/D[a]	O[b]	43	-1.7	91	Cargill 111	5, 6
		I	40	-2.1	92	BR-201	13
	HT	O	35	-1.7	94	BR-5102	4
Peru	HT	U	8	-1.4	98	Amarillo PB	11
P. Rico	W/D	U	0	-1.3	100	Pioneer 306	1
S. Africa	W/D	O, U	15	-1.4	95	Local hybrid	7
Nigeria	HT	U	18	-0.6	96	IITA TZB	9
Australia	W/D	O, U	0	-1.0	98	Pioneer 3270	2
Indonesia	HT	O	9	-0.8	96	Cargill C-1	10
U.S.	Temp.	U	41	-2.1	95	Pioneer 3369A	3

[a] W/D = wet-dry; HT = humid tropical; Temp = temperate.
[b] O = Oxisol; I = Inceptisol; U = Ultisol

The linear-plateau relation for an Oxisol and Ultisol in Kwazulu-Natal, South Africa is shown in Figure 15; the default relation currently used in NuMaSS for corn is included for comparison. Data in this figure for South Africa illustrate two potential problems associated with the uncertainty or lack of knowledge about corn germplasm selection by a user:

- Diagnosis of an acidity problem - reductions in crop yield occur at a lower % Al saturation value;
- Prediction of lime requirements - when sub-optimal yields are targeted, improper estimations of the yield response to liming could lead to erroneous predictions about the economic benefits due to liming.

Inclusion of these new relations for corn, as cultivar/germplasm options, as well as modification of the default yield vs. Al saturation function in NuMaSS will help users evaluate potential alternatives when location-specific knowledge is limited.

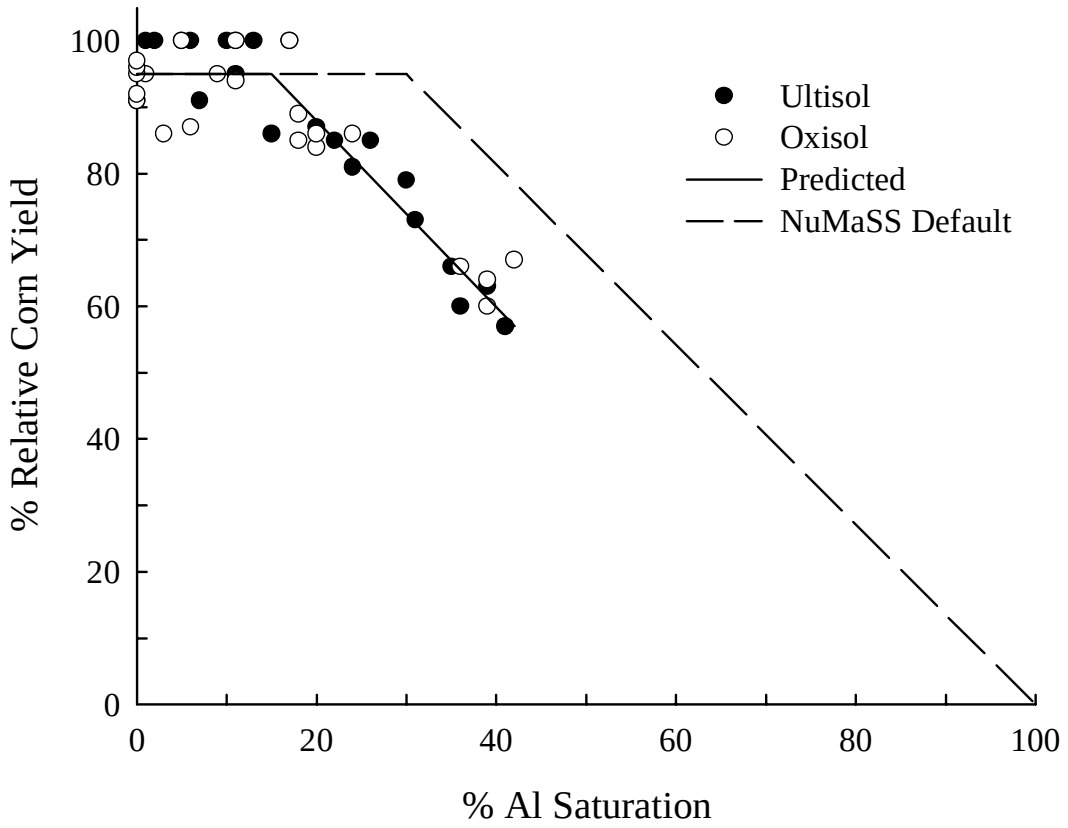

Figure 15. Observed and predicted corn grain yield - Al saturation relations for two soils in Kwazulu-Natal, S. Africa compared with the existing default relation used in NuMaSS.

Among 7 published lime trials with soybean in Brazil and Indonesia, critical Al saturation values ranged from 0 - 44% and there was a 2.5-fold variation in linear regression slopes among experiments and cultivars (Table 36). Relations between relative yield and Al saturation were similar across sites within experiments in Brazil and Sitiung, Sumatra which included multiple locations. However, soybean cultivar Willis had a lower critical Al saturation than cultivar Orba across locations in trials at Sitiung.

Soybean cultivar data will be added to NuMaSS to expand user options in acidity diagnosis and, when needed, lime recommendations. These results for corn and soybean illustrate the importance of similar ongoing literature searches to assess variability in yield vs. Al saturation relations for other commodities in NuMaSS.

Table 36. Linear-plateau regression coefficients for liming trials with soybean in Asia and Latin America relating % relative grain yield to % Al saturation.

COUNTRY	REGION	SOIL ORDER	CRITICAL Al SAT.	LINEAR SLOPE	YIELD PLATEAU	CULTIVAR	ID No.
			%		%		
Indonesia	HT[a]	O, I[b]	14	-1.2	90	Willis	10, 15
		O, I	25	-1.5	93	Orba	15
Brazil	W/D	O	44	-1.2	94	Viçoja, IAC-2	6, 11
		O	0	-1.1	98	Santa Rosa	14
		I	15	-0.8	97	Savana, Itiquira	13
	Temp.	O	12	-1.3	94	Bragg	12
	HT	O	44	-2.1	94	Tropical	4

[a] HT = humid tropical; W/D = wet-dry; Temp = temperate.
[b] O = Oxisol; I = Inceptisol.

2. *Diagnostic criteria and recommendations for Ca/Mg deficiencies, Mn toxicity and lime equivalence of organic inputs* - Hue continued investigations with Oxisols in Hawaii to refine information on interactions between organic materials and Ca movement, Mn solubility and Mn toxicity.
   Movement of Ca in a soil column by surface application of lime-compost mixtures - a relatively high Al, acid Ultisol (Kandiudult, Paaloa series), which had a pH of 4.44 and 1.7 $cmol_c\ kg^{-1}$ as KCl-extractable Al, was amended with gypsum ($CaSO_4.2H_2O$), lime ($CaCO_3$), Nitrohumus compost, a yardwaste compost, and combinations of lime and either Nitrohumus compost or yardwaste compost. The Nitrohumus compost is a biosolids-based product of the Kellogg Supply Inc., California. The yardwaste compost was collected from a 1-month-old compost pile made by the University of Hawaii. The two composts were air-dried and ground to pass a 1-mm sieve. Selected chemical composition of the composts is listed in Table 37.

Table 37. Selected chemical properties of the composts used in the Ca movement experiment.

COMPOST	C	N	S	Ca	Mg	K	Na	pH[†]	EC[‡]
	---------- g kg^{-1} ----------								dS m^{-1}
Yard waste	424	10.3	1.0	16.7	1.9	2.9	0.9	6.55	1.9
Nitrohumus	276	17.8	18.0	27.9	3.8	4.5	5.1	5.74	4.2

[†] 1:10 (compost:water) by weight.
[‡] 1:2 (compost:water) by weight.

Treatments consisted of 1.1 kg soil mixed with 13.1 g gypsum, 7.87 g $CaCO_3$, 23.64 g Nitrohumus compost, 23.64 g yardwaste compost, a combination of 7.87 g $CaCO_3$ and 23.64 g of either Nitrohumus or yardwaste compost in plastic bags. The inorganic amendment rates were equivalent to the amount of lime needed to raise the soil pH to 6.5. The unamended soil served as a control. The mixtures were moistened to field water holding capacity (250 g water kg^{-1}) and incubated in sealed plastic bags for 1 w. The treated soils were air dried and crushed to pass a 1-mm sieve, then moistened again and incubated for another week before being packed into leaching columns.

Leaching columns were prepared by first placing 920 g moist untreated soil into the bottom 35 cm of a polyvinyl chloride (PVC) column with 55 cm length and 5.8-cm inside diameter, which was lined with a plastic sheet to allow easy removal of the entire soil column for segmentation. Next, 460 g moist treated soil was packed into the top 15 cm. The bottom end of the column was supported by a nylon net, which was lined with a thin layer of glass wool to facilitate drainage. A 150-mL plastic bottle containing 2 drops of 1.0 g L^{-1} NaN_3 was attached to the bottom-end of the column to receive leachate. The seven treatments and their Ca inputs are shown in Table 38. The columns were arranged in a lab at 24 ± 2 ºC in a completely randomized design with three replications per treatment. Forty mL of deionized water was added daily to each column at 10 mL per 15 min. over a period of 27 d, which was equivalent to 40 cm of "rainfall" in 27 d. The leachates from each column were collected every 2 d and pooled into a larger bottle. The pooled leachates were kept frozen until analysis. The soil columns were allowed to drain for 2 d, then the soil was removed from the PVC casing and cut from the top into 15, 10, 10, and 10-cm long layers. The soil layers were air dried, weighed, and ground to pass a 1-mm sieve. Soils and leachates were subjected to chemical analysis.

Table 38. Amounts of Ca applied to each column by the various treatments.

TREATMENT	**Ca ADDED**
	mg/column
Control	0
Gypsum	1016
Lime	1050
Yardwaste compost	132
Nitrohumus compost	220
Lime and Yardwaste compost	1182
Lime and Nitrohumus compost	1270

Figure 16 shows the distribution of exchangeable Ca in the soil profile as affected by surface application of the various amendments. Because nothing was added to the control,

exchangeable Ca in this treatment remained nearly constant throughout the profile. In the $CaCO_3$ treatment, exchangeable Ca in the top layer was significantly increased to 12.5 $cmol_c$ kg^{-1}. The exchange between Ca^{2+} from lime and Al^{3+} and H^+ of the soil occurred as follows:

$CaCO_3 + H_2O$ <==> $Ca^{2+} + 2\ OH^- + CO_2$

Clay-H + ½ Ca^{2+} <==> Clay- ½ $Ca^{2+} + H^+$

$H^+ + OH^-$ <==> H_2O

Clay-Al + 3/2 Ca^{2+} <==> Clay-3/2 $Ca^{2+} + Al^{3+}$

$Al^{3+} + 3\ OH^-$ <==> $Al(OH)_3$

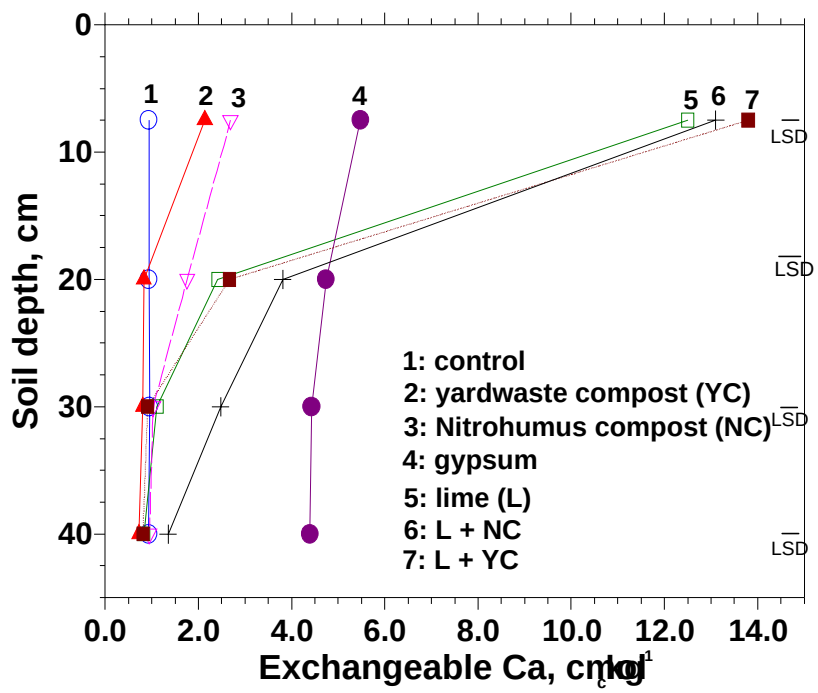

Figure 16. Distribution of Ca along soil depths as affected by lime, gypsum, and compost applications.

Thus, most of $CaCO_3$ applied reacted with soil acidity of the top layer, and most of Ca^{2+} was held by negatively charged sites on the soil surface. In addition, adding lime to a variable-charge soil may increase the soil's CEC in proportion to the increase in exchangeable Ca as shown below.

$CaCO_3 + H_2O$ <==> $Ca^{2+} + 2\ OH^- + CO_2$

{Oxide mineral}Al-OH + OH^- <==> {Oxide mineral}Al-O^- + H_2O

{Oxide mineral}Al-O^- + ½ Ca^{2+} <==> {Oxide mineral}Al-O-$Ca_{1/2}$

The electrical neutrality principle requires that Ca^{2+} movement must be accompanied by an equivalent of anions. Thus, Ca^{2+} , which is adsorbed on the exchange sites, could not move

even under the leaching condition because its accompanying “anion” was the immobile solid phase. In fact, exchangeable Ca at depths below 15 cm in the lime treatment increased only slightly (Fig. 16).

Surface application of gypsum significantly increased exchangeable Ca throughout the soil profile (Fig. 16). The movement of Ca from gypsum in the soil profile is effective because (1) the solubility of gypsum in water is relatively high (240 mg/L at 25 ^{o}C); (2) SO_4^{2-}, the accompanying anion of Ca, is a mobile anion since the formation of HSO_4^-, $AlSO_4^+$ and pair with other cations in the soil solution is much weaker than the formation of H_2O and $Al(OH)_3$ by OH^-. This explanation is supported by the extractable SO_4^{2-} concentrations in the gypsum treatment, which were significantly higher than those of the control at all depths (Fig. 17).

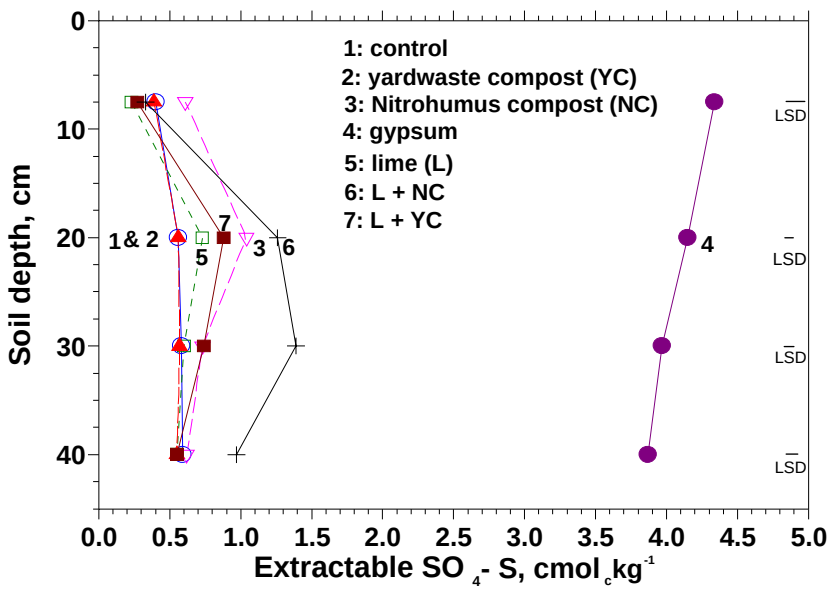

Figure 17. Distribution of SO_4-S along soil depths as affected by lime, gypsum and compost applications.

The application of the yardwaste compost provided 132 mg total Ca to the 0-15 cm layer, some of which became exchangeable (Fig. 16). However, no added Ca moved beyond the application zone. In contrast, the application of the Nitrohumus compost increased exchangeable Ca from 0.94 to 2.69 $cmol_c$ kg^{-1} in the top layer, and from 0.94 to 1.76 $cmol_c$ kg^{-1} in the second layer (Fig. 16). Thus, a portion of Ca in the Nitrohumus compost was mobile, and the accompanying anions could be fulvates, Cl^-, NO_3^-, and evidently SO_4^{2-} (Fig. 17).

The combination of lime and the yardwaste compost increased exchangeable Ca of the top 2 layers (Fig. 16). The Ca increase in the second layer, however, was not different from that caused by the lime addition alone. In contrast, the combined application of lime and the Nitrohumus compost increased exchangeable Ca in all soil layers (Fig. 16). Possible

explanations for the enhanced Ca downward movement by the combined application of lime-Nitrohumus compost are: (1) some Ca ions from the compost exchanged with other cations on the exchange sites and were held there when the compost was applied alone, whereas such an exchange was less likely when exchange sites were saturated with Ca from lime. (2) A greater portion of Ca in the compost became mobile when the soil was limed. The increased pH by liming reduced positive charges on the soil surface, thereby reducing the adsorption of anions, such as SO_4^{2-}, which accompany Ca^{2+}. The movement of SO_4^{2-} in the combined lime-Nitrohumus treatment was evident in Figure 17. (3) Also, Ca can become mobile by forming complexes with organic anions/molecules. However, this organics-assisted movement of Ca apparently played only a minor role in this experiment because there was little Ca movement in the combined treatment of lime and the yardwaste compost, which would have contained a considerable quantity of organics.

Dissolution of soil Mn by selected organic molecules - sixteen low-molecular-weight organic molecules were used to dissolve Mn from the Wahiawa Oxisol at pH 4.5 in 0.1 *M* KCl solution. The soil-to-solution ratio was 1:10 (by weight), concentrations of the organic molecules were 0, 25, 50, and 100 µ*M* and equilibration time was 2 hrs. The experiment was repeated at pH 5.5 and 7.0 for catechol, citric acid, l-cysteine, gallic and tannic acids at 100 µ*M*. Effect of equilibration time (0.5, 1, 2, 4, 8, 16, and 24 hrs) on Mn solubility by 100 µ*M* of catechol, citric acid, l-cysteine, gallic and tannic acids was also evaluated. The studied solutions were centrifuged at 10,000 rpm for 10 min., then the supernatants were filtered through a 0.45-µm membrane, and soluble Mn was determined with an atomic absorption spectrophotometer.

Among the 16 organics studied, tannic acid, gallic acid and catechol, which have at least two OH functional groups in the ortho position, were most effective in dissolving soil Mn at pH 4.5 in 0.1 *M* KCl (Fig. 18). Resorcinol, hydroquinone, ascorbic acid, and l-cysteine were intermediate. Acetic, oxalic, p-hydroxy benzoic, phthalic acids, and p-nitrophenol dissolved less Mn than KCl alone, whereas citric and salicylic acids, EDTA and EDDHA dissolved slightly more Mn than KCl.

The Mn dissolving effects of catechol, gallic acid and tannic acids became stronger (relative to KCl) as solution pH increased from 4.5 to 5.5 and 7.0 (Fig. 19). These molecules apparently can maintain Mn^{2+} in solution at high pH by chelation following the dissolution of solid soil Mn. Longer equilibration time made tannic acid and l-cysteine more effective in dissolving soil Mn (at pH 6.0), whereas the Mn dissolving power of catechol and gallic acid seemed to reach a plateau after 16 hours. In contrast, equilibration time had little effect on the Mn dissolving power of citric acid.

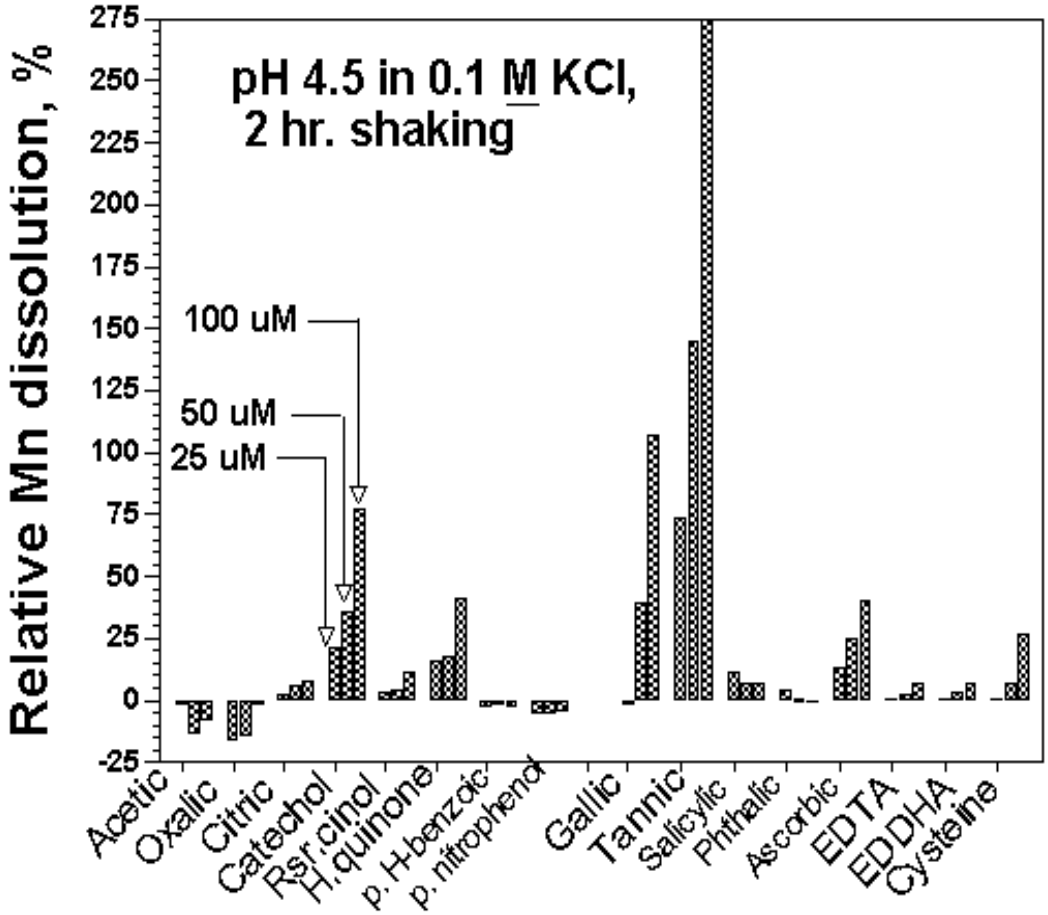

Figure 18. Soil Mn dissolution as affected by different organics. Relative Mn dissolution = 100*{(organics-extractable Mn - KCl-extractable Mn)/KCl-extractable Mn}.

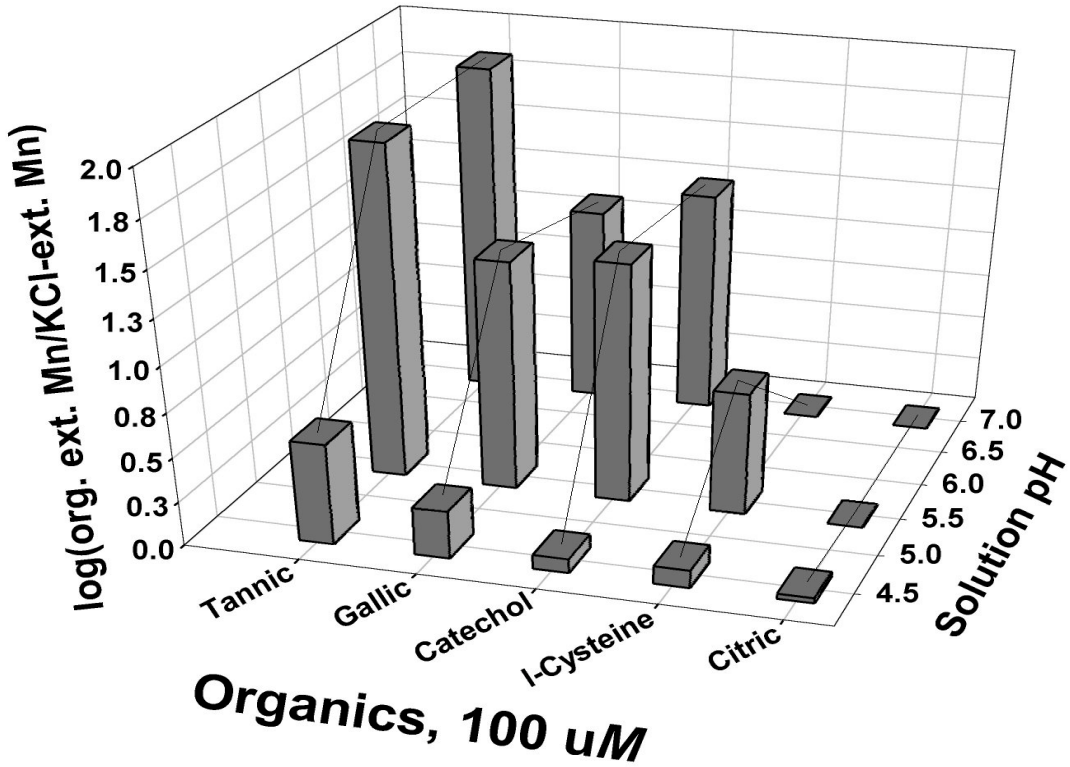

Figure 19. Effect of 6 organics on soil Mn dissolution at different pH. Supporting electrolyte: 0.1 M KCl, Soil-to-solution ratio: 1:10, Equil. Time: 2hrs.

<u>Mn toxicity in soybean as affected by organic amendments</u> - a greenhouse experiment was conducted in pots containing 2.0 kg soil of the Wahiawa series (Eutrustox). In the unamended state, the soil had a pH of 4.4 and approximately 60 mg Mn L^{-1} in saturated paste extract. KCl-extractable Al was only 0.1 $cmol_c$ kg^{-1}, however. There were 14 treatments (Table 39), each with 3 replicates.

All the lime treatments, including MgO, increased soybean growth 2 to 5 fold (Fig. 20). By contrast, the applications of Ca as $CaSO_4$ and/or $Ca(NO_3)_2$ had little effect on plant growth, suggesting the soil was not Ca deficient. All the organic amendments either had little effect on growth or reduced it as in the treatment with 5.0 g kg^{-1} fresh cowpea (Fig. 20). It appears that Mn toxicity was increased by these fresh organic additions. However, effects of the treatments on soil pH and soluble Mn were rather complex (Fig. 21). Although lime increased soil pH and decreased soluble Mn as predicted, additions of fresh cowpea green manure substantially increased both soil pH and soluble Mn, indicating the overiding effects of Mn dissolution and chelation by organic substances released from the fresh manures. Compared to cowpea, peach palm leaves virtually did not change soil pH (perhaps owing to its poorer nutrient content), but nearly doubled the soluble Mn concentration (Fig. 21). Thus, applications of green manure to high Mn soils may aggravate Mn toxicity.

Table 39. Treatment description for the greenhouse experiment on Mn toxicity in soybean.

TREATMENT NO.	DESCRIPTION
1	Control
2	Low lime, with 1.5 $cmol_c$ kg^{-1} as $Ca(OH)_2$
3	High lime, with 3.0 $cmol_c$ kg^{-1} as $Ca(OH)_2$
4	MgO, with 2.0 $cmol_c$ kg^{-1} as MgO
5	Low Ca, with 1.5 $cmol_c$ kg^{-1} as $CaSO_4.2H_2O$
6	High Ca, with 1.5 $cmol_c$ kg^{-1} as $CaSO_4.2H_2O$ and 1.5 $cmol_c$ kg^{-1} as $Ca(NO_3)_2$
7	Low ashed cowpea, with 2.5 g kg^{-1} of ground cowpea leaves ashed at 300 °C for 3hrs
8	High ashed cowpea, with 5.0 g kg^{-1} of ground cowpea leaves ashed at 300 °C for 3hrs
9	Low ashed peach palm, with 2.5 g kg^{-1} of ground leaves ashed at 300 °C for 3hrs
10	High ashed peach palm, with 5.0 g kg^{-1} of ground leaves ashed at 300 °C for 3hrs
11	Low fresh cowpea, with 2.5 g kg^{-1} of ground cowpea leaves dried at 70 °C
12	High fresh cowpea, with 5.0 g kg^{-1} of ground cowpea leaves dried at 70 °C
13	Low fresh peach palm, with 2.5 g kg^{-1} of ground leaves dried at 70 °C
14	High fresh peach palm, with 5.0 g kg^{-1} of ground leaves dried at 70 °C

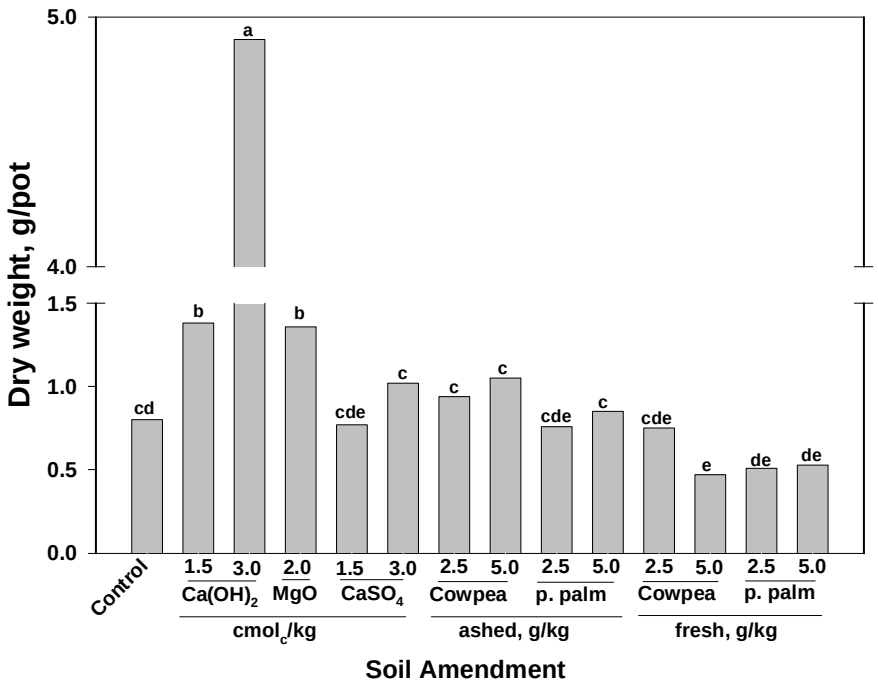

Figure 20. Dry weight of 4-w-old soybeans as affected by amendments. Letters above bars denote a significant difference at 95% probability.

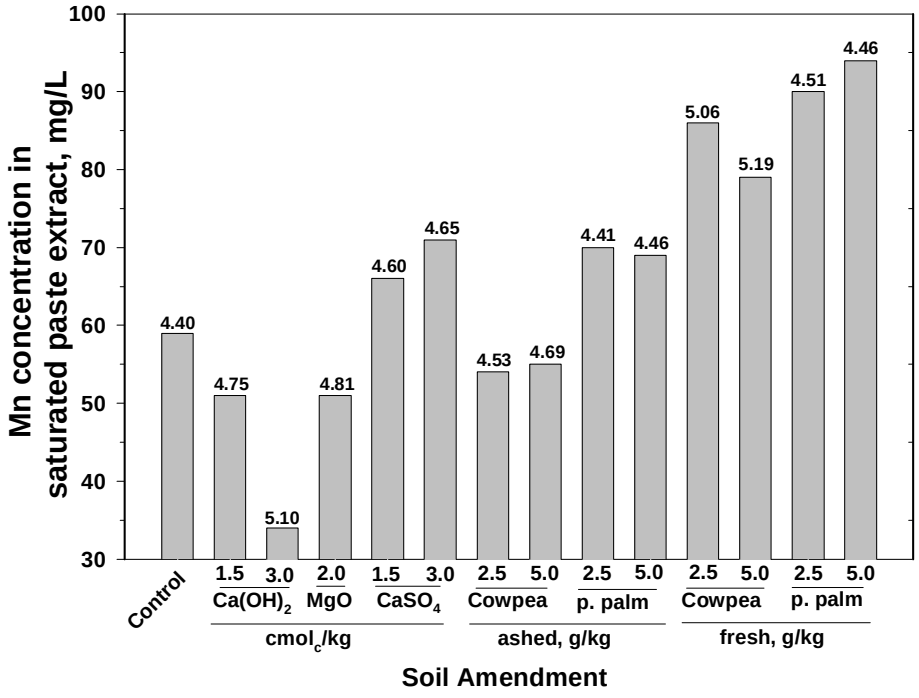

Figure 21. Saturated paste extract Mn concentration as affected by soil treatments. Numbers on the top of bars are soil pH in water (1:1 ratio).

3. *Calcium and Mg movement in sub-Saharan soils as influenced by ameliorant source and rate* (conducted by Y. Nino and G. Tiau with support from A. Juo and L. Hossner) - soil acidification and movement of Ca and Mg are being monitored in a Oxic Paleustalfs (Egbeda series) in Nigeria following applications of fertilizers and mulch. Nitrogen was applied at a rate of 150 kg ha^{-1} as either urea or ammonium sulfate. A mulch of *Alchornea* prunings was also applied at a rate of 150 kg N ha^{-1}. Two additional treatments consist of 75 kg N ha^{-1} as Alchornea prunnings in combination with 75 kg N ha^{-1} as either urea or ammonium sulfate. Soil samples were taken from incremental depths to 30 cm to evaluate soil acidification, Ca and Mg movement. Soil pH in the surface has decreased from a value of 6.2 to 4.5 following application of ammonium sulfate and two cropping seasons. Soil surface pH values, after two cropping seasons and application of different treatments, decreased in the following order: ammonium sulfate > Alchornea + ammonium sulfate > urea > Alchornea + urea > Alchornea > control with no fertilizer N or mulch. Yuji has now returned to Texas A&M University to complete laboratory analyses and interpretation of data collected on this experiment.
   While in Nigeria, Yuji and Dr. Tiau assembled data on exchangeable cations in surface soil layers for two long-term experiments monitored by IITA. These data sets will be analyzed and interpreted with the aim of improving predictions on Ca and Mg movement, soil acidification and residual lime effects in the sub-Saharan region. Description of the experiments and data sets are as follows:
   <u>Kandiudults, Onne, Nigeria</u>:
   Five lime rates (0-4 t ha^{-1}) with three replications cropped to a maize-cowpea rotation. Data set contains nine years of annual data for surface soil Ca, Mg, Al and K collected during the period of 1976-1986.
   <u>Oxic Kandiustalfs, Ibadan, Nigeria</u>:
   Three replications of different maize cropping strategies in a maize-cowpea rotation: (1) maize with residues removed, (2) maize with residues maintained and (3) maize-cassava intercrop. Data set contains annual surface soil Ca and Mg data for the period of 1972-1986.
4. *Distribution of leguminous species in tropical forests of Costa Rica* (conducted by R. Wesch, E. Gonzales and O. Vargas with support from A. Juo and L. Hossner) - legumes play important roles in tropical forests due to their contributions to N_2 fixation and nutrient cycling. A study in Costa Rica was designed to determine which soil properties, if any, affect the occurrence and distribution of leguminous tree species in both wet and dry tropical forests, to make small-scale inventories of the legume populations of these same forests, and to study the soil ameliorative effects of legumes and non-legumes.
   Tree and soil surveys were undertaken in both forests. Soil properties found to influence legume occurrence in the dry forest were texture and exchangeable Mg content. Exchangeable K, Ca and available P were influential on the occurrence of the member of the *Leguminosae* subfamilies. In the wet forest, soil properties found to influence legume occurrence were levels of available P and exchangeable Al. In additions to these, other variables such as texture and exchangeable Ca and Mg were influential on the occurrence of the legume *Pentachethra macroloba*, a very abundant species in this forest. Based on the Shannon index of diversity, legume species were most diverse in the dry forest, followed by Ultisol and Inceptisol sites in the wet forest. Difference in the soil under legumes and non-

legumes in the tropical forest include levels of exchangeable Ca, pH and total molybdenum.

External Funding and Support

Collaborators at intensive sites are conducting laboratory, greenhouse and field trials on various aspects of soil acidity management. Estimates of their funding contributions to this output are contained in values provided for Objective 1, Output 2.

OTS/Costa Rica senior and technical staff time, transportation, laboratory and computing facilities provided for R. Wesch's thesis are estimated at $6,000. Wesch's graduate work was supported through a $25,000 fellowship from the Peace Corps.

Travel and Meetings Attended

- Nguyen Hue - travel to Philippines to initiate evaluations of lime, gypsum and organic input treatments in field trials at San Antonio. January 17-23.
- Jot Smyth - travel to Brazil and South Africa to discuss local experiences and assimilate pertinent knowledge in soil nutrient diagnosis and remediation for NuMaSS, and to become familiar with Philippine research site and initiate plans for workshop. March 7-31.
- Yuji Nino - travel to IITA at Ibadan, Nigeria to initiate experiments in collaboration with Dr. G. Tian of IITA on Ca and Mg loss/depletion under cropping and N fertilization of Alfisols. March 9 - November 30.
- Jot Smyth - present a paper on NuMaSS at PCCMCA meetings in Guatemala, work with collaborator in Honduras on field, greenhouse and laboratory P experiment data, and provide technical backstopping to UCR collaborators in Costa Rica. April 13-22.
- Lloyd Hossner, Frank Hons and Frank Smith - travel to Mali to assist collaborators in on-farm compost/nutrient management trials, assess progress of nutrient interaction trials, provide backstopping assistance to ongoing project activities and conduct project's mid-term socio-economic survey. June 20-July 14.
- Jot Smyth and Russell Yost - travel to Bolivia to assess/assist in tree crop programs, visit to CIAT, Cali to explore potential collaboration, and technical backstopping assistance to ongoing activities in Costa Rica. November 28 - December 15.

Relevant Publications, Reports and Presentations at Meetings

Hue, N. 1999. Trip report to the Philippines. Decision Aids for Integrated Soil Nutrients Project. 7p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hue_Phil_0199.pdf)

Hue, N.V. and D.L. Licudine.1999. Amelioration of subsoil acidity through surface application of organic manures. J. Environ. Qual. 28:623-632.

Hue, N.V., S. Vega, and J.A. Silva.1999. Manganese toxicity as affected by organic amendments. p. 119-127. *In*: T.A. Tindall and D. Westermann (eds.), Western Nutrient Management Conf. Vol. 3. Salt Lake City. UT.

Hossner, L., F. M. Hons and F.J. Smith. 1999. Report on trip to Mali. Decision Aids for Integrated Soil Nutrients Project. 7p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hossner_Hons_Smith_MaliRept_0699.prn.pdf)

Smyth,T.J. 1999. Presentation of ADSS as part of NuMaSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Smyth, T.J. 1999. Report on travel to Brazil, South Africa and Philippines. Decision Aids for Integrated Soil Nutrients Project. 16p.

(http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Smyth0399_World_Rept.pdf)
Smyth, T.J. 1999. Report on trip to Guatemala, Honduras and Costa Rica. Decision Aids for Integrated Soil Nutrients Project. 16p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Smyth_CAmerica_0499Rept.pdf)
Wesch, R.A. 1999. The occurrence and diversity of tree legumes as influenced by soil properties in selected tropical forests in Costa Rica. M.S. Thesis, Texas A&M University, College Station, TX. 187p.

Output 2 Enhancing the knowledge base for the N decision support system - collecting, developing and synthesizing soil, plant and management information to improve the diagnosis and recommendations of location-specific N problems.

Diagnosis and recommendations for N are based on N content of total above ground dry matter production for the targeted crop yield. Fertilizer N requirements are based on the differences between total above ground N needs and the N supplied by soil, manures and atmosphere. Unlike acidity and P, there is no single measure of soil N that allows an evaluation of N source efficiencies and mineralization transfer coefficients among different soils and climates. Coefficients must, therefore, be derived for a variety of soil, crop and climate conditions using prior experimentation whenever possible. Given the size of this task, acquisition and refinement of coefficients will be an ongoing process throughout the entire project. Transfer coefficients for contributions of biologically fixed N need to be categorized in terms of a variety of factors: the legume source and its nutrient requirements, innoculant availability, C constituents, plant age, soil conditions, and timing and method of incorporation. Nitrogen losses need to be either incorporated into to transfer coefficients or predicted.

Milestone events for this output, during the 5-year plan are as follows:

annual improvement of the database on N transfer and mineralization coefficients to encompass a broader combination of soil, crop and climate conditions;
prediction of N losses - year 3; and
guidance for legume management and prediction of BNF contributions - year 5.

Lead Investigators and Contributors

Shaw Reid provides overall coordination to activities related to the N module. During the past year investigators at Cornell and N.C. State University received funding to continue the collection and calibration of N transfer and mineralization coefficients. Funding was also provided to all universities to work on legume management. N.C. State, Cornell and Hawaii also received funding to work on prediction of N losses. However, all other U.S. members of the N group and testing site collaborators have begun to share via correspondence their findings upon searches of the existing literature as well as core experiment activities related to N management. Overseas collaborators contributing to this output during year 3 are listed according to their respective institutions:

Center for Agricultural Research/University of Costa Rica - Alfredo Alvarado, Gabriela Soto and Raphael Salas

Institute d'Economie Rurale/Mali - Mamadou Doumbia and Aminata Sidibe (Sotuba Station); Adama Coulibaly and Zoumana Kouyate (Cinzana Station)

International Rice Research Institute - Thomas George

Philippine Rice Research Institute - Teodula Corton

Progress

1. *Calibrating N coefficients* (Shaw Reid, Pedro Luna, Dan Israel, Michael Wagger, Deanna Osmond and Jot Smyth) Pedro Luna continued to refine the procedure for summarizing and identifying meaningful differences among coefficients collected from published investigations. Once the procedure is suitably developed for the data base on maize in South America it will be applied to other commodities like sorghum, millet and upland rice.

The data set used in this activity consists of N fertilization trials in six publications

encompassing crops grown between 1973 to 1991 in four locations: (1) EMBRAPA/CPAC for the Cerrados of Brazil, EMBRAPA/Manaus for both (2) the "uplands" ('terra firme') and (3) "lowlands" (alluvial floodplains) in the Brazilian Amazon, and (4) Yurimaguas for the uplands of the Peruvian Amazon.

Adjustments to results reported last year involved use of nested models for a particular relationship with a *likelihood ratio test*. The difference between the -2 log likelihood terms for each model was calculated. Then the absolute value of this difference was compared with a Chi-square distribution with degrees of freedom equal to the difference in the number of parameters between the two models (Wolfinger, 1992). This test allowed to determine for a particular relationship whether the four data sets from Amazon and Cerrado had: (a) similar slopes but different intercepts, (b)similar intercepts and slopes, (c)similar intercepts and different slopes.

Maize grain yield relations to fertilizer N (relationship 2) was expressed on a relative yield basis within each individual trial. The Linear-Plateau procedure (Marquardt method in PROC NLIN of SAS version 6.12) was used to obtain functions representing the linear response of maize grain yield to applied N, along with the critical amounts of N beyond which no profitable yield response occurs. The linear response segment of each yield vs. applied N relation, was used to select data for the relation between N recovery and applied N. Thus, data falling in the yield plateau segment were exclude from this analysis. A summary of results for each relationship is described in the following.

a. Relationship 1: *aboveground N accumulation vs. grain yield* - the four data sets have similar slopes and different intercepts, and can be represented by individual reduced models (Table 40) (Figure 22).

Table 40. Functions for relations between aboveground N accumulation and grain yield in multiple crop-years of trials at each South American location..

DATA SET	FUNCTION[a]
1: Cerrado, Brazil	N accumulation = 0.023Grain yield - 7.84
2: Amazon "upland", Brazil	N accumulation = 0.023Grain yield + 10.81
3: Amazon "lowlands", Brazil	N accumulation = 0.023Grain yield + 5.86
4: Amazon "upland", Peru	N accumulation = 0.023Grain yield - 3.54

[a] Units are in kg ha^{-1}.

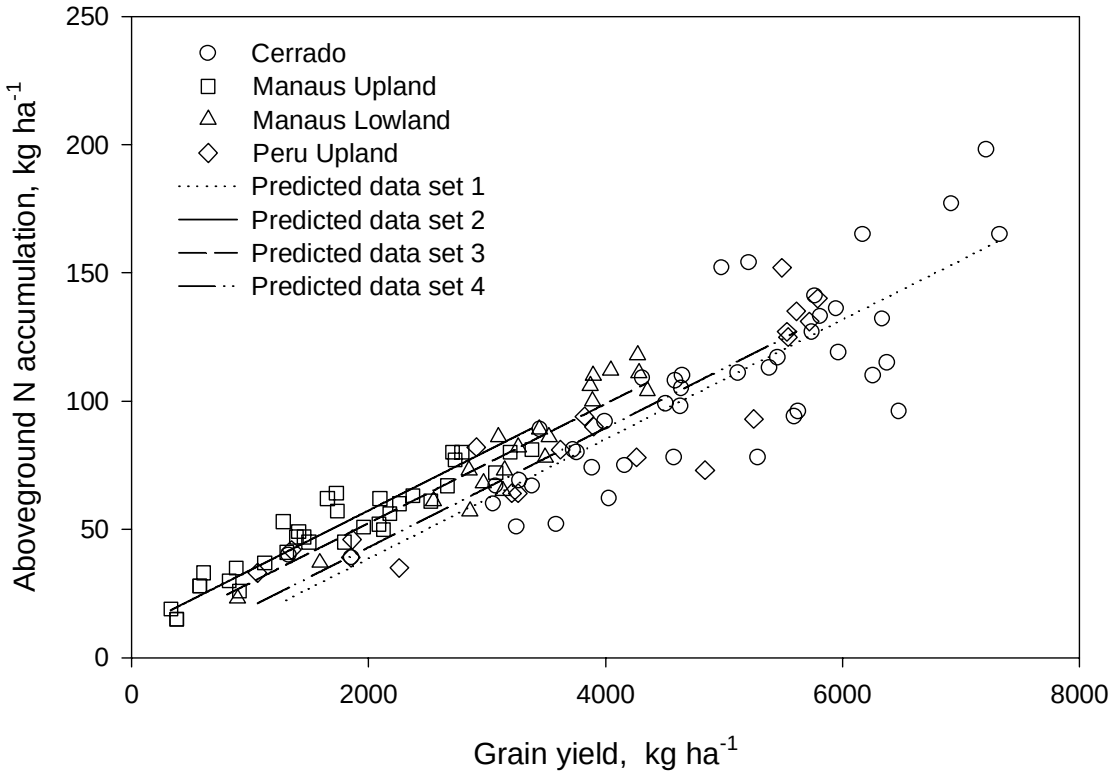

Figure 22. Relation between aboveground N accumulation and maize grain yield in four maize data sets for Cerrado and Amazon regions of South America.

b. Relationship 2: *grain yield vs. applied N* - data sets 1 and 3 need to be represented by individual full models, whereas data sets 2 and 4, with similar slopes and intercepts, are represented by a common reduced model (Table 41). Examples of these relations are shown for Cerrado data in Figure 23 and upland data for Manaus and Yurimaguas in Figure 24.

Table 41. Equations for relations between relative maize grain yield and applied N (kg ha^{-1}).

DATA SET	FUNCTION
1: Cerrado, Brazil	Rel. grain yield = $54.92 + 0.483N - 0.00128N^2$
2: Amazon “upland”, Brazil	Rel. grain yield = $31.88 + 0.842N - 0.00245N^2$
3: Amazon “lowland”, Brazil	Rel. grain yield = $58.55 + 0.667N - 0.00263N^2$
4: Amazon “upland”, Peru	Rel. grain yield = $31.88 + 0.842N - 0.00245N^2$

The linear-plateau response functions and amounts of fertilizer N to attain yield plateaus indicated that N required to reach optimum yield was ranked among data sets in order of 1> 2 and 4 > 3 (Table 42). Examples of these relations are shown for the Cerrado in Figure 25 and

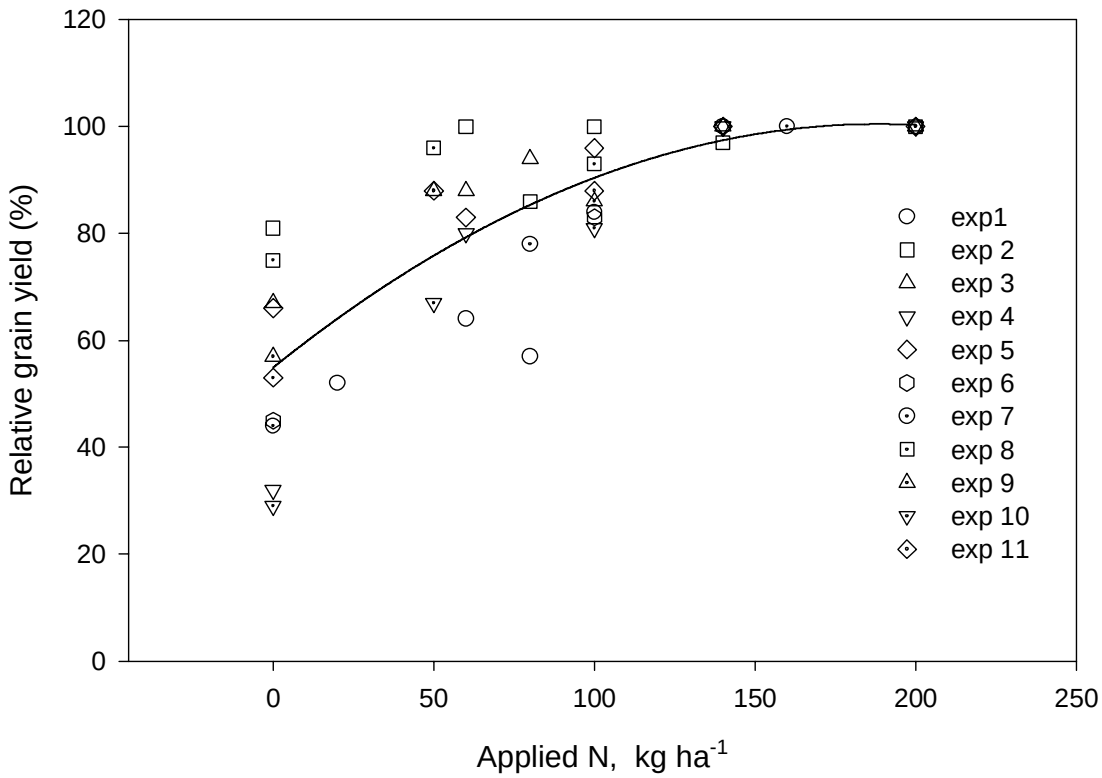

Figure 23. Observed and predicted relative grain yield of maize in Cerrado trials as a function of applied N.

uplands at Manaus and Yurimaguas in Figure 26.

Table 42. Linear response functions, critical levels of applied N and yield plateaus for data sets from the Cerrados (1), Amazon uplands, and Amazon lowlands near Manaus, Brazil.

DATA SET	LINEAR-PLATEAU	CRITICAL N (kg ha^{-1})	PLATEAU (%)
1	Y = 56.79 + 0.3436N	125	99
2 and 4	Y = 31.64 + 0.8189N	74	92
3	Y = 57.34 + 0.6804N	57	96

Ranges in maximum yield values and N concentrations for grain and stover within each of the 4 data sets were determined by taking the maximum observed yield of each trial within applied N rates corresponding to the linear response segment of the predicted equation (Table 43). Once incorporated to NuMaSS, range values in yield and N content will help users to select realistic target values. The average values will be included as default target values for each subregion.

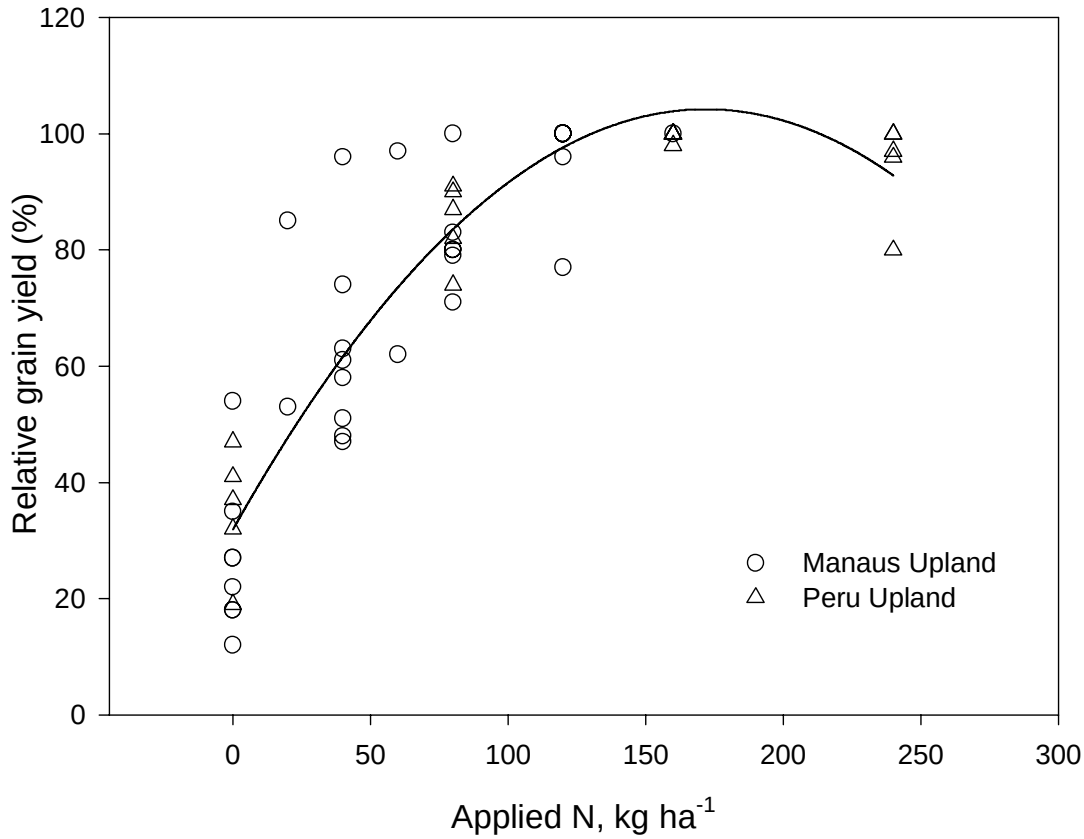

Figure 24. Observed and predicted relative maize grain yield for Amazon upland sites in Peru and Brazil as a function of applied N.

Table 43. Critical applied N levels, and range and mean values of optimum maize yield and N concentrations in grain and stover among trials within each data set for South America.

DATA SET[a]	OPTIMUM APPLIED N	OPTIMUM GRAIN YIELD		N CONCENTRATION			
				GRAIN		STOVER	
		RANGE	MEAN	RANGE	MEAN	RANGE	MEAN
	kg ha^{-1}	----- t ha^{-1} -----		%			
1	125	3.7 - 6.5	5.3	1.14 - 1.89	1.50	0.36 - 0.94	0.60
2	74	1.1 - 2.7	2.0	1.46 - 1.69	1.60	0.71 - 1.29	0.89
3	57	2.6 - 4.3	3.4	1.44 - 1.76	1.62	0.48 - 0.86	0.64
4	74	3.2 - 5.3	4.2	1.69[b]	1.69	0.22 - 0.27	0.25

[a] 1 = Cerrados, Brazil; 2 = Amazon upland, Brazil; 3 = Amazon lowland, Brazil; 4 = Amazon upland, Peru
[b] No range in values were reported in the original publication

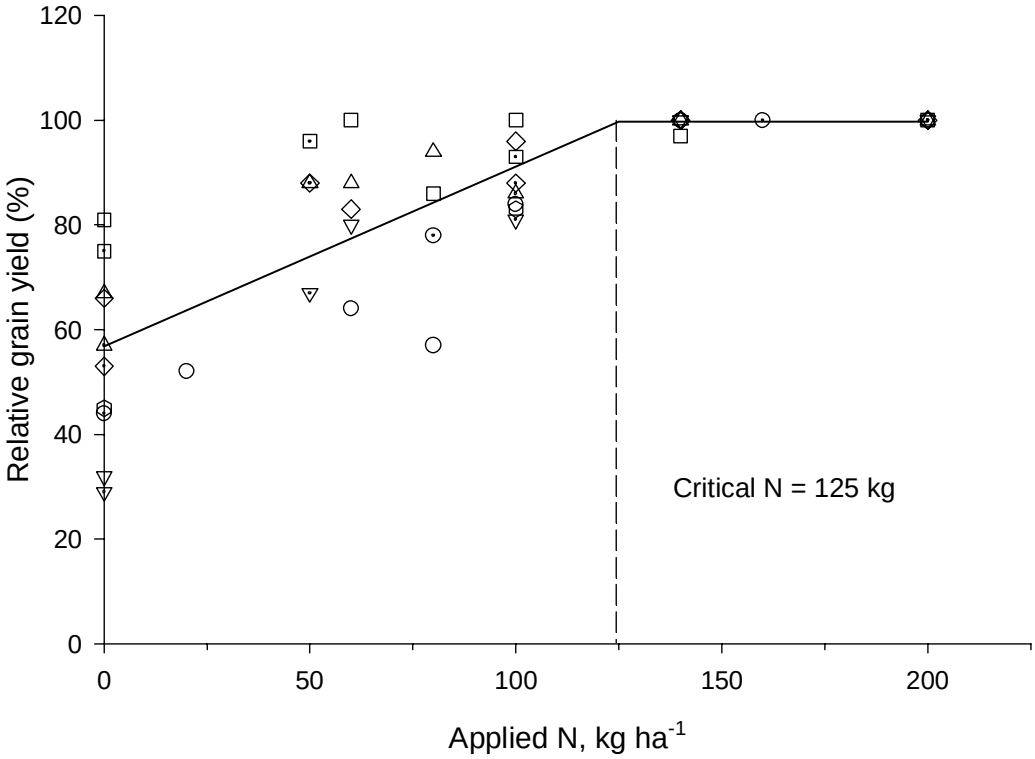

Figure 25. Relative maize grain yield of Cerrado trials as a function of applied N and predicted linear-plateau equation.

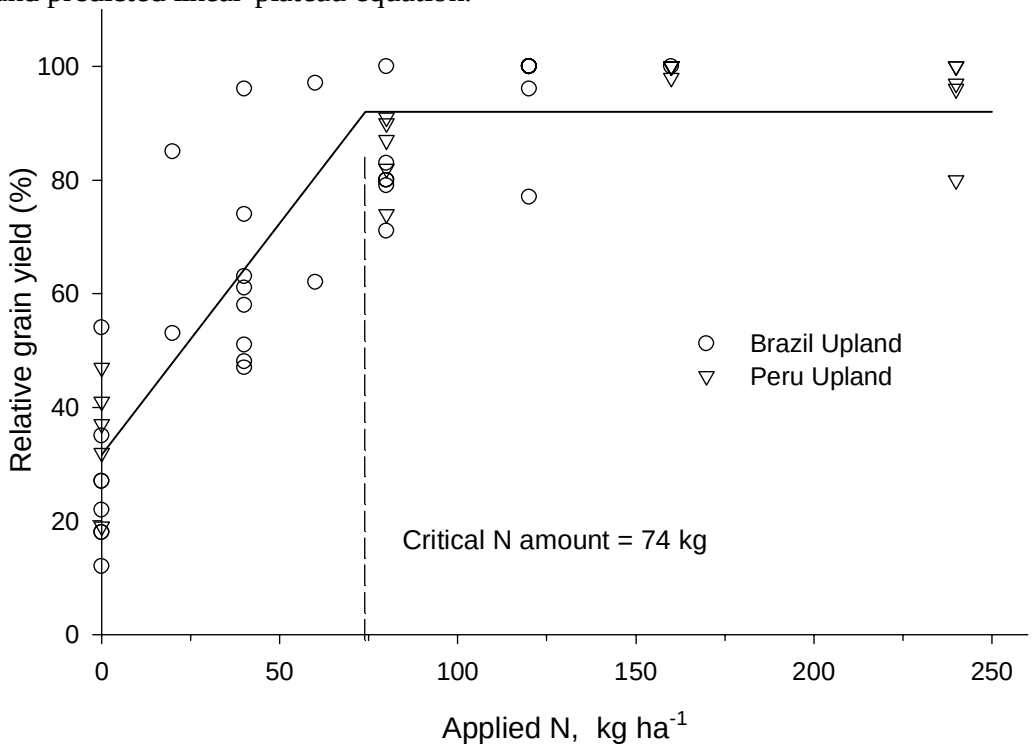

Figure 26. Observed data and linear-plateau function for Amazon upland data.

c. Relationship 3: *nitrogen recovery vs. applied N* - there were no differences in intercept or slope for data sets 1, 2 and 4; they are therefore represented by a single reduced model. Data set 3 is represented by an individual function (Table 44). The efficiency value of 0.43 is greater than the one previously reported for these data (0.31). This is the result of excluding fertilizer N treatments above the critical levels from the current statistical analysis.

Table 44. Equations among the four data sets for plant N recovery as a function of applied N.

DATA SET[a]	FUNCTION
1, 2 and 4	Nitrogen recovery = 0.43N
3	Nitrogen recovery = 0.61N

[a] 1 = Cerrados, Brazil; 2 = Amazon upland, Brazil; 3 = Amazon lowland, Brazil; 4 = Amazon upland, Peru.

d. *Native soil N contributions* - there was considerable variability in soil N contributions both within regional dataset and between regions. Calculations of fertilizer N needs are affected by the soil N variability. The Cerrado data set, for instance, has soil N values ranging from 39 to110 kg ha^{-1} (Table 45). Range and average soil N values will be included in NuMaSS to provide reference information for users to consider when determining appropriate values for their location-specific conditions.

Table 45. Ranges and mean values of soil N supply to maize for each data set.

	SOIL N SUPPLY TO MAIZE	
DATA SET	RANGE	MEAN
	---------- kg ha^{-1} ----------	
Cerrados, Brazil	39 - 110	69
Amazon upland, Brazil	15 - 45	31
Amazon lowland, Brazil	23 - 86	55
Amazon upland, Peru	33 - 46	39

e. *Green manure N contributions* - many of the N trials in the Cerrados also contained treatments with N supplied as incorporated legume cover crops. Across nine separate species of leguminous cover crops, there was a linear relation between dry matter yield of legumes and aboveground N accumulation in legumes. The relation was as follows:
Dry mat. N acc. (kg ha^{-1}) =8.63 + 0.0216Dry mat. yield (kg ha^{-1})
Efficiency of N supplied as green manure was determined as the slope of the regression between green manure N recovery by maize (corrected for soil N supply) and N applied as green manure. The resultant N efficiency factor was 0.39.

Although the relation between N accumulation and dry matter yield of cover crops in the Amazon was similar to the Cerrados, preliminary analysis suggests that the N efficiency factor for legume green manures is lower for corn in the Amazon than in the Cerrados.

f. *Application of compiled data for maize* - this can be illustrated by considering a situation where a farmer in the Cerrados wishes to produce an optimum maize yield (5.3 t ha^{-1}) using a green manure crop that will produce 1.0 t dry matter ha^{-1}. The fertilizer N recommendation uses the algorithm as described in Objective 1, output 1:

Nfert = (Yr*Ncr) - [Nsoil + (Ngreen man.*Cgm) + (Nmanure*Cm)] / Ef

Using values from the tables presented herein,

$$\text{Nfert} = \frac{114 \text{ kg N ha}^{-1} - [69 \text{ kg N ha}^{-1} + (30 \text{ kg N ha}^{-1} * 0.39 \text{ kg N ha}^{-1} \text{ kg}^{-1} \text{ N ha}^{-1})]}{0.43 \text{ kg N ha}^{-1} \text{ kg}^{-1} \text{ N ha}^{-1}}$$

= 77 kg fertilizer N ha^{-1}.

2. Assistance in NuMaSS evaluation at core sites (S. Reid, D. Israel and D. Osmond in support of T. Corton, T. George and M. Doumbia) - during the year and prior to the release of NuMaSS 1.0, team-members assisted investigators at the core sites in developing fertilizer N recommendations for ongoing experiments and on-farm trials to evaluation recommendations of N, P and lime from NuMaSS. Paper versions of the algorithms were provided to enable prediction of fertilizer N recommendations for targeted crop yields of different commodities in the field trials. Appropriate crop and soil coefficients were researched in existing literature and defined following consultations with on-site collaborators. This information exchange, primarily via e-mail, enabled the initiation of field investigations prior to the release of NuMaSS software in August 1999. Further details of these experiments are reported under Objective 1, Output 2.

3. Predicting N losses (S. Reid, T. George and D. Israel) -

4. Guidance for legume management (S. Reid, D. Israel, M. Wagger, A. Wollum, F. Hons and T. George) -

External Funding and Support

Collaborators at intensive sites are conducting laboratory, greenhouse and field trials on various aspects of soil acidity management. Estimates of their funding contributions to this output are contained in values provided for Objective 1, Output 2.

Travel and Meetings Attended

- Jot Smyth - travel to Brazil and South Africa to discuss local experiences and assimilate pertinent knowledge in soil nutrient diagnosis and remediation for NuMaSS, and to become familiar with Philippine research site and initiate plans for workshop. March 7-31.
- Jot Smyth - present a paper on NuMaSS at PCCMCA meetings in Guatemala, work with collaborator in Honduras on field, greenhouse and laboratory P experiment data, and provide technical backstopping to UCR collaborators in Costa Rica. April 13-22.
- Lloyd Hossner, Frank Hons and Frank Smith - travel to Mali to assist collaborators in on-farm compost/nutrient management trials, assess progress of nutrient interaction trials, provide backstopping assistance to ongoing project activities and conduct project's mid-term socio-economic survey. June 20-July 14.
- Jot Smyth and Russell Yost - travel to Bolivia to assess/assist in tree crop programs, visit to CIAT, Cali to explore potential collaboration, and technical backstopping assistance to

ongoing activities in Costa Rica. November 28 - December 15.

- Gabriela Soto - travel to Raleigh to work with collaborators on data for field trial in Costa Rica on peach palm residue decomposition/nutrient release. August 17 - September 2.
- Dan Israel - travel to Mali to assist collaborators in assessment of cowpea BNF among lime, P and N treatments in ongoing field trials. August 21-27.

Relevant Publications, Reports and Presentations at Meetings

Blanton-Knewtson, S.J., L.R. Hossner, Z. Kouyate and M. Doumbia. 1999. Effect of Sahel rainy season on inorganic soil nitrogen availability. 91st Annual Meeting. Amer. Soc. Agron., Oct. 31-Nov. 4, 1999, Salt Lake City, UT.

Luna, P., T.J. Smyth, D.L. Osmond, D.W. Israel. 2000. Collection and Evaluation of Literature on Crop Responses to N Application – The Case of Corn (Maize in South America). (http://intdss.soil.ncsu.edu/sm-crsp/Download/Documents/Corn_NDSS_0299.pdf)

Reid, W.S. Presentation of NDSS as part of NuMaSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

George *et al*. 1999. SM-CRSP Project Decision Aids for Integrated Nutrient Management: On-Farm Testing. Paper presented at the Decision Aids Workshop, 6-11 September, PhilRice, Philippines.

Hossner, L., F. M. Hons and F.J. Smith. 1999. Report on trip to Mali. Decision Aids for Integrated Soil Nutrients Project. 7p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hossner_Hons_Smith_MaliRept_0699.prn.pdf)

Smyth, T.J. 1999. Report on trip to Guatemala, Honduras and Costa Rica. Decision Aids for Integrated Soil Nutrients Project. 16p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Smyth_CAmerica_0499Rept.pdf)

Smyth, T.J. 1999. Report on travel to Brazil, South Africa and Philippines. Decision Aids for Integrated Soil Nutrients Project. 16p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Smyth0399_World_Rept.pdf)

Soto, G. 1999. Trip report to North Carolina. Decision Aids for Integrated Soil Nutrients Project. 13p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Gabriela_Rept_0899.pdf)

Output 3 Enhancing the knowledge base for the phosphorus decision support system - collecting, developing and synthesizing soil, plant and management information to improve the diagnosis and recommendations of location-specific P problems.

The P module in NuMaSS is at a younger stage of development than the modules for acidity and N. For many conditions, predicted P requirements are uncertain or undetermined; existing coefficients need to be improved and expanded over more soil and crop conditions; our current ability to diagnose and prescribe P requirements for tree species is limited. Rock phosphate exists in local deposits and, when of high quality and applied to acid soils or perennial crops, it can be as effective as soluble fertilizer P. To enable users to consider rock P options algorithms are needed that predict their performance based on data and information available to the intended users.

Milestone events for this output, during the 5-year plan are as follows:

Development of P diagnosis, prediction and fertilizer guidance for tree crops - beginning in year 1 and completed in year 3;
Refinement of soil P coefficients for improved P predictions - beginning in year 2 and completed in year 3;
Predicting effects of P fertilizer placement - year 3; and
Prediction and fertilizer guidance for rock P use - beginning in year 4 and completed in year 5.

Lead Investigators and Contributors

Russell Yost provides overall coordination to activities related to the P module. During the past year Yost received funding to continue P activities related to tree crops and predicting placement effects of fertilizer P. Cox continues to work on testing short-term methods for estimating P buffer coefficients using residual funds from years 1 and 2. Hossner continues testing diagnostic methods and P recommendations in on-station and on-farm trials in Mali. All U.S. members of the P group and testing site collaborators continued to share via correspondence their findings upon searches of the existing literature. Yost, Cox and Hossner are also contributing on P-related issues of the core experiments at the three intensive testing sites. Collaborators contributing to this output during year 2 are listed according to their respective institutions:

University of Hawaii - X. Wang, X. Shuai, Adrian Ares, and Richard Kablan.
University of Costa Rica - Alfredo Alvarado, Rafael Salas, Eloy Molina, Lidieth Uribe, Gabriela Soto and Jimmy Boniche.
Amazonia National Research Institute/Brazil - Charles Clement, Newton Falcão, Kukio Yuyama.
University of the South, Sewanee, TN - Deborah MacGrath
Institute d'Economie Rurale/Mali - Mamadou Doumbia, Aminata Sidibe, M. Keita, O.B. Coumare.
ICRISAT/Niger - A. Bationo
International Rice Research Institute - Thomas George and J. Quiton.
Philippines Rice Research Institute - Teodula Corton, Josephina Lasquite
Ilagan Research Station - Quirino Ascuncion and Danilo Tumamao.
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Progress

1. *Tree crops*

Incorporating a peach palm knowledge base in NuMaSS - (supervised by Adrian Areas with collaboration of Eloy Molina at UCR, Charles Clement at INPA, Deborah MacGrath at Univ. of the South, Sewanee, TN, Ernst Mutert at PPI-Singapore, and Russell Yost) several modifications will be made to NuMaSS to accommodate the particular characteristics of perennial tree crops. For peach palm, four growth stages were proposed:

Phase 1 - before out-planting nursery seedlings in the field,

Phase 2 - before first harvest, relatively low biomass accumulation rate,

Phase 3 - rapid biomass accumulation, and

Phase 4 - nearly constant biomass accumulation.

Values of probability of acidity constraint, and P and N deficiency as well as response functions should be determined for every phase.

To estimate probabilities of P deficiency in peach palm, versions in English and Spanish of a survey on probabilities of P deficiency were distributed among some 25 worldwide experts with field experience on peach palm. About 40% of the experts answered the survey. Some of the experts indicated that knowledge for peach palm is insufficient to fully answer the survey. Results of the survey are being processed.

P cycling in peach palm systems (supervised by Adrian Ares with collaboration of Eloy Molina at UCR, Charles Clement at INPA, Deborah MacGrath at Univ. of the South, Sewanee, TN, Ernst Mutert at PPI-Singapore, and Russell Yost) a P cycling model in peach palm systems is being developed using the STELLA software. Data from studies on plant residue decomposition and P release by UCR collaborators, root decomposition by D. McGrawth and biomass accumulation from different sources have been used to develop the model. Information is still insufficient on P mineralization rates from the soil P organic pool, root turnover and net P plant uptake.

2. *Test and improve estimates of P buffer coefficients*

Comparision of laboratory with NuMaSS predictions of buffer coefficient (collaboration of A. Sidibé, M. Keïta, O.B. Coumaré and M.D. Doumbia at IER, A. Bationo at ICRISAT-Niger, and R. A. Kablan and R. S. Yost at Univ. Hawaii) - it has long been believed that rainfall was the most limiting factor for crop production in Mali as well as in many regions of West Africa. Recently, many research programs have provided evidence that soil fertility is indeed the number one factor limiting crop production in these regions (Stroosnijder, 1981; Doumbia et al., 1998; Breman et al., 1998). Phosphorus is the most deficient and plant growth-limiting nutrient in these soils (Poulain, 1976; Manu et al., 1991; Doumbia et al., 1993). Jones and Wild (1975) documented that P deficiency could be so acute that plant growth stopped once the seed reserve of P had been depleted.

Fertilizer recommendations in Mali were made according to Chaminade (1965). For economical reasons corrective rates were recommended (Piéri, 1973). For the case of P, rates of about 20 kg ha^{-1} are recommended for most crops in most soils of Mali (Poulain, 1977). When applied, these rates lead to soil mining (Van der Pol, 1992; Kieft et al., 1994). For increased crop production and sustained soil fertility, there is a need for recommendations based on factors such soil properties, yield goal, etc. These site specific recommendations are better handled by decision aids. The P module of NuMaSS offers a strong potential in making

these recommendations. It gives P recommendation on the basis of primarily soil clay and plant available P contents (Yost et al., 1992). However, the model needs to be adapted to soil and socio-economic conditions of West Africa. Phosphorus requirement predictions are made according to the following formula:

$P = (B_c - B_o) * a_1/a_2 * D/10$,

where:

P = P requirement prediction, B_c = P critical level in the soil, B_0 = P initial level in the soil, a_1 = long term retention rate of P, a_2 = P buffer coefficient, and D = depth of application.

This investigation was undertaken to test P-buffer coefficients used by NuMaSS to estimate fertilizer P requirement. Forty five soil samples representing major agricultural regions of Mali and Niger were selected on the basis of texture class. These samples were analyzed for clay content, Bray-1 P, and pH (Sparks et al., 1996). Laboratory incubations were performed to determine P buffer coefficients in the laboratory. These coefficient were compared to those predicted by the P module in NuMaSS from clay percentage alone. Known rates of P, in solution form, were added to soil (1:1), and the mixtures were allowed to dry at room temperature during 6-7 days. The slope of the regression obtained by plotting extractable P against the amount of P added was considered as P buffer coefficient (a_i). This coefficient was compared with the coefficient (a_m) obtained by the model, according to the following formula (Yost at al., 1992):

$a_m = 0.6665 * \exp(-0.02739 * \text{clay})$.

The soils selected represented cropping systems including rainfed agriculture, bottom land (waterlogged), and irrigated systems, of both Mali and Niger. These soil samples were classified into two textural and two Bray-1 P groups. The textural groups included: (i) the clay soils such as the soils from Kollo, Niger (56% clay), Moursi, Mali (43% clay) and Longorola bf, Mali (35% clay) and (ii) the sandy soils such as the Seno-S, Mali (3.9% clay) and Dounga S. (2% clay). The Bray-1 P level groups included: (i) soil with “sufficient” P such as Kollo and Longorola bf (with >10 mg P kg^{-1}) and (ii) soils very deficient in P such as Moursi and Tanda, Niger (with < 1 mg P kg^{-1}). The soils Kollo and Longorola bf were high in both clay and Bray-1 P.

The different buffer coefficients are shown in Figures 1 through 7. In general, buffer coefficients estimated by the model are higher than those determined by incubation. In addition, sandy soils have higher buffer coefficients. Figure 1 shows buffer coefficients for a sandy soil (Seno), a loamy soil (Kita), and a clayey soil (Moursi 1). The steeper slope (higher buffer coefficient of 0.87) for the sandy Seno has a lower buffering capacity. In contrast, the less steep slope (lower buffer coefficient of 0.21) for the clayey Moursi 1 has a higher buffering capacity. The Moursi 1 is a soil under irrigated rice cropping system. Similarly, Figure 2 shows the same pattern between the sandy soil of Dougouba and the clayey soil of Longorola BF. The Longorola BF is a bottom-land soil (waterlogged for about 3-4 months) under rice production. Figure 3 shows the above patterns for soil from different cropping systems of Niger, while Figure 4 shows the buffer coefficients for the very sandy soil from Dougouba in relation to the clayey soils.

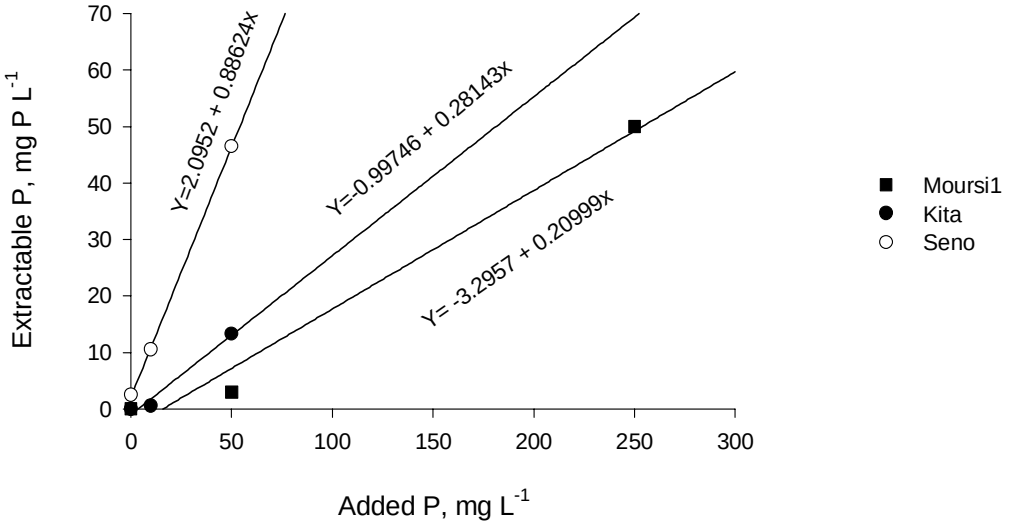

Figure 1. Buffer coefficient of selected soils (Incubation method)

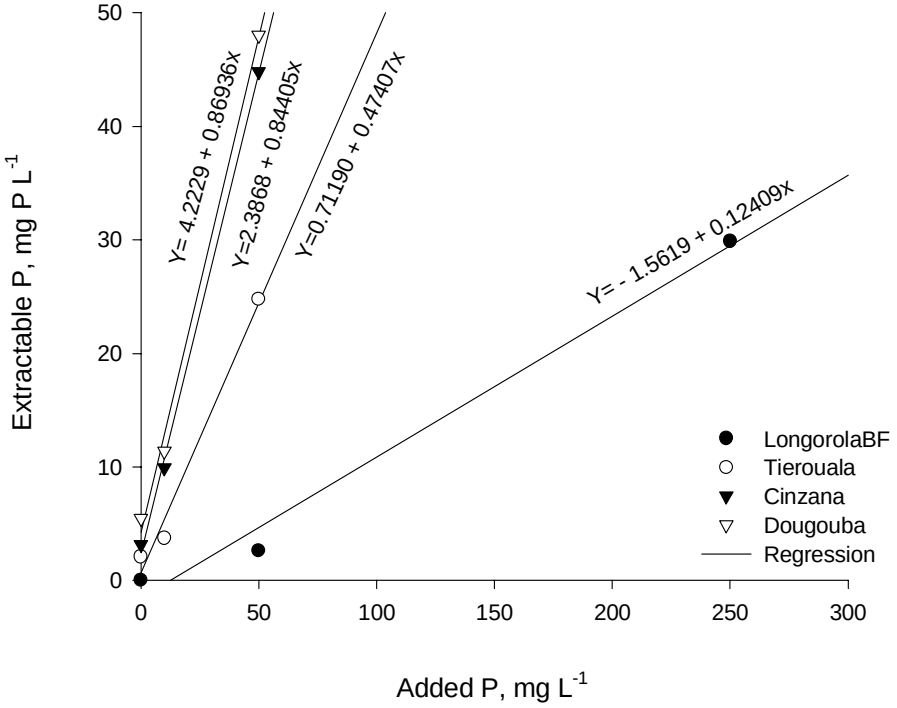

Figure 2. Buffer coefficient of selected soils (Incubation method)

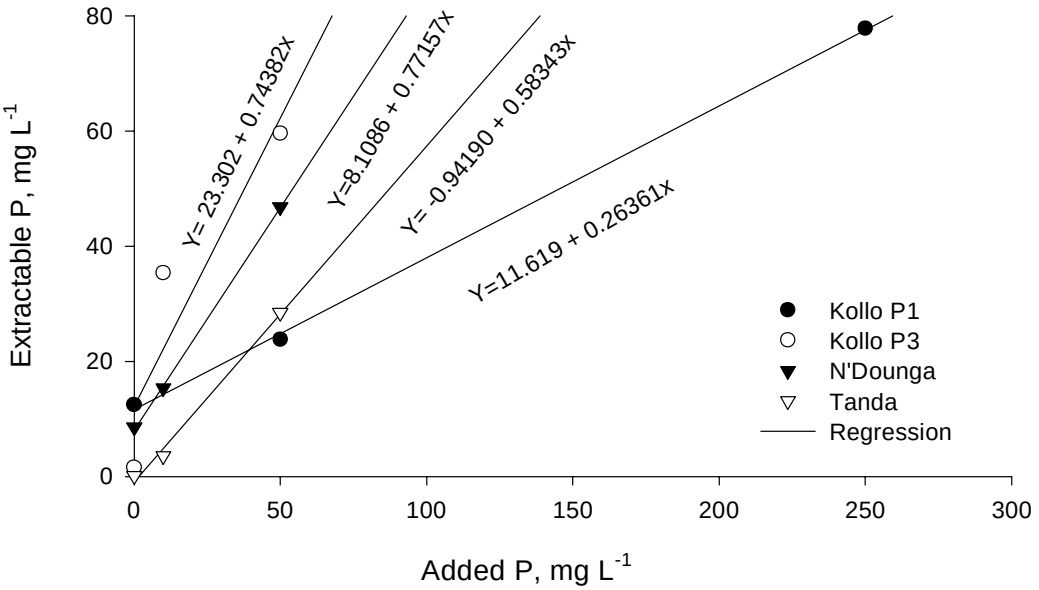

Figure 3. Buffer coefficient of selected soils(Incubation method)

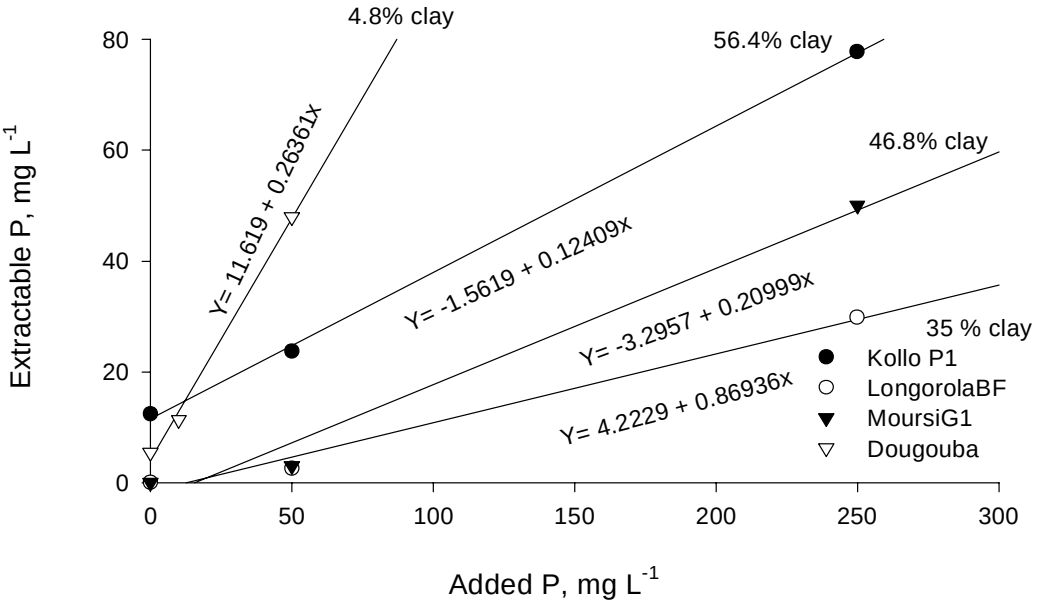

Figure 4. Buffer coefficient of selected soils (Incubation method)

Figure 5 compares buffer coefficients estimated by PDSS2 (i.e. the P module of NuMaSS) (a) with those measured in the laboratory incubation (b). The PDSS2 predicted buffer coefficients were significantly higher than the coefficients measured by the laboratory incubation, as indicated by Duncan test. Figure 6 shows the comparison buffer coefficients a_m(PDSS2) and a_i (Incubation) of 10 samples collected from major cropping systems of Mali. The model predicted a significantly higher coefficient for the clayey Moursi 1 soil (under irrigated rice cropping system), but not for the clayey Longorola BF soil (a bottom-land soil, waterlogged for about 3-4 months, under rice production). This comparison on the basis of clay percentage suggests that there may be some other factor affecting the buffer coefficients besides clay in these soils.

For soil containing a wide range of clay content (2 to 56%), steeper slopes (indicating higher buffer coefficients, but lower buffering capacity) were obtained for sandy soils (0.87 for the sandy, Seno soil), in contrast to the less steep slopes for clayey soils (0.21 for the clayey, Moursi 1 soil). Buffer coefficients derived from the model (a_m) were significantly higher than those obtained from laboratory incubation (a_i). In addition there were differential responses of soils to methods of buffer coefficient determination. The buffer coefficient derived from the model (a_m).was significantly higher for the clayey Moursi 1 soil (under irrigated rice), but not for the clayey Longorola BF soil (bottom-land, waterlogged soil). Predictions from NuMaSS will tested in field plots against “conventional” fertilizer recommendations. These tests will be implemented with sorghum and maize. One of the limitations of the current version (1.0) of NuMaSS is that it does not make recommendations using phosphate rocks (PR). Attempts will be made to include phosphate rocks, especially Tilemsi PR, into the recommendations. Phosphate rocks will require defining both specific P buffer coefficients and soil P depletion rates in relation with the use of PR’s.

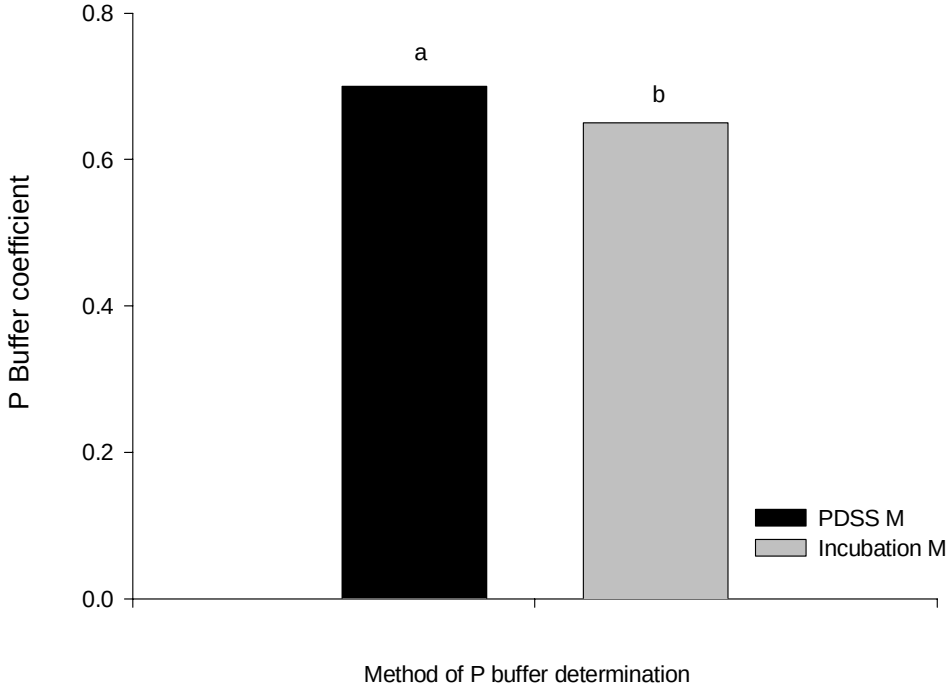

Figure 5. Comparaison of methods of determining P Buffer coefficient. 'a' and 'b' indicate Duncan classes

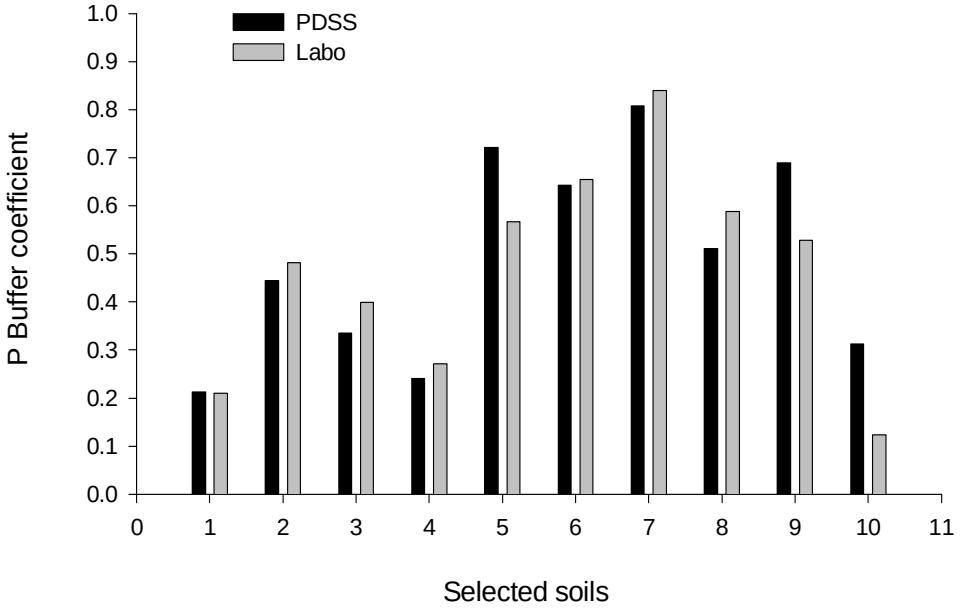

Figure 6. P Buffer coefficient of selected Malian soils

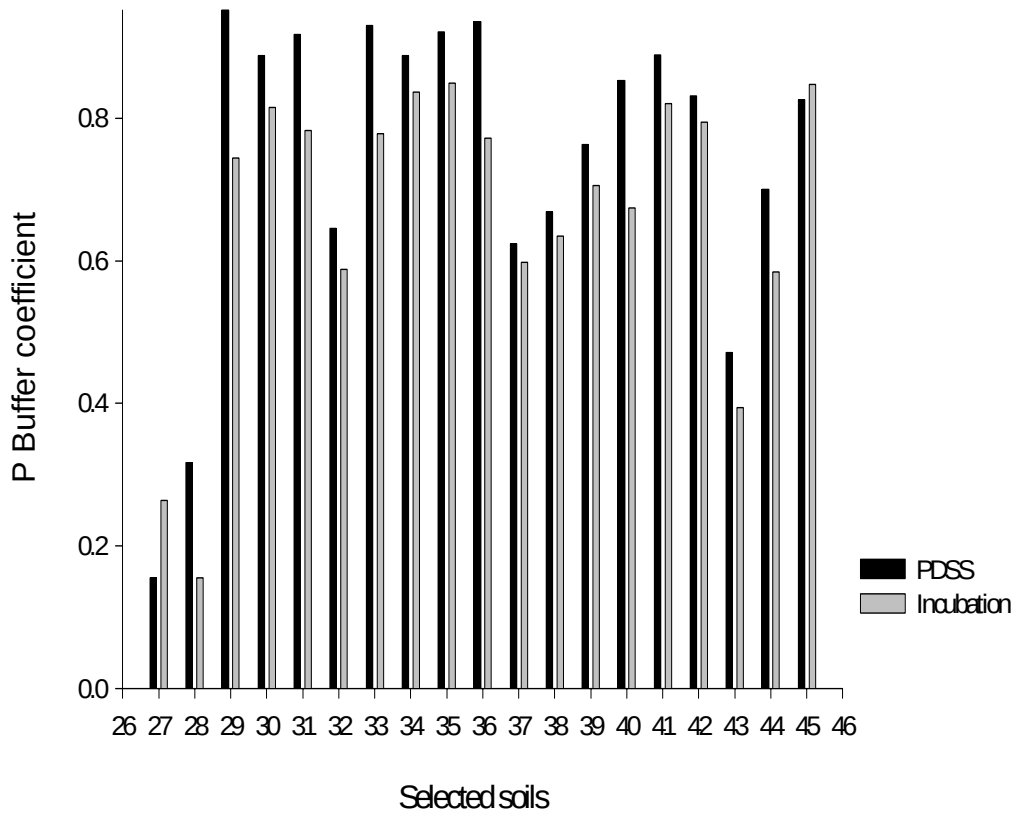

Figure 7. P Buffer coefficient of selected soils of Niger

Short-term, laboratory method simulating field-estimates of P buffer coefficients - (collaboration of Alfredo Alvardo and Eloy Molina at UCR, Teodula Corton and Josephina Lasquite at PhilRice, Thomas George at IRRI, Quirino Ascuncion and Danilo Tumamao at Ilagan Research Station, and supervised by Fred Cox) the Soils Laboratory at the University of Costa Rica (UCR) analyzed selected chemical and physical properties of 62 soils. This data is to be used to determine the relationship between P sorption and soil properties for soils which vary in clay type from crystalline to non-crystalline for use in NuMaSS. Countries of origin and number of samples for each were Costa Rica 45, Ecuador 8, Panama 3, Hawaii 3, Honduras 2, and Guatemala 1. Data included nutrients extracted by Modified Olsen, pH, organic matter, acidity, texture, amorphous Fe, amorphous Al (AmAl), and KOH-extractable Al (OHAl).
The soils were also mixed with 0, 35, 70, and 140 ug P cm^{-3}, allowed to dry, and extracted

with both Modified Olsen and Mehlich 3 to determine the change (recovery) in soil test P per unit of P applied. Soil test P generally increased linearly with rate of P applied. The slopes determined from these relationships were termed the Delta MOP and Delta M3P. These slopes were markedly greater for soils with high initial soil test P, so soils with P greater than 20 ug cm^{-3} by either method were deleted from further evaluation. Soils with high soil test P do not require diagnosis and interpretation by NuMaSS anyway. There were 19 of these soils, although 7 were greater than 20 ug cm^{-3} by only one of the extractants, and that extractant was not consistent. Another six soils were deleted from further evaluation because data from the two methods did not concur well, usually because the relationship with Mehlich 3 P was not linear. Thus, data from 25 soils was deleted, leaving a set of 37 with 15 Andisols, 20 Ultisols, and 2 Oxisols.

Delta MOP and Delta M3P were correlated with soil properties, first for all soils and then by soil order for the Andisols and Ultisols. The only factors showing a linear relationship were KOH-extractable Al (KOHAl) and amorphous Al (AmAl). In prior work (Alvarado, 1984; Blakemore, 1983) KOHAl was found to be a quick, reliable estimate equaling about half that of the AmAl in Andisols. In the present set of data KOHAL is about two-thirds that of AmAl. These relationships are slightly curvilinear (concave).

The relationships between forms of extractable Al and Delta M3P were slightly better than those between soil properties and Delta MOP, and were better for either all soils or the Andisols than for the Ultisols. The highest r-values, however, were only around 0.5, so only about 25% of the variation was being explained by these forms of Al. The relationship between Delta M3P and AmAl appears similar for all three soil orders. Primary interest in Al, however, is for use with the Andisols, and oxalate-extractable Al appears greater for Andisols than for the Ultisols and Oxisols.

There was not a linear correlation between Delta MOP and amorphous Al with the Andisols. Alvarado and Buol (1985) found an exponential relationship which I suggested for use in NuMaSS in March 1999. The current observations sent by Eloy Molina were compared with the Alvarado and Buol data and the relationship was similar for the two sets of data. There are a number of outliers, especially at low oxalate-extractable Al and low Modified Olsen buffer coefficient, and likely the data from these observations should be checked again for correctness.

The relationship between Delta M3P and clay content from the Costa Rica data also was compared with previous data for the Ultisols. There is a set of observations on Delta M3P from field data that serves as one of the foundations of the P module and Delta M3P was shown to be similarly related to clay content for the two sets of data. Again, there are some outliers in the relationship, but this may be due to a mixture of clay types, as in some of the Ultisols from Costa Rica there may be both kaolinite and allophane. An analysis of clay type may explain some of this variation.

Another observation from the current set of data is that the concentration of P extracted by Mehlich 3 and Modified Olsen are very similar. Sobral and Cox (1998) reviewed concentrations of soil P obtained from various extractants and found Mehlich 3 P very close to Bray 1 P, but that from Modified Olsen was only about 53% as much those two. It is unusual, therefore, to find Mehlich 3 and Modified Olsen to be as close as in the Costa Rica

data. This comparison is based on the 37 soils with the four rates of P applied, and the relationship appears similar for the three soil orders.

From the observations thus far, the following may be concluded:

(1) Nineteen soils had P levels too high to give a valid estimate of a P buffer coefficient that would be applicable for NuMaSS. Several of these, however, should be analyzed again for P sorption because of discrepancies between the two methods. Reruns need to be conducted on soils 90, 102, 104, 108, 114, 115, 116, and 117.

(2) There were also six soils in which the change in soil test P was not linear with P applied, so reruns should also be conducted on soils 89, 97, 98, 101, 107, and 112.

(3) There is more similarity in P concentrations extracted with Mehlich 3 and Modified Olsen than is expected. It is suggested that a set of standard samples be included in all laboratories for quality control.

(4) The relationship between the change in soil test P per unit of P applied (P buffer coefficient) and extractable Al in the Andisols, and with clay content in the Ultisols, was not especially good with the set of data from Costa Rica. However, the data do seem to generally adhere to the relationships derived previously and give them credence.

Refining and improving prediction of P buffer coefficients (collaboration by J. Quiton at IRRI, X Shuai at UH, with supervision by Russell Yost)

a. Estimating linear response plateau (LRP) equations - such estimations have often been a bit complicated because of the nonlinearity in the parameters of the equation. This has required the use of various nonlinear estimation routines such as SAS's PROC NLIN and the use of logical operators in the estimation equation (eq. 1). Xiufu Shuai has proposed a simplified expression to use in fitting the LRP models as well as multiple segment equations as listed below (eq. 2). The two equations were compared and the results appear to be identical.

Equation 1. A typical formulation of the LRP code for estimation using SAS Proc Nlin;-

```
proc nlin DATA=A NOITPRINT;                                (1.1)
   parms a=1.50 b=1 x0=200;
   file print;
   if x<x0 then do;              * LINEAR part of model;
   model y = a + b*x;
   der.a = 1;
   der.b = x;
   end;
   else do;                      * plateau part of model;
   model y = a +b*x0;
   der.a = 1;
   der.b = x0;
   end;
   bounds a>0, b>0, x0>3;
   if _obs_=1 & _model_=1 then do; * print out if 1st obs;
   plateau = a +b*x0;
   put x0= plateau=;
   end; run;
```

Equation 2. An improved linear plateau code -

```
proc nlin method=dud; parms node = 200 a=1.50 b= 1;      (1.2)
/* a is interception and b is the slope of the linear part */
model yldkgmn = a + b*min(n1, node); run;
```

Terminologies and symbols used in the models are shown in Table 46.

Table 46. Comparison of the traditional formulation of the LRP model with Shuai's formulation.

VARIABLES/PARAMETERS	SHUAI MODEL	LTPE LINEAR PLATEAU
Dependent variable	yldkgmn	Y
Independent variable	n1	X
Parameters		
critical value	node	X0
Slope	b	b
Intercept	a	a

Both models require the same number of parameters and use the same number of variables. Both rely on initial parameter estimates and both calculate the least squares according to the Method=DUD (this is the default in SAS). The plateau happens after the critical value. In the Shuai expression the plateau is expressed by selecting the minimum between X and X0 and definitely a plateau is reached when X becomes larger than X0. The LTPE method uses the "if-then" statement, which is equal to the minimum function in the Shuai expression. The advantage of the Shuai method is that it is simpler while the LTPE is the direct translation of the linear plateau model. The above data was tried using the two models and the results are identical.

b. Effects of differing expression of the buffer coefficient and critical level - the original formulation of the equation to predict soil P requirement was based on the following equation in the simplest form:

Preq = (bc - b0)/a2 (1.3)

where:

Preq = the phosphorus requirement in order to increase extractable soil P (b0) to the extractable P critical level (bc), kg P ha^{-1},

b0 = field measurement of extractable P by the same method as used for bc and a2, mg dm^{-3},

bc = critical level of extractable P by method used for bc and a2, mg dm^{-3}, and

a2 = buffer coefficient representing the amount by which extractable P increases per unit applied P fertilizer using the same extractable P method as b0 and bc, (mg dm^{-3})/(kg P ha^{-1})

The coefficients bc and a2 are, in turn, estimated from clay percentage (Cox, 1994; Cox, Oct.7, 1999 memo):

Mehlich 3 critical level = 30.7*exp(-0.0336*clay) (Cox, 1994), or

Mehlich 3 critical level = 27.8*exp(-0.0266*clay) (Updated with Smyth data, 10/7/1999), or

Mehlich 3 critical level = 7.1 + 29.3*exp(-0.066*clay) (Updated by further analysis, 10/7/1999)

Five equations were compared in ability to predict the P critical level for soils of differing clay percentage:

1. Quadratic-plateau (minimum), join point at the minimum Y;
2. Quadratic-plateau (random), join point located at optimum least squares (not necessarily at the minimum Y);
3. Linear-response plateau;
4. Mitscherlich (model proposed by Cox, 1994; Cox, Oct. 7, 1999); and
5. Exponential-plateau.

The above equations were compared in ability to predict the P buffer coefficient for soils of differing clay percentage. The data set used in this comparison were the same as assembled by Cox, Oct. 7, 1999, but include two soils from West Africa: Seno, 3.9% clay and buffer coefficient of 0.886, and Dougouba, 4.8% clay, buffer coefficient of 0.869.

Comparison of model fits to P critical level data and P buffer coefficient data are shown in Tables 47 and 48, respectively. The recommended equations, based on these results are:

P Critical Level = 30.2772 - 0.769*clay (clay<28.7634%) (1.4)

P Buffer Coeff = 0.8440 - 0.0193*clay (clay<36.7057%) (1.5)

Table 47. Comparison of various models in fitting P critical level data.

MODEL	b0	b1	b2	KNOT	RMS
QRP-min (1)	32.47	-1.1461	0.0134	-	28.8739
QRP-rand (2)	27.88	-0.4059	-0.0117	27.2484	29.8015
LRP (3)	30.2772	-0.769	-	28.7634	28.5346
Mitsch (4)	7.1220	29.2755	-0.0667		28.9484
Exp-RP (5)		31.7417	-0.0362	40.5814	29.3441

Table 48. Comparison of various models in fitting P buffer coefficient data.

MODEL	b0	b1	b2	KNOT	RMS
QRP-min (1)	0.5027	-0.10	0.02	-	0.0710
QRP-rand (2)	0.7969	-0.0117	-0.0117	34.507	0.0134
LRP (3)	0.8440	-0.0193	-	36.7057	0.0129
Mitsch (4)	0.0771	0.8692	-0.0467		0.0151
Exp-RP (5)	-	0.9337	-0.0398	46.6866	0.0143

As indicated above, both the P critical level and the P buffer coefficient are used to predict P

requirement (eq. 1.3). The combination of these two equations can produce some surprising sensitivity to initial extractable P levels. An example is the sensitivity of the relationship between P requirement and % clay to the initial soil P level (Figures 34 & 35). Phosphorus requirement increases substantially from low clay to high clay content, when initial P is 0, however, changing the initial P level from 0 to 1 results in the relationship shown in Figure 35.

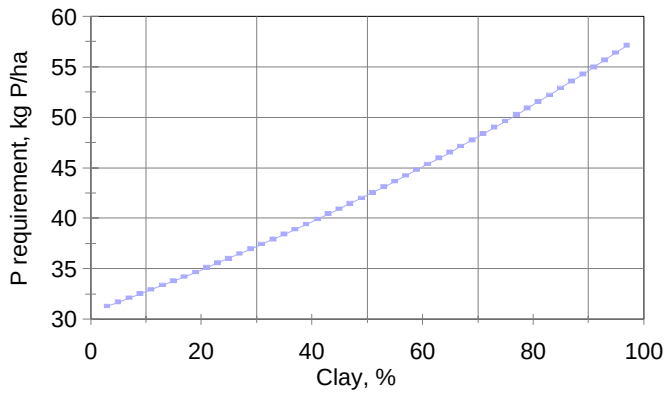

Figure 34. Effect of clay% on P requirement, PBC=exp(-0.04), PCL=30.7*exp(-0.0336*%clay), initial P=0.

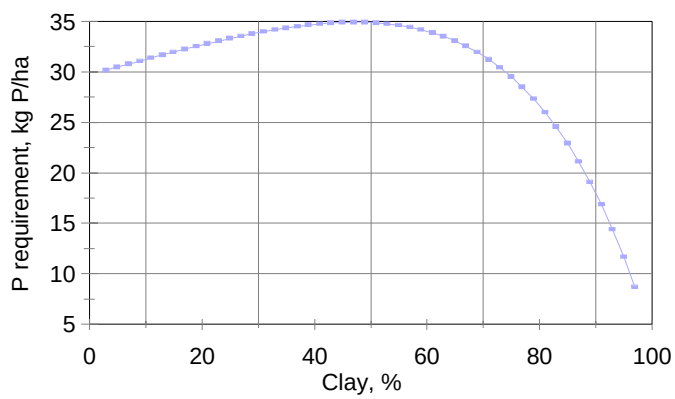

Figure 35. Effect of clay% on P requirement, PBC=exp(-0.04), PCL=30.7*exp(-0.0336*%clay), initial P=1

It was thought that perhaps expressing the PBC and PCL as LRP equations, based on the improved fit shown in Tables 47 & 48 would result in a smoother more realistic variation of P requirement depending on the % clay. However, as shown in Figure 36, the use of LRP models leads to a discontinuity.

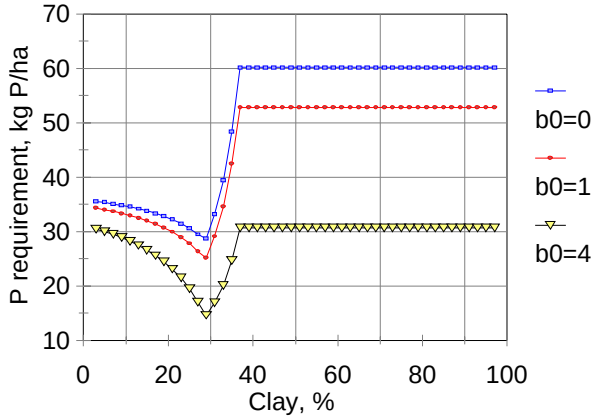

Figure 36. Effect of clay% on P requirement,
PBC=0.8440-0.0193*(%clay<36.7057), P=0,1,4.

None of the presently fitted equations seems to smoothly predict the change in P requirement as a function of % clay. Ideally, a single equation should be used for the prediction, however, this remains a challenge. The combined equation is

P requirement = (bc - b0)/a2

where,
P requirement = the phosphorus requirement in order to increase extractable soil P (b0) to the extractable P critical level (bc), kg P ha^{-1},
b0 = field measurement of extractable P by the same method as used for bc and a2, mg dm^{-3},
bc = critical level of extractable P by method used for bc and a2, mg dm^{-3}, and
a2 = buffer coefficient representing the amount by which extractable P increases per unit applied P fertilizer using the same extractable P method as b0 and bc, (mg dm^{-3})/(kg P ha^{-1}).

The erratic behavior of the combined equation around 30 % clay seems to occur because of the diffenent join points of the two equations:
bc = 30.277 - 0.769*min(clay, 28.8%) MS = 28.5
a2 = 0.844 - 0.0193*min(clay, 36.7%) MS =0.0130
Consequently, if the join points are fixed to the same value for both equations, such as using the mean of the two values used in equations for bc and a2, (28.8+36.7)/2 = 33, we can test the result using the proc nlin regression:
bc = 28.418 - 0.636*min(clay, 33%) MS = 28.0
a2= 0.867 - 0.0215*min(clay, 33%) MS =0.0129
The results, shown in the Figure 37, show the predicted effect of clay percentage on P requirement at various initial extractable P levels: 0, 1, 2.83, 4, and 8. The sharp discontinuity present in Figure 36 is now resolved into a smooth transition of dependency on clay percentage to no dependency at clay percentages above 33%.
We note that it is very difficult to find the proper combinations of field data for differing soil clay percentages and differing initial P levels to adequately test these predictions, but they

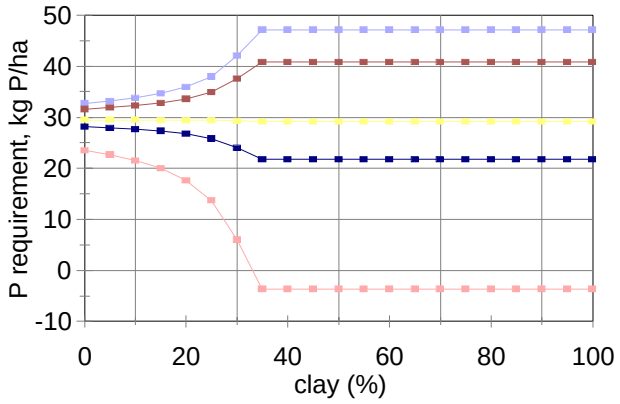

Figure 37. Effect of clay percentage on the overall P requirement (combined effects of clay on the P buffer coefficient and on the P critical level. Curves are from top to bottom, Initial P (b0) of 0, 1, 2.83, 4, and 8 mg P dm^{-3}.

appear to be an improvement over the previous approach of considering only the independent equations and assuming that the overall prediction will be correct and logical. We suggest that there is a principle here, the analysis and fitting of component equations to a model does not ensure that the combination of those predictions gives correct and logical results as well. It is clearly necessary to also test the aggregated prediction against experimental results. This principle relates to hierarchy theory in which one can go one level more detailed for mechanistic predictions but one level above for the context, limitations, and to explore the consequences of factors at the level of focus (Wu, 2000). We suggest that the high dependence of P requirement on clay percentage above 33% is consistent with our experience

in Hawaii, where clay is not a good predictor of differences in clay percentage in soils with greater than 40 to 45% clay (Jackman et al, 1997; Wang et al., 2000).

3. Predicting placement and use of organo-mineral fertilizers

Placement of fertilizers (collaboration of Mamadou Doumbia at IER with supervision of Richard Kablan and Russell Yost at Univ. Hawaii) - fertilizers are known to be important to supplement plant nutrients during a cropping season. For most fertilizer, especially N, inappropriate placement and timing of application can seriously undermine its availability to plants. The relative value of methods of fertilizer application was recognized as earlier as the 1930's. It has been reported that under favorable conditions, up to 90% of the fertilizer was saved by proper placement (Avodin, 1949). In England during World War II, when it became necessary to restrict the use of fertilizer, localized placement was widely used by farmers (C.T. de Wit, 1953). For example, it was reported that on soils seriously deficient, more than 50% of the fertilizer could be saved by drilling seed and fertilizer together (combine-drilling).

Recent studies have shown that source and composition of fertilizer and its proper placement are equally important in providing crops the nutrients needed for optimum performance. It is well known now that, the most satisfactory way to apply urea is through soil incorporation. When applied to soil surfaces, the ammonia is released from the urea (NH_2CONH_2 (Urea)+ H_20----->$2NH_3$ (ammonia) + CO_2) vaporizes and is lost.

Placement techniques available include broadcast application, band placement, injection, foliar application, and liquid application. For most farms in the U.S. for instance, fertilizer placement strategy is an integral part of farm plans, whether organic or inorganic fertilizer is used. For example it has been established that the time of manure application is known to be extremely important and may be dictated by site conditions. Often, environmental hazards are taken into consideration when planning for field manure application. Application of manure long before planting to allow the manure to break down before the crop uses the nutrients can lead to environmental hazards if N loss from the soil is a concern.

Among farmers who utilize manure, broadcasting is a common way to apply it. But it is believed that broadcast followed by incorporation in the soil is more beneficial. The potential for nutrient runoff can be minimized. Some studies have suggested that manure that is broadcast but never incorporated can lose about half of its total N (Minnesota, extension service, 1999).

In the Sahel, most farmers do not have access to large quantity of manure for their personal use and those who do have it usually lack the farm equipment to either transport it to the field or incorporate it into the soil. In addition, most fertility recommendations do not provide information on how fertilizer should be applied. Often, it is up to the farmers to make sure that the fertilizer is applied correctly. Therefore, farmers who do have access to manure are devising creative ways to apply it in their field. Innovative practices include soil surface spot application based on plant performance in different parts of the field during the previous growing season. The most interesting one was practiced by some farmers in Cinzana (Mali). In order to obtain a full coverage of the entire field, the farmer applies whatever quantity of manure available for the growing season in rows of some small piles or mounds (spot placement) across the entire field. The crop is then planted around the piles. Wether or not crop yield is affected by such fertilizer placement has apparently not been studied and therefore is not known. Only visual observation that indicated that plants near the pile grew faster and taller than those away from the piles has been recorded. Therefore, the overall objective of this study is two fold: 1) to test the null hypothesis of no difference in crop yield and no difference between soil chemical and physical properties subjected to two methods of fertilizer placement - standard broadcast (and mix in the soil) and spot placement (experiment 1); and 2) to understand fertilizer dynamics around the pile and how it affects crop growth and yield (experiment 2). The latter objective may ultimately help improve the method.

a. Experiment 1 - Broadcast vs. Spot Placement in this experiment the objective is to evaluate and compare the impact of the innovative fertilizer application (Spot Placement) and traditional broadcast methods on sorghum yield and soil properties.

Field site - Dougouba, near Cinzana experimental station, Mali

Treatments - Control (To), Broadcast and incorporation fertilization (T1), spot placement (T1).

Design - a completely randomized design with four replications.
Crop Variety - sorghum local variety label as CSM 219
Plot size - 10.5m x 4.8m, each plot consists of 6 plant rows: two borders and four harvest rows.
Planting density - 80cm x 40cm initially planted at 4 seeds per hole and thinned to two plants per hole for a plant population of 62,500plants ha^{-1} (nationally recommended plant population in Mali).
Data to be collected -
Soil: Chemical - pH, CEC, total N, exchangeable Ca, K, Mg, total C, available P, and the micronutrients Fe, Zn, Mn. Physical - texture, bulk density, and soil water characteristic (field capacity and wilting point). Depth of sampling: 0-15, 15-60cm.
Crop: Periodic plant height measurement (cm); three samplings of plant biomass for nutrient uptake determination: a) 45 days after planting, b) during the flowering period, and c) at maturity. One combined sample per treatment on the alternate second outer row for the first and second sampling and on the last two central rows for the last (maturity) sampling. Final yield of grain, biomass and head weight.
Data collected will be analyzed for nutrient content to evaluate difference in crop nutrient uptake in the course of the growing season. It is expected that crop nutrient uptake will depend on fertilizer application method (Singh &Singh, 1987) and crop growth phase.
b. Experiment 2 - Fertility gradient around fertilizer pile the fertilizer placement technique (manure pile) practiced in the region of Dougouba and Cinzana can be an asset to farmers only if the interaction with the surrounding soil is well understood. As described above, the manure pile is not incorporated in the soil. The manure pile is usually deposited on the soil surface at equidistances of about 2m (M. Doumbia, personal communication). Two or three seeds are planted at the edge and around of each pile, then another seed is sown between two consecutive piles. As of now, the distance between piles is arbitrary. Because plant growth and yield can be adversely affected if piles are placed too far apart, or valuable manure may be wasted if piles are placed too close, it became apparent that fertility gradient around the pile must be known if the intent is to improve the chance of wide range adoption of the technology. Therefore, the objective of this experiment is to evaluate soil fertility (chemical and physical properties) around the manure pile and determine its impact on millet yield.
Field Site - on farm at Dougouba, near Cinzana experimental station, Mali
Treatments - Control (To), Spot placement (T1).
Design - a completely randomized design with four replications.
Crop Variety - Local millet variety
Sampling technique - 1) Control plot: soil sample collected a different location in the field
2) Pile plot: Two sampling method will be used

i) a) center of the pile
   b) edge of the pile close the plant
   c) half way between two piles but close to a plant
   d) between the plant at the edge of the pile and the plant half way
ii) a) a systematic soil sampling of 50cm interval from the center of the pile to the plant half way between two piles.

Data to be collected -
Soil: Chemical - pH, CEC, total N, exchangeable cations (Ca, K, Mg), total C, available P, and micro-nutrients (Fe, Zn, Mn). Physical - texture, bulk density, and soil water characteristics (field capacity and wilting point). Depth of sampling: 0-15, 15-30, 30-60, and 60-90cm.
Time of soil sampling - at the beginning of the following growth phase: 3 leaves, 5 leaves, 50% flower, flag leaf and silky phase. Sampling strategies: 1) from crop stand: a) in the middle of the pile, at the edge of the pile near the stand, near the stand of the middle and between the stand of the middle and the next stand at the edge of the next pile. 2) systematic sampling: systematic sampling from the center of the pile of 50cm interval up to the middle.
Crop: Periodic plant height measurement (cm) at the following growing stage: 3 leaves, 5 leaves, 50% flower, flag leaf and silking
Final yield - grain, biomass, number of heads, and plant biomass sampling for nutrient uptake determination:
Data collected will be analyzed for nutrient content to evaluate difference in crop nutrient uptake in the course of the growing season. It is expected that crop nutrient uptake, growth and subsequent final yield will depend on fertilizer availability around the manure pile. Special attention will be paid to nutrient deficiency and its impact on crop growth stages in plants away from the pile.
<u>Organo-mineral fertilization</u> (collaboration of Mamadou Doumbia at IER with supervision of Richard Kablan and Russell Yost at Univ. Hawaii) - currently, the general belief is that the productivity of the soils of the Sahel under continuous land use can be sustained, provided soil erosion is controlled and soil organic and physical and chemical characteristics are maintained at a favorable level. For that to happen, combination of various cultural practices must be implemented in tandem or separately. Studies have shown that crop yields are superior in a production system where organic mulches are applied on a consistent basis than conventional system (IITA, 1986). This is likely due the ability of the organic mulch to protect the soil from raindrop impact, reduce runoff, minimize nutrient losses, minimize soil detachment and dispersion, and maintain soil infiltration rates. The establishment of contour ridging and furrow system can be a useful erosion control measure. Bonsu (1981) found that ridging reduced soil loss to 5.5 - 10.4 % of that from control plots in Ghana. Two adjacent ridges are sometimes tied together to develop a series of small basins that retain rainwater longer and hasten infiltration into the soil.
However, the use of the combination of inorganic and organic (manure) fertilizer is emerging as a serious technology, probably the most promising to improve the efficiency of fertilizer use, but the least understood. To date, numerous studies in the Tropics of Africa have shown that combinations of organic and inorganic fertilizers are the most efficient means of maintaining soil productivity and sustained crop yields. It is commonly believed that the benefit has mainly come from improved chemical and physical properties of the soil due to the organic portion of the mixture - improved soil water infiltration rate and structure, lower soil temperature, increased soil biological activities, increased of the humus content and the cation exchange capacity of the soil. Unfortunately, few if any of these listed advantaged has been scientifically verified. Currently, there are no guidelines for determining if manures

applied are adequate for crop requirements. Often, manure is applied without knowledge of its chemical composition nor that of the soil, during and after the application. Also it is often applied without knowing the extent of its physical improvement or whether additional quantities would improve yields through physical benefits even more. Usually optimum yields as well as nutrient efficiency can be achieved only if the amount of manure to be applied is appropriate considering the nutrient status of the soil, the nutrient needs of the crop to be grown and the nutrient content of the manure. Furthermore, data on the beneficial impact of either manure alone or mixed with chemical fertilizer on soil physical and chemical properties is virtually nonexistent in the literature.

It is to remedy this situation that the following experiments were installed at Sotuba Experimental Station, near Bamako. In Mali, most farmers know the value of fertilizer but use little of it. The reasons are that the amendment is either is too expensive to buy (case of mineral fertilizer) or they cannot produce enough of it (case of manure) to be used effectively in farming. Therefore, we believe one way to solve this problem might be to mix the two in small quantities "manure extender". One possible effect of such a mixture is that the beneficial physical properties of the manure can be used to the maximum by ensuring that the N, P, and K are not the most limiting as probably is usually the case without the mixture of N, P, K and manure.

a. Experiment 1 - Manure-DAP in this experiment the mixture combined two sources of fertilizers, manure and DAP (local fertilizers blend of (18-46-0) that is primarily used for P nutrition in sorghum. Because most of the soils in Mali are reported to be deficient in P, it is a primary concern in the appraisal of the soil resources in that country. Therefore, the objective here is to find out if manure can replace DAP, if farmers are not able to afford it, if so at what proportion and, most importantly, to better understand the complex interactive processes that take place when DAP is mixed with manure. The proportion of Manure-DAP mixture was based on the local recommended rates of 100 kg ha-1 DAP and 5t ha^{-1} of manure. We note that if a negative interaction is the result then it tends to indicate that the primary effect of the manure is the same as the DAP. However, if the interaction is positive, then it suggests that the manure is providing some benefit other than that provided by the DAP. Perhaps such an effect would be the physical or biological benefits of the manure?

The field was laid out as a completely randomized design with four replications. The treatment combinations (Table 49) were as follows:1) Control (CT),with no fertilizer applied, 2) Manure alone (MA), 3) Chemical fertilizer alone (CF) using DAP as the source, and 4) three mixtures (M1, M2 and M3) with varying proportions of P provided by manure and DAP. Except for the control, all other treatments received a total of 100 kg P ha^{-1}. Combined fertilizer was physically mixed prior to its application on the experimental area. Plot size was 10m x 4.8m. Crop variety was a local sorghum variety labeled as CSM 219. Planting density was 80x40cm, initially planted at 4 per hole and thinned to two per hole for a plant population of 62,500 plants ha^{-1} according to recommended plant population for the region. Each plot consisted of 6 rows of plant, two borders and four harvest rows.

Table 49. Treatment code, total applied P and percent distribution of applied P between manure and diammonium phosphate (DAP[a]).

TREATMENT CODE	TOTAL APPLIED P	% OF APPLIED P FROM MANURE	DAP
	kg ha^{-1}		
CT	0	0	0
MA	100	100	0
CF	100	0	100
M1	100	75	25
M2	100	50	50
M3	100	25	75

[a] The local fertilizer blend with 18-46-0 of N, P and K.

Data to be collected -
Soil: Chemical - pH, CEC, total N, exchangeable cations (Ca, K, Mg) organic matter and available P. Physical - texture, bulk density, and soil water characteristic (field capacity and wilting point).
Crop: Periodic plant height measurement (cm); three samplings of plant biomass for nutrient uptake determination: a) 45 days after planting, b) during flowering period, and c) at maturity. One combined sample per treatment on alternate second outer row for the first and second sampling and on the last two central row for the last (maturity) sampling
Soil Sampling - each plant sampling will coincide with soil sampling between 0-20cm and 20-40cm depths.
Data will be analyzed according laboratory techniques in place at the Laboratoire des Soils, Eaux et Plantes (LaboSEP) located at Sotuba experimental station, near Bamako.
b. Experiment 2 Manure-Complex Cereal fertilizer - in this experiment the mixture combined two sources of fertilizers, manure and "complex cereal fertilizer" (local fertilizer blend of 15-15-15) that is primarily used in sorghum production. The overall objective of this study is to evaluate the impact of different mixtures of the nationally recommended rate of manure and complex cereal fertilizer on sorghum yield and soil properties. The intent is to determine the ideal combination rate of the two fertilizers to maintain sorghum yield. Especially, the optimal rate that utilizes small amount of mineral fertilizer and greater amount of manure. The specific objective is to better understand the complex interactive processes that take place in the soil profile (in terms of soil chemical, physical and biological properties) when complex cereal is mixed with manure, especially why yield is increased when the two are mixed together.
This experiment was laid out as a split plot design with four replications. The treatment combinations were as follow: Manure treatment (main plot) with the following rates: 0, 1.25,

2.5 and 5t ha^{-1}. Mineral treatment (sub-plot) with the following rates: 0, ½ and 2 times the national mineral fertilizer recommended -100kg ha^{-1} NPK (15-15-15) + 50kg ha^{-1} urea. Plot size is10x4.8m. Planting density is 80x40cm initially planted at 4 per hole and thinned to two per hole for a plant population of 62,500plants ha^{-1}. Each plot will consist of 6 rows of plants, two borders and four harvest rows.

Data to be collected-

Soil: Chemical - pH, CEC, total N, exchangeable cations (Ca, K, Mg) organic matter and available P. Physical -tTexture, bulk density, and soil water characteristic (field capacity and wilting point).

Crop: Periodic plant height measurement (cm); three samplings of plant biomass for nutrient uptake determination: a) 45 days after planting, b) during flowering period, and c) at maturity. One combined sample per treatment on alternate second outer row for the first and second sampling and on the last two central row for the last (maturity) sampling.

Soil Sampling - Each plant sampling will coincide with soil sampling between 0-20cm and 20-40cm depth.

Data will be analyzed according laboratory techniques in place at the Laboratoire des Soils, Eaux et Plantes (LaboSEP) located at Sotuba experimental station, near Bamako.

External Funding and Support

Collaborators at intensive sites are conducting laboratory, greenhouse and field trials on various aspects of soil acidity management. Estimates of their funding contributions to this output are contained in values provided for Objective 1, Output 2. Additional estimates of contributions in kind from collaborators in the P activities are as follows:

- INPA and EMBRAPA assistance in activities at Manaus with transportation, labor, experiment maintenance and laboratories - $8,000.

Travel and Meetings Attended

- Jocelyn Bajita - travel to Hawaii to begin graduate studies at the Univ. of Hawaii on decision aids for nutrient management in the Philippines. February 20.
- Teodula Corton - travel to Univ. of Hawaii to work with collaborators on matters related to project field trials in San Antonio, Philippines. March 7-31.
- Fred Cox - travel to Australia to present a paper on the P module of NuMaSS at the 6th Int. Symp. on Soil and Plant Analysis. March 18-31.
- Adrian Ares - travel to Costa Rica and Brazil to work with collaborators on P experiments with peach palm in Costa Rica and assimilate pertinent knowledge for NuMaSS on tree crops in Brazil. March 14-27.
- Richard Kablan - travel to Mali to work with IER collaborators to prepare experiments associated with testing the P component of the project. June 2-5.
- Jot Smyth and Russell Yost - travel to Bolivia to assess/assist in tree crop programs, visit to CIAT, Cali to explore potential collaboration, and technical backstopping assistance to ongoing activities in Costa Rica. November 28 - December 15.

Relevant Publications, Reports and Presentation at Meetings

Ares, A. 1999. “Decision support systems for integrated nutrient management in agroecosystems.” Seminar at Instituto Nacional de Pesquisas da Amazônia, March 16 1999, Manaus, Brazil.

Ares, A. 1999. "Nutrient diagnosis and fertilization responses in perennial tree crops for the humid tropics: the case of peach palm (*Bactris gasipaes*) in Costa Rica, Brazil and Hawaii." Seminar at the University of Hawaii, May 12, Honolulu.

Ares, A. 1999. Report on trip to Brazil and Costa Rica. Decision Aids for Integrated Soil Nutrients Project. 10p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Adrian_Brazil_CRica_99Rept.pdf)

Cox, F.R. 1999. Report on a trip to Australia. Decision Aids for Integrated Nutrient Management. 3p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Cox0399_Australia_Rept.pdf)

Deenik J, Ares A. and Yost RS. 1999. Fertilization responses and nutrient diagnostic methods for peach palm (*Bactris gasipaes*). Nutrient Cycling in Agroecosystems 55 (4):1-13.

George, T. 1999. Long-Term Phosphorus Experiments in Asia. Poster presented at the ASA Annual Meetings, 31 Oct.- 5 Nov., Salt Lake City.

George *et al*. 1999. SM-CRSP Project Decision Aids for Integrated Nutrient Management: On-Farm Testing. Paper presented at the Decision Aids Workshop, 6-11 September, PhilRice, Philippines.

George, T., R. Magbanua, B. Tubana, J. Quiton, A. Almendras, W. Khatib, F. Cox, and R. Yost. 1999. Estimating buffer coefficients for the Phosphorus Decision Support System. Poster presented at the 6th International Symposium on Soil and Plant Analysis "Opportunities for the 21st Century: Expanding the Horizons for Soil, Plant and Water Analysis", 22-26 March 1999, Brisbane, Australia.

George, T., R. Magbanua, B. Tubana, J. Quiton, A. Almendras, W. Khatib, F. Cox, and R. Yost. 2000. Estimating buffer coefficients for the Phosphorus Decision Support System: preliminary comparisons among field and laboratory estimates from three Asian upland soils. Commun. Soil Sci. Plant Anal. (In press).

Hossner, L., F. M. Hons and F.J. Smith. 1999. Report on trip to Mali. Decision Aids for Integrated Soil Nutrients Project. 7p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Hossner_Hons_Smith_MaliRept_0699.prn.pdf)

Novais, R.F. and T.J. Smyth. 1999. Fósforo em solo e planta em condições tropicais. Federal Univ. Viçosa, Viçosa - MG, Brazil. 399p.

Sidibé, A., M. Keïta, O.B. Coumaré, M.D. Doumbia, A. Bationo, R. A. Kablan and R. S. Yost. 2000. Phosphorus buffer coefficients of selected soils of West Africa. Proceedings, InterCRSP/West Workshop, Kaolack, Senegal, January 1999.

Yost, R.S. and X. Wang. 1999. Presentation of the P module of NuMaSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Wang, X., J. Jackman, R. S. Yost, and B. A. Linquist, 2000. Predicting soil phosphorus buffer coefficients using potential sorption site density and soil aggregation (accepted). SSSAJ (2000).

Objective 3 Develop auxiliary tools to the integrated knowledge base to enable local agriculturalists to diagnose and solve soil acidity and nutrient problems that predominate within the social, economic and agronomic characteristics of their regional domains

Output 1 Extensive evaluation network - evaluation of products and capturing knowledge under a variety of location-specific conditions

Within this group we envisage a) individuals with knowledge that should be incorporated into products. b) individuals with field and laboratory data sets that could be used to evaluate products for location-specific conditions, and c) established networks who would be interested and benefit from using our products in their programs. Milestones in activities related to this task are project meetings held in years 1, 2, 4 and 5. Participants would be asked to consider relevance of planned tools to their local needs and suggest potential modifications or additions. In later years we would focus on obtaining feedback on evaluations of NuMaSS and auxiliary tools when applied to their local conditions.

Lead Investigators and Contributors

Deanna Osmond provides overall coordination to activities related to the network, but all U.S. project team members participate as they travel overseas and interact with network members. Collaborators from the following institutions (countries/regions) have agreed to participate in the network, contribute their nutrient management knowledge base and evaluate the decision support software prototypes and auxiliary tools under their location specific conditions:

IBSRAM Steepland Network (Asia)
IRRI Rice Consortium (Asia)
CIMMYT Regional Maize Program (Central America)
Potash&Phosphate Institute Andean Program (Central-Latin America)
IBTA (Bolivia)
ICRAF (Peru)
INIAP (Ecuador)
EMBRAPA (Brazil)
University of Viçosa (Brazil)
SRI (Ghana)
ISRA (Senegal)
Cedara Agric. Res. Station (S. Africa)

Some of these and many others attended the workshop held in Philippines and are active in the network.

Progress

1. *Visits to Network Member Sites*

   Through travel opportunities during the year, several members of the NuMaSS team have made worldwide contacts. Those listed below generated significant interest and mutual benefit to the program.

   Brazil -

   a. Field experiments with peach palm in Brazil - (Adrian Ares with local collaboration by Charles Clement, Newton Falcão and Kukio Yuyama at the Amazon National Research Institute(INPA) in Manaus, and Manoel Cravo and Jefferson Macêdo at EMBRAPA,

Manaus) as part of the effort to determine growth response, foliar and soil critical levels of peach palm to P additions, three field experiments on peach palm carried out by INPA researchers were visited and sampled during March 1999. One experiment was located at Rieda farm about 8 km from Manaus on BR-174, and two experiments were located at the Yuricam Farm, Rio Preto da Eva, on AM-10, about 100 km from Manaus. The experiment at Rieda farm was started on March 1996 with the objective of determining the optimal levels of N, P and K and the effect of liming, animal manure and micronutrients on peach palm for heart-of-palm production. Twenty treatments were set up in a replicated experiment on a "terra firme" (upland) Oxisol. The "terra firme" area is of Tertiary age and, therefore, older than the "várzea" or flood plains of Quaternary age. The "terra firme" soils known as "latossolo amarelo" in Brazil are common under peach palm and have high clay and moderate organic C contents. Ranges in fertilizer rates were between 0 and 180 kg ha^{-1} for urea, 0 and 90 kg ha^{-1} for TSP and 0 and 240 kg ha^{-1} for KCl. Peach palm responded to P additions six months after fertilization based on increased plant stem diameter and plant height (data not shown). At age 3 years of the experiment, we sampled soil at 0-5 cm and 5-20 cm and the third and sixth leaf of peach palm plants.

The other two experiments at Yuricam Farm were also on an Oxisol. Experiment I was set up in 1996 to study the effect of NPK levels, spacing and trunk numbers on heart-of-palm production. The experiment is a 3 x 5 factorial with three plant spacings (1x1, 1x2 and 1.5x2 m) and 5 different NPK levels. Ranges in fertilizer rates were between 0 and 225 kg ha^{-1} for N, 5.5 and 39.3 kg ha^{-1} for P and 74.7 and 224.1 kg ha^{-1} for K. A randomized complete block design with three reps was followed. We sampled the plots with plants at the 2 m by 1 m spacing within two blocks out of three. Results at six months after fertilization have indicated a response to P additions for the 2 x 2.5 m spacing treatment. Also, recent measurements showed that P additions (39.3 vs 10.9 kg ha^{-1}) increased the number of harvested stems which, in turn, positively correlated to stem diameter, plant height and number of stems.

Experiment II within Yurican Farm was set up in 1996 to determine the effect of increasing levels of NPK on peach palm fruit production. There are 10 treatments with P amounts ranging from 0 to 59 kg ha^{-1} and K_2O doses varying between 0 and 224 kg ha^{-1}. The experiment followed a completely randomized design with three replications. At 26 months after planting, stem diameter and height for peach palm plants under all fertilization treatments were higher than those for the control but there were no differences among the treatments with nutrient additions.

Soil and foliar sampling for experiments I and II at Yuricam farm was performed as at Rieda farm. In experiment II, an older leaf (determined as the total number of leaves divided by two) has been sampled recently and foliar nutrient data from this tissue will be compared to those from the 3rd and 6th leaves.

Peach palm tissues of different age and soil P values obtained by different methods (e.g. modified Olsen, Mehlich I and III) and for different depths are being compared to select the best method of P diagnosis. Mehlich I is the standard extraction method used for soil P at INPA laboratory and a calibration phase was necessary to carry out the modified Olsen and Mehlich III methods. An analysis on soil and tissue sensitivity to P additions and yield response for the experiments in both Costa Rica and Brazil will be run as follows:

Fertilization Level	Yield Response	Deficiency Symptoms	Response Obtained by P Levels			
			3rd Leaf	6th Leaf	Soil 0-5 cm	Soil 5-20 cm
Control						
Level X	*yes/no*	*yes/no*	*yes/no*	*yes/no*	*yes/no*	*yes/no*
Level 2X	*yes/no*	*yes/no*	*yes/no*	*yes/no*	*yes/no*	*yes/no*
etc.	*yes/no*	*yes/no*	*yes/no*	*yes/no*	*yes/no*	*yes/no*

b. Diagnostic criteria for P deficiency in peach palm - (Adrian Ares in collaboration with Charles Clement, Newton Falcão and Kukio Yuyama at the Amazon National Research Institute(INPA) in Manaus, Brazil) a conceptual analysis of diagnostic methods for plant nutrient status and their use in decision support systems was presented to the workshop on NuMaSS held at PhilRice in the Phillippines. The framework for discussing the characteristics of sound diagnostic methods followed the criteria developed by Meynard in France for N deficiency diagnostics (Meynard et al., 1996).

Peach palm stands in the Amazon region provide better opportunities to detect P deficiencies than most stands in Costa Rica. Photographs of whole plants and plant organs were taken in representative plots of every treatment of INPA experiments. Plant and organ characteristics are being examined in relation to growth responses and P deficiencies. Exercises with independent observers are being conducted to obtain unbiased estimates of P deficiency symptoms. Plant species that can be indicators of P deficiency were recorded in the field and their characteristics and relationships to site conditions were discussed with collaborators both in Brazil and Costa Rica.

Also, symptoms of nutrient deficiency in peach palm were recorded in greenhouse experiments carried out by INPA collaborators. In these studies, symptoms of deficiency were studied by using the 'missing element' method (all macro and micronutrients are applied at one time except one). As in previous research, there were no clear symptoms of P deficiency in peach palm seedlings. Some of the observed symptoms for other nutrients were:

a) *N deficiency* - reduced growth and development, and generalized chlorosis,
b) *K deficiency* - chlorosis and subsequent necrosis of the tips of old leaves,
c) *Mn deficiency* - interveinal chlorosis in leaves,
d) *Ca deficiency* - dark green-colored leaves, and
e) *S deficiency* - chlorosis of young leaves.

Results so far indicate that whole-plant characteristics may be more useful than tissue features to characterize P deficiencies in peach palm. Number of shoots per plant, for instance, may indicate nutrient deficiencies in early (before harvest) stages of peach palm development. In mature plantations, number of shoots may also indicate level of management.

c. Visits to EMBRAPA-CPAC and Federal Univ. Viçosa - Jot Smyth had the opportunity to visit both of these institutions. Both have strong interests in decision support systems and data bases with information needed to fill knowledge gaps in NuMaSS. A seminar on the project's 5-year workplan and the NuMaSS software was presented at each location. A

pre-release version of NuMaSS 1.0 was also demonstrated to interested parties.
The Cerrado Research Center (CPAC) is interested in collaborating with NuMaSS development. They are particularly interested in helping ensure that the final version is translated into Portuguese. CPAC would also like project assistance in coding the ruleset for diagnosis and recommendations for soil acidity based on the method which they use in the Cerrados - % base saturation of cation exchange capacity measured at pH 7. Two of their staff, Drs. Leo Miranda and Claudio Sanzonowicz, were designated as CPAC contacts for project-related matters. A major constraint to timely collection of unpublished data for use in NuMaSS is funds to support clerical staff to transfer and organize printed data on electronic files. A visit to the U.S. AID representative in Brasilia for assistance in this matter produced no encouraging results.
Faculty in the Soil Science Department at the Federal University of Viçosa (UFV) have 5-6 graduate students who are compiling published data in Brazil on soil nutrient diagnosis and fertilizer recommendations as their thesis topics. They have agreed to provide us with copies of the compile information. UFV also is interested in approaches used in NuMaSS used to diagnose soil acidity and N problems and recommend lime and fertilizer applications. UFV provides technical assistance in eucalyptus production and management to cellulose companies throughout Brazil. Their extensive database on soil nutrient management and production of eucalyptus offers an excellent opportunity to test, refine and expand NuMaSS functionality with tree crop commodities once it is fully developed for palmito.
Kwazulu-Natal, South Africa - the approaches used to diagnose soil nutrient constraints and recommend lime and fertilizers by Cedara Agric. Dev. Institute at Pietermaritzburg has many common features with those used in NuMaSS. Liming is based on exchangeable Al, N is based on crop accumulation for a targeted yield, and P is based on P buffer coefficients and clay content. The Cedara Institute staff, with Mr. Alan Manson as the designated contact, is interested in evaluating NuMaSS and comparing its diagnosis and recommendations with those they have developed via numerous field trials on Alfisols, Oxisols and Ultisols.
Guatemala - Jot Smyth attended by invitation the annual meetings of the Central American Crop and Animal Improvement Program (PCCMCA) and presented a paper on the fundamental rulesets used in NuMaSS to diagnose constraints and recommend corrective nutrient management strategies. This meeting provided opportunities to establish and renew contacts scientists from CIAT, Mexico and Panama who are interested in collaborating in NuMaSS development and evaluation.
CIAT, Colombia - (Russell Yost in collaboration with D.K. Friesen, IFDC/CIMMYT formerly IFDC/CIAT, and Mariela Rivera and I.M. Rao, CIAT, Colombia) during recent travels in Latin America, Russell Yost visited CIAT and developed protocols to perform a comparison of decision-aid predictions of fertilizer requirement (level 0 comparisons) with field-determined P fertilizer requirements. Subsequently coefficients used in PDSS2 and the P module of NuMaSS will be compared to predict P fertilizer requirement (level 1 comparisons and testing).
a. Carimagua maize - a series of experiments have been carried out at the CIAT, Colombia site in Eastern Colombia. The purpose of the experiments was to determine the nutrient P requirements and residual value of P applications for several annual crops including maize,

cowpea, and upland rice grown in cereal-legume rotations. Two of the experimental sites and three crops were selected to test the predictions of the PDSS2 and the P module of NuMaSS with estimates of P requirements from the response curve experiments conducted in the field. As indicated in Figure 38, the PDSS2 prediction of P requirement for maize on this soil was slightly more than that estimated from the field-experiment, although the differences were not great. The experimental response curve is also shown in the figure and indicates a relation between the prediction and the field estimates. The predictions from PDSS2 are based on coefficients developed largely from experiments from the Brazilian Cerrado and from North Carolina (Cox, 1994).

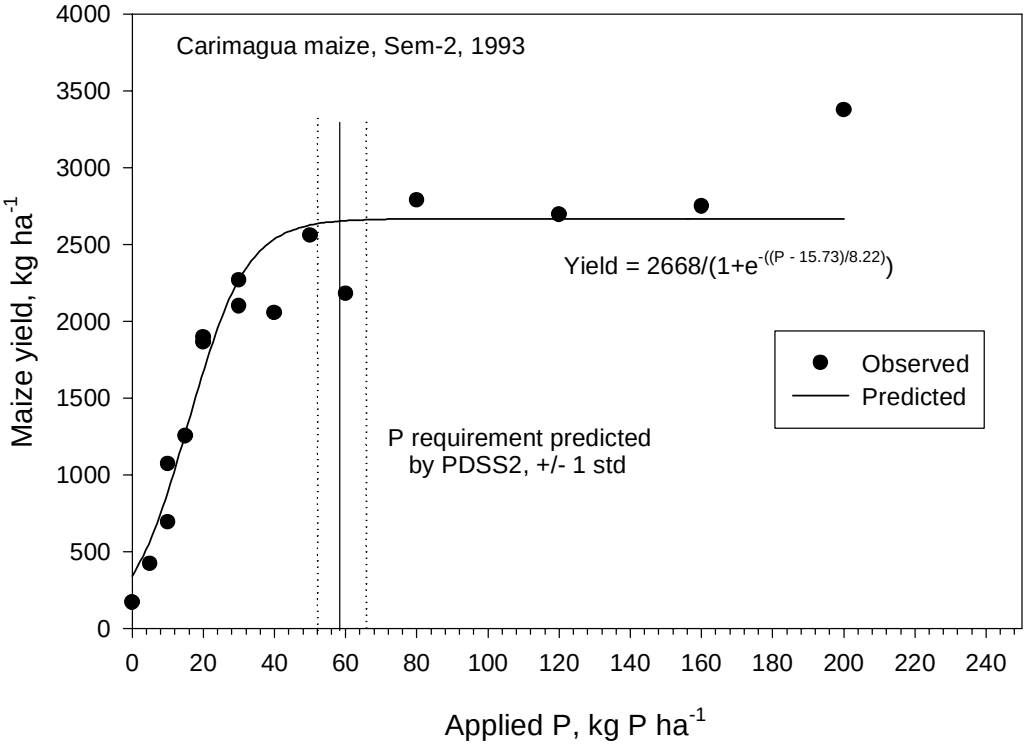

Figure 38. Comparison of P requirement estimated from PDSS2 with experimentally determined P response curve. Carimagua maize, initial crop, Sem-2, 1993. Data from D. Friesen et al. 1994. The prediction based on initial 0.5*M* $NaHCO_3$ P of 5.2, critical level for maize of 15, and 42 % clay.

b. Matazul initial upland rice, cowpea and second upland rice crop. - a comparison was also made between the field estimates of P requirement for the initial crop of upland rice, second crop cowpea and second crop upland rice at Matazul and the PDSS2 predictions (Figs. 39, 40 and 41). As in the case of Carimagua, this site is also located in the Eastern Llanos of Colombia. The results were somewhat different than those of the Carimagua site. The PDSS2 prediction for the first crop of rice (93) was very close to the amount of P that would be recommended from the response curve in order to give 80 - 90% relative yield. The PDSS2 prediction for the second crop of rice tended to be somewhat less than that suggested from the response curve (Figs. 40 and 41). The under-prediction in the case of the cowpea and the second crop upland rice may be related to the fact that the P was applied either entirely to the previous year's crop (residual value treatments) or in equal annual applications to each rice crop. The P requirement for cowpea may also have been underestimated because this crop grew on residual P applied to the preceeding rice crop, that is, no fresh P was applied to cowpea in any of the treatments. Critical levels for the cowpea were derived from experiments in which the 0.*5M* $NaHCO_3$ had been modified with the addition of EDTA in order to measure micronutrients. The critical levels and buffer coefficients for the modified Olsen may also have affected the cowpea underprediction. Nonetheless, we conclude that the PDSS2-based estimates of P requirement were sufficiently close to be useful in estimating P requirements for these crops in soils of this type.

Further studies are underway to compare field estimates of the remaining coefficients used in PDSS2 predictions: P critical levels for Bray P2 for maize, cowpea, and upland rice, P buffer coefficients for Bray P2 and 0.5*M* $NaHCO_3$, coefficients for the slow reaction of fertilizer P with the soils at Carimagua and Matazul, and coefficients for the desorption of extractable P.

Bolivia (collaborators are Larry Szott at DAI/NCSU, Armando Ferrufino at PRAEDAC/IBTA, Walter Gomez at IBTA and Angel Salazar at FAO) North Carolina St. Univ. and Development Alternatives Inc. (DAI) are partners in the Counter Narcotics Consolidation of Alternative Development Efforts (CONCADE) project funded by AID-Bolivia and targeting the Chapare region of that country. At CONCADE's invitation and sponsorship, Russ Yost and Jot Smyth traveled to Bolivia to assess existing practices in soil nutrient management and recommend actions favoring farmer adoption of alternative cropping systems to coca production. Banana and peach palm for 'palmito' are the two most promising crop alternatives. Production systems for both crops target the export market in the Southern Cone region of South America. Collaborators are interested in using NuMaSS to assist farmers in diagnosing nutrient problems and recommending lime and fertilizers. Based on previous work conducted in this region by the SM-CRSP, we identified K as a major nutrient constraint in addition to those currently addressed by NuMaSS. Based on the existing soil and crop performance data, compiled by Armando Ferrufino, we assisted collaborators in designing field trials and ancillary laboratory analyses that would enable development of region-specific coefficients needed to provide fertilizer recommendations in NuMaSS. This activity illustrates how AID Mission-sponsored projects can benefit from collaboration with SM-CRSP projects.

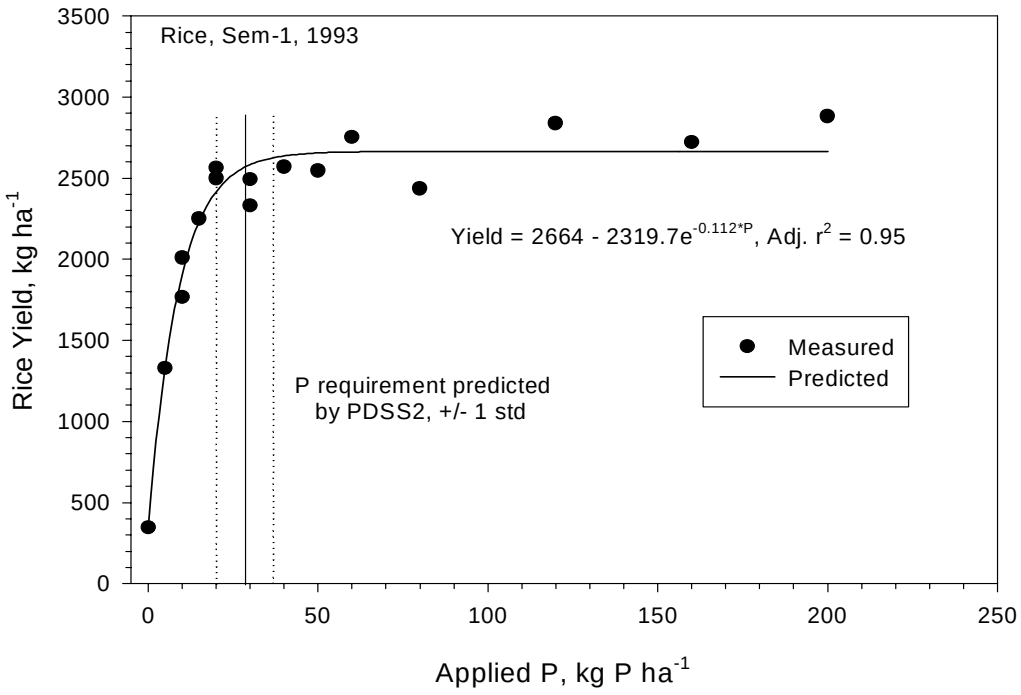

Figure 39. Comparison of P requirement predicted by PDSS2 with the experimentally determined response curve. Matazul rice, initial crop, Sem.1, 1993. Data from D. Friesen et al., IFDC/CIAT.

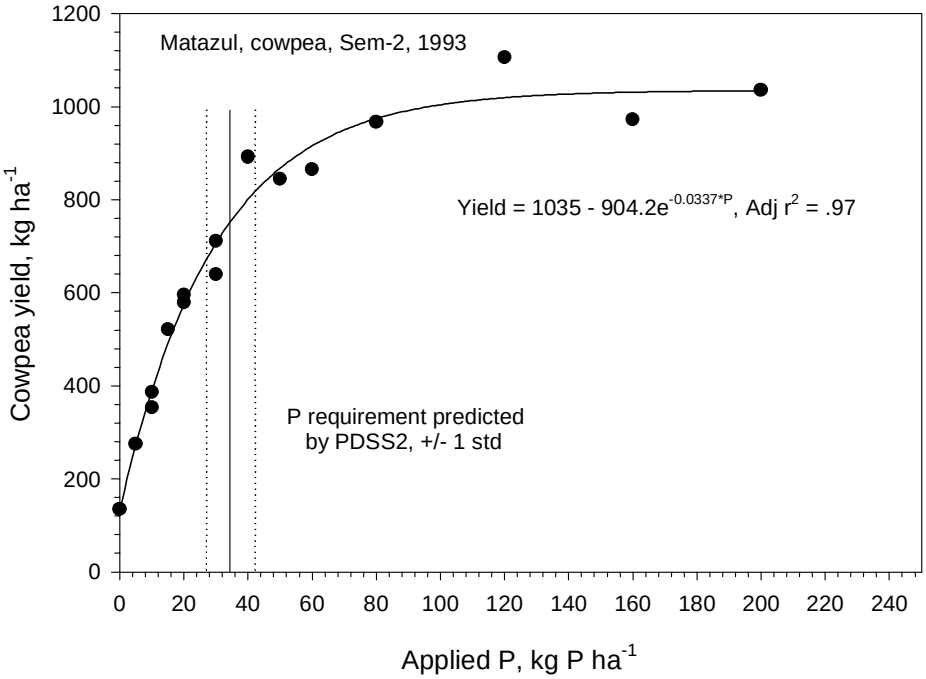

Figure 40. Comparison of P requirement estimated by PDSS2 with the experimentally determined P response curve. Matazul cowpea, Second semester, data from Friesen et al., 1994.

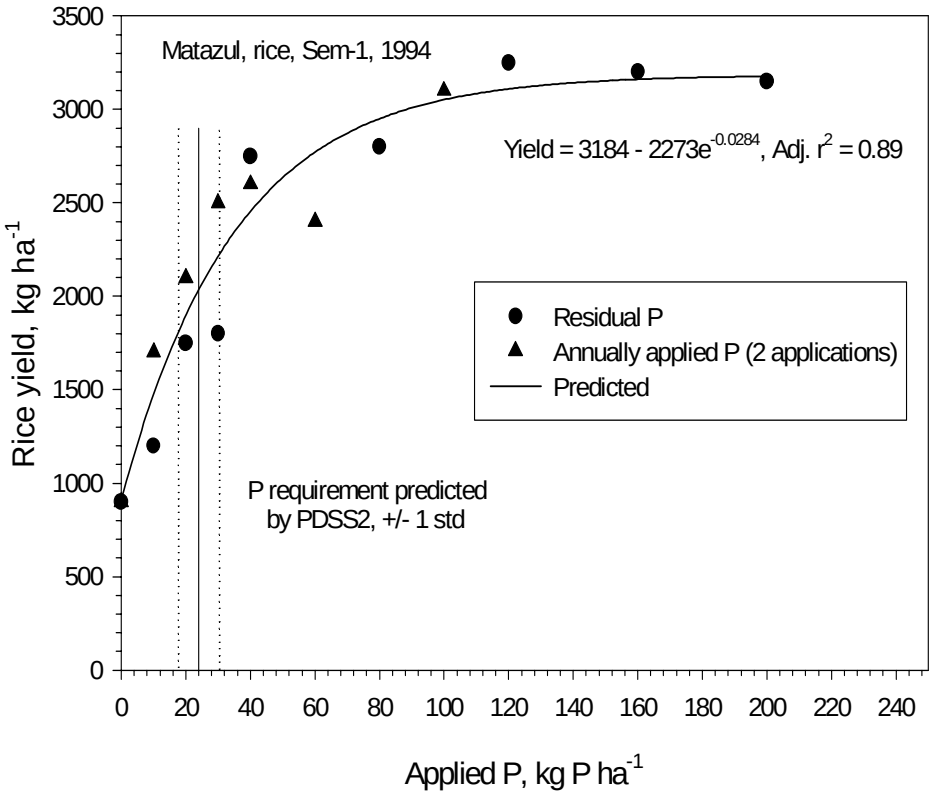

Figure 41. Response of upland rice to residual P and annually applied treble superphosphateat the Matazul farm, data from D. Friesen, J.I. Sanz, and Mariela Rivera, CIAT, Colombia.

2. *NuMaSS Evaluation Workshop* (Deanna Osmond and Teodula Corton coordinated the workshop) - selected participants from Africa, Asia, and Latin America were invited to participate in a nutrient management workshop in the Philippines during September of 1999. The Philippine Rice Research Institute (PhilRice) and the International Rice Research Institute co-sponsored the workshop, which was held at PhilRice's headquarters. There were

26 Asian participants, 22 from the Philippines and 4 from either Laos, Viet Nam or Indonesia. The ten Africans came from Senegal, Mali, Ethiopia, South Africa, Zambia, and Tanzania. There were seven Central and South Americans representing Brazil, Equador, Bolivia, Venezuela, and Costa Rica. In addition, a researcher from PPI-Singapore was in attendance as were two representatives of the SM-CRSP External Evaluation Panel (EEP) and USAID's Project Officer for the CRSP. Participants, their country and work affiliation are listed in Table 50.

Objectives of the workshop were to threefold:

1. Compare among countries and regions decision making processes which are used to diagnose soil nutrient problems, recommend solutions, and assess their economic feasibility;
2. Evaluate the current prototype of the integrated decision support system (NuMaSS) software and identify future developments needed to improve its performance and usability; and
3. Work with interested parties in providing pertinent data and/or designing and planning experimentations in support of NuMaSS refinement to suit regional needs.

There were three expected outcomes of the workshop:

4. Present country- and region-specific decision-making processes for diagnosis of soil nutrient problems and fertility recommendations;
5. Evaluation of the IntDSS software prototype; and
6. Design of experiment for IntDSS refinement to suit regional needs.

The agenda of the workshop, designed to meet the workshop objectives, is attached as an Appendix.

In order to meet the first objective of the workshop, participants were asked to bring papers describing nutrient management in their countries. To standardize this reporting effort, a suggested format for the paper was sent to the participants. We received reports from the majority of the participants. These reports have been edited into a proceedings that is currently being printed by PhilRice and IRRI. Participants presented and summarize their information on nutrient management by climatic regime (humid, wet/dry, and semi-arid).

During the second day of the workshop, presentations on IntDSS (NuMaSS) were made. Participants were divided based on the climatic region that they work in. The software was then used and tested by the participants. Recommendations were subsequently reported in a plennary session.

At a group meeting, held by the EEP, all workshop participants endorsed the continued development of the NuMaSS software. All believed that NuMaSS provides an important tool that can be regionalized by participants for their own countries. The participants are anxious to contribute to the development of NuMaSS by providing regional data and testing the performance of the software. They also view the project as providing a forum that allows them to interact closely with an international group of soil scientist and agronomist.

The workshop concluded with a field trip to Ilagan in Isabela Province, where on-farm trials conducted by the SM-CRSP project, in collaboration with PhilRice, IRRI and local agencies of the Department of Agriculture, demonstrated approaches that could be used to field test and adapt NuMaSS to regional conditions within a given country. Results from the on-farm

Table 50. List of workshop participants and their institutional affiliations.

NAME	INSTITUTION	COUNTRY
Dr. Agusli Taher	Sukarami Assessment Institute for Agricultural Technology	Indonesia
Mr. Boun-Ome Soulideth	Soil Survey and Land Classification Center	Laos
Mr. Soulasith Maniphone	Luang Prabang Rainfed Upland Research Program	Laos
Mr. Pham Tien Dung	Hanoi Agricultural University	Vietnam
Ato Solomon Abebe	Bureau of Agriculture	Ethiopia
Ato Kindu Mekonnen	Sirinka Research Center	Ethiopia
Ato Yihenew G. Selassie	Adet Research Center	Ethiopia
Dr. Mohamed Kebbeh	WARDA-Sahel	Gambia
Dr. Charles Yamoah	Council for Scientific and Industrial Research	Ghana
Dr. Mamadou Doumbia	Institut d'Economie Rurale	Mali
Dr. Aminata Badiane	Institut Senegalese de Recherche Agricole	Senegal
Mr. Alan Manson	KwaZulu-Natal Department of Agriculture	South Africa
Dr. Gerald Kimbi	Sokoine University of Agriculture	Tanzania
Dr. Vernon Chinene	University of Zambia	Zambia
Dr. Manoel S. Cravo	EMBRAPA-CPAA Manaus	Brazil
Dr. Leo Nobre de Miranda	EMBRAPA-CPAC Brasilia	Brazil
Dr. Roberto F. Novais	Universidade Federal de Vicosa	Brazil
Dr. Alfredo Alvarado	Universidad de Costa Rica	Costa Rica
Ing. Francisco Mite	INIAP	Ecuador
Dr. Armando Ferrufino	IBTA-Chapare	Bolivia
Ms. Yamily Zavala	FONAIAP	Venezuela
Dr. Jot Smyth	North Carolina State University	USA
Dr. Deanna Osmond	North Carolina State University	USA
Dr. Russell Yost	University of Hawaii	USA
Dr. Shaw Reid	Cornell University	USA
Dr. Anthony S. Juo	Texas A & M University	USA
Dr. Eric Craswell	IBSRAM	Thailand

NAME	INSTITUTION	COUNTRY
Dr. Amit Roy	IFDC	USA
Dr. Charles Sloger	USAID/Washington	USA
Dr. Ernst Mutert	Potash & Phosphate Institute	Singapore
Dr. Eduardo Paningbatan	UPLB	Philippines
Ms. Jovelyn Du-Quiton	UPLB	Philippines
Dr. Perfecto P. Evangelista	BSWM	Philippines
Dr. Rogelio N. Concepcion	BSWM	Philippines
Mr. Jonathan T. Quiton	IRRI	Philippines
Dr. Thomas George	IRRI	Philippines
Dr. Mark Bell	IRRI	Philippines
Dr. V. Manoharan	IRRI	Philippines
Engr. Andrew Valdeavilla	PCARRD	Philippines
Mr. Danilo Tumamao	DA-CVIARC	Philippines
Mr. Quirin Asuncion	DA-CVIARC	Philippines
Mr. Warlito Cayaba	LGU-DA Ilagan	Philippines
Mr. Bonifacio Macarubbo	LGU-DA Ilagan	Philippines
Dr. Arturo Gomez	SEARCA	Philippines
Dr. Santiago R. Obien	PhilRice	Philippines
Dr. Frisco Malabanan	PhilRice	Philippines
Ms. Karen Barroga	PhilRice	Philippines
Engr. Leo Javier	PhilRice	Philippines
Mr. Paterno Rebuelta	PhilRice	Philippines
Dr. Teodula Corton	PhilRice	Philippines
Dr. Sergio Francisco	PhilRice	Philippines
Dr. Genaro O. San Valentin	PhilRice	Philippines
Dr. Cesar P. Mamaril	PhilRice	Philippines
Mr. Josue Descalsota	PhilRice	Philippines

trials are expected to have a major impact on upland agriculture in the Philippines. PhilRice is currently considering potential options to extend the results to other upland regions within the country.

A two-page synthesis of the workshop was developed for USAID distribution.

Additional Funding and Support

- PCCMCA Meeting, travel for Jot Smyth to Guatemala - $980
- CIAT, travel for Russell Yost to Colombia - $800
- CONCADE/Bolivia, travel for Jot Smyth and Russel Yost to Bolivia - $5,800
- IRRI, in kind contributions to workshop for airport reception desk, transportation, and publication of workshop proceedings
- PhilRice, in kind contributions for state-of-the-art meeting facilities, lodging and support staff, transportation, publication of workshop proceedings, and in-country logistics throughout the workshop.
- Institutions employing workshop participant provided one full week of their time to the worshop

Travel and Meetings Attended

- Travel by Jot Smyth to Brazil, South Africa and Philippines
- Travel by Jot Smyth to Guatemala for PCCMCA meeting
- Travel by Juo, Osmond, Reid, Smyth, Yost, Zavala (from US) and numerous foreign participants to the workshop at PhilRice
- Travel to Bolivia by Smyth and Yost
- Travel by Russell Yost to CIAT, Colombia

Relevant Publications, Reports and Presentations at Meetings

Ares, A. 1999. "Decision support systems for integrated nutrient management in agroecosystems." Seminar at Instituto Nacional de Pesquisas da Amazônia, March 16 1999, Manaus, Brazil.

Ares, A. 1999. "Nutrient diagnosis and fertilization responses in perennial tree crops for the humid tropics: the case of peach palm (*Bactris gasipaes*) in Costa Rica, Brazil and Hawaii." Seminar at the University of Hawaii, May 12, Honolulu.

Ares, A. 1999. Report on trip to Brazil and Costa Rica. Decision Aids for Integrated Soil Nutrients Project. 10p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Adrian_Brazil_CRica_99Rept.pdf)

Deenik J, Ares A. and Yost RS. 1999. Fertilization responses and nutrient diagnostic methods for peach palm (*Bactris gasipaes*). Nutrient Cycling in Agroecosystems 55 (4): 1-13.

George, T. et al. 1999. SM-CRSP Project Decision Aids for Integrated Nutrient Management: Mid-Term Evaluation. Paper presented at the Decision Aids Workshop, 6-11 September, PhilRice, Philippines.

George *et al*. 1999. SM-CRSP Project Decision Aids for Integrated Nutrient Management: On-Farm Testing. Paper presented at the Decision Aids Workshop, 6-11 September, PhilRice, Philippines.

Osmond, D.L. 1999. Presentation of an overview of IntDSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Osmond, D.L., T. Corton, T.J. Smyth W.S. Reid, and R.S. Yost . 2000. Proceedings from a Workshop on Decision Processes for Determining Diagnostic and Predictive Criteria for Soil Nutrient Management. September 6-10, 1999. PhilRice Maligaya, Muñoz, Nueva Ecija, Philippines. (near completion).

Reid, W.S. Presentation of NDSS as part of NuMaSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Smyth, T.J. 1999. Decision support systems for integrated soil nutrient management. Plennary Session presentation at PCCMCA Annual Meetings, April 14, Guatemala, Guatemala.

Smyth,T.J. 1999. Presentation of ADSS as part of NuMaSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Smyth, T.J. 1999. Report on trip to Guatemala, Honduras and Costa Rica. Decision Aids for Integrated Soil Nutrients Project. 16p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Smyth_CAmerica_0499Rept.pdf)

Smyth, T.J. 1999. Decision aids for integrated soil nutrient management: 5-year workplans and software development. Seminar to Soil Science Dept., Federal Univ. Viçosa, Viçosa, Brazil. March 10, 1999.

Smyth, T.J. 1999. Decision aids for integrated soil nutrient management: 5-year workplans and software development. Seminar to EMBRAPA-CPAC staff, Brasilia, Brazil. March 18, 1999.

Smyth, T.J. 1999. Decision aids for integrated soil nutrient management: 5-year workplans and software development. Seminar to Cedara Agric. Dev. Inst. staff, Pietermaritzburg, South Africa. March 23, 1999.

Smyth, T.J. 1999. Report on travel to Brazil, South Africa and Philippines. Decision Aids for Integrated Soil Nutrients Project. 16p. (http://intdss.soil.ncsu.edu/sm-crsp/Download/Trip_Reports/Smyth0399_World_Rept.pdf)

Smyth, T.J. and D.L. Osmond. 1999. Synthesis of the Workshop on Decision Processes for Determining Diagnostic and Predictive Criteria for Soil Nutrient Management. September 6-10, 1999. PhilRice Maligaya, Muñoz, Nueva Ecija, Philippines. 2p.

Yost, R.S. and X. Wang. 1999. Presentation of the P module of NuMaSS at the Philippines workshop, Sept. 1999, PhilRice, Maligaya, Philippines.

Yost R, Ares A., Bajita J and Wang, X. 1999. Diagnosing nutrient deficiencies. Proceedings Workshop on Integrated Nutrient Management, The Philippines.

Appendix - Workshop Program

Decision Processes for Determining Diagnostic and Predictive Criteria for Soil Nutrient Management

September 6-10, 1999

PhilRice, Maligaya, Muñoz, Nueva Ecija, Philippines

Sunday, Sept. 5	Participant arrival in Manila; check-in at hotel	
Monday, Sept. 6		
0600	Leave hotel for PhilRice (Maligaya)	
1000	Check-in at PhilRice dormitory	C. Tibayan
1030	Coffee break	
1045	Registration (PhilRice Lobby)	E. Javier
1130	Briefing on PhilRice Story and R&D Programs	J. Villanueva
1200	Lunch at PhilRice cafeteria	
1300	Tour of PhilRice laboratories and field experiments	S. Obien
1500	Coffee break	
1530	Opening ceremonies	R. Beronio
	Invocation "Great is Thy Faithfulness"	PhilRice Coral
	National Anthem	PhilRice Coral
	Welcome Remarks	S. Obien
	Opening Remarks	J. Smyth
	Participant Introduction	R. Yost
	Introduction of Keynote Speaker	S. Obien
	Keynote Address	E. Ponce
	Discussion of Workshop Objectives, Mechanics and Expected Output	D. Osmond
	Viewing of posters and exhibits (PhilRice Lobby)	J. de Dios/J. Quilang
1800	Dinner at PhilRice cafeteria	
1930	Social/Cocktails (Social Hall)	H. Orge/L. Abaoag
Tuesday, Sept. 7		
0700	Breakfast	
0800	Group discussion on nutrient management decisions - presentation of participant reports	

	Wet/dry	J. Smyth
	Semiarid	S. Reid
	Humid	R. Yost
0930	Coffee Break	
1000	Continuation of group discussions	
1200	Lunch Break	
1330	Continuation of group discussions	
1500	Coffee Break	
1530	Plennary Report of Group Discussions	
1730	Wraep-up	
1800	Dinner	
1900	Core experiment at Ilagan Intensive Testing Site	T. Corton
2015	On-farm field trials in San Antonio	T. George
Wednesday, Sept. 8		
0700	Breakfast	
0800	Discussions on DSS	
	IntDSS	D. Osmond
	ADSS	J. Smyth
	NDSS	S. Reid
	PDDSS	R. Yost
1000	Coffee Break	
1030	Group Discussion (focus on individual DSS, what works/does not, future modifications needed)	
1200	Lunch Break	
1300	Continuation of group discussions	
1500	Coffee Break	
1530	Continuation of group discussions	
1800	Dinner	
1930	Plennary report on group discussions	
Thursday, Sept. 9		

0700	Breakfast	
0800	Group discussion on IntDSS (future modifications and direction)	D. Osmond
0900	Lessons learned at IRRI in building DSS	M. Bell
0930	Coffee Break	
1000	Probabilities in DSS (presentation followed by participants filling out survey worksheets)	R. Yost
1200	Lunch Break	
1330	Ilagan Mid-term Socio-economic Survey	R. Yost/T. George
1400	Information on visit to Ilagan, Isabela	D. Tumamao
1430	Departure for Ilagan, Isabela (packed snack)	
2000	Dinner (Lutong Bahay at Ilagan)	
2100	Check-in at hotel in Ilagan	
Friday, Sept. 10		
0600	Breakfast at hotels	
0700	Departure for field visit to core experiment	
0900	Visit of on-farm experiment	
1100	Visit of corn and upland rice techno-demo farms	
1200	Lunch, Wrap up, and Closing Ceremonies	

Output 2 Auxiliary tools to complement NuMaSS software - products that facilitate use of the NuMaSS knowledge base where computers are not readily accessible or interest is in a summary of predictions and nutrient management guidance for prevailing cropping systems, cultivars, lime and fertilizer materials, and soils within a given region.

Examples of such tools are printed materials, spreadsheets, decision-making structures and map overlays. Such tools will be developed as we perceive their need among users. Two current tools under development are (a) the lime material and cost integrator and (b) a nutrient balance calculator.

Yost and colleagues developed a spreadsheet for selection of liming materials. The spreadsheet optimizes selection from locally-available liming materials and determines their correct proportional mixture while considering a variety of constrains such as quantity, cost, quality and distance of transport. We are currently translating the spreadsheet to Spanish, Portuguese and French before testing under a variety of global conditions.

The idea for a nutrient budget estimator cam about during travel to select intensive testing areas. This tool should allow users to determine inputs, outputs and balance of major nutrients. By providing a nutrient budget farmers or planners can appreciate what their management practices are doing: depleting soils or particular nutrients, adding excess nutrients, or maintaining a balanced profile. A paper prototype has been developed to function at different scales: field, farm or farms.

Progress:

1. *Selection of Liming Material Spreadsheet* - collaborators have been identified, but we have not yet completed translation. Nevertheless, the spreadsheet and journal publication continues to be distributed upon request.
2. *Nutrient Budget Estimator* - programming of this tool was delayed until release of NuMaSS version 2.0. Much of the data needed for this tool will come from data collected and assembled for NuMaSS.

External Funding and Support

None

Travel and Meetings Attended

None

Relevant Publications, Reports and Presentations at Meetings

None