Annual Progress Report
Decision Aids for Integrated Soil Nutrient Management
February 11, 2001 - October 25, 2002

Executive Summary

Software release and evaluation - the project's final version (2.0) of the Nutrient Management Support System (NuMaSS) software was released in October 2002. Prior to the release, beta versions of the software were evaluated by 65 network participants from 24 countries via regional workshops in Africa (Togo), Asia (Philippines) and Latin America (Costa Rica). Interaction with and feedback from participants, during their hands-on use of the software, enabled us to identify and correct/revise various aspects of the software prior to the final release. To date, over 300 copies of the NuMaSS 2.0 CD have been distributed among the project's network members and the SM-CRSP 'family'. In addition to the regional workshops, training in the use of NuMaSS 2.0 was also provided to 45 additional users in Africa and Costa Rica via workshops organized by other institutions.

Relative to prior versions of the software, NuMaSS 2.0 addresses acidity, N and P constraints in a more integrated fashion across the Diagnosis, Prediction, Economics and Results sections. New crops have been added and crop data tables contain over 500 additional records. Seventy new images of nutrient deficiencies were added to help in Diagnosis. The Diagnosis of all three nutrient constraints now use Bayesian probabilities. The interface and program structure for Economics was changed to provide the user with more options to explore costs and benefits from the inputs. Despite all these changes and additions, the final software version has 18 fewer tab pages than prior versions.

Intensive testing sites -

Costa Rica - based on two years of field trial data on Dystrudepts, fertilizer N requirements for maximum yield of mature peach palm stands under heart-of-palm production are within the range of 193 - 400 kg N ha^{-1} $year^{-1}$. Fertilizer N increases heart-of-palm yield by 30-39%, but there is no difference between sources (NH_4NO_3 vs. urea) of surface-applied fertilizer. Nitrogen accumulated in one year of total harvested biomass is in the range of 250-270 kg ha^{-1}, of which only 4-9% is exported in heart-of-palm and 82-83% comprises foliage retained in the field as a surface mulch. Estimates from litter bag decomposition studies were that 67-81% of the foliage N was released during the year. Fertilizer N use efficiency, estimated by apparent N recovery methods, was 57% when averaged across the two years. The 3rd youngest leaf showed promising results for future use in the diagnosis of plant N status.

Cumulative heart-of-palm yields for 3 years of a mature stand in an Inceptisol were increased by 9% with P fertilization. In contrast with N, petiole P concentration was a better diagnostic indicator of plant P status than the 3rd or 5th youngest leaves. However, greenhouse studies with peach palm seedlings showed significant growth responses to P fertilization when grown in Ultisols with < 10 mg cm^{-3} of Modified Olsen extractable P. Collectively, these results suggest that P response by peach palm is greater in the stage of stand establishment than when mature.

Greenhouse trial results on seedling growth response to various acid soil conditions in Andisols and Ultisols support the common observation that peach palm is relatively tolerant to soil acidity.

Thirty-week trials testing NuMaSS Diagnosis of soil N and P constraints were completed at six farms on Andisols and Ultisols. Yield response data to fertilizer N and P indicate that the likelihood of N and P limitations for heart-of-palm production were properly diagnosed by the software.

Fertilizer and lime recommendations for peach palm in Costa Rica have decreased considerably as project research data replaced information based solely on average local practices. Research information will help farmers to achieve greater efficiencies in heart-of-palm production and better withstand the growing pressures of the international markets.

Mali - fertilizer and lime recommendations by NuMaSS for millet, sorghum, maize and upland rice were compared to two other recommendation systems during 3 years of field trials at three locations. Grain yields with all recommendations were significantly different from the unfertilized treatment in all years. However yields with NuMaSS differed from the other recommendation schemes in only one year and was attributed to the lime recommendation to correct soil acidity for sorghum and maize. Millet yield response to the addition of Tilemsi phosphate rock (PR) during traditional composting of organic wastes was evaluated in 12 on-farm trials. When compared to the control treatments without inputs, average yields across sites were increased by 65% with PR-amended compost, as opposed to 35% with compost alone. Both compost treatments increased soil pH from 4.2 to 4.7-4.8, averaged across sites, but only the PR amended compost increased soil test P from 5 to 8 mg kg^{-1}.

Despite increased government taxation of fertilizer imports, farmer use of chemical fertilizers in the Cinzana region has increased since 1998. Farmers in the region understood the impact of project activities on their own farms and there is independent evidence that knowledge is shared extensively among farmers and villages.

Philippines - four years of cropping with upland rice, corn, peanut, soybean and mung bean to evaluate NuMaSS recommendations for lime, N and P were completed on Ultisols at Ilagan. Predicted lime, N and P requirements for the cereals and legumes were within 50% of the field-determined values for optimum yield. Exceptions were crop years where climatic conditions such as low temperatures and rainfall excess or deficit deviated significantly from the seasonal averages.

Some of the acid soils in the Ilagan region have Mn nodules and peanut and soybean crops often display symptoms of Mn toxicity. Field investigations with lime, green manures, chicken manure, straw mulches and fertilizer P indicated that liming only decreased soil solution Mn when soil pH was >5.0. Additions of manures and mulch, with moderate lime rates, increased solution Mn levels above the controls, but soybean yields were greater than in the controls. Subsequent greenhouse investigations with soybean revealed that the phytotoxic response to Mn involves a continuous interaction between the plant's rate of growth and the rate of Mn accumulation.

A total of 79 on-farm trials to evaluate NuMaSS diagnosis and regional recommendations for upland rice and corn were conducted in the Ilagan and Arakan Valley regions during the period of 1998-2000. Collectively, the trials indicated good accuracy by NuMaSS in diagnosing acidity, N and P constraints in both regions. In general, yields with NuMaSS recommendations were not different from those with regional recommendations. The trial results highlight several important areas for consideration in future NuMaSS "adoption" activities: (a) better knowledge of the crop cultivars' yield performance, nutrient requirements and tolerances in the test regions, (b) continuation of site-specific trials for more than one crop to evaluate NuMaSS accountability for residual lime and fertilizer P effects, and (c) treatment design (and replication) to assess crop response to lime, N and P individually.

Enhancing the acidity, N and P knowledge base -

Acidity - investigations were completed, in collaboration with IITA, evaluating the extent of soil acidification and leaching of bases due to N fertilization of an Oxic Paleustalf. Nitrogen supply as an organic source maintained higher pH than urea and ammonium sulfate, because the organic inputs presumably provided a buffer for H^+ produced from nitrification. After two cropping seasons, exchangeable acidity with N provided as ammonium sulfate was significantly greater than the control within all depth increments sampled from 0 to 15cm. Losses of exchangeable Mg from the 0-30cm depth were greater with ammonium sulfate and urea, whereas Mg stocks increased in the control without N inputs and N supplied by *Alchornea*. The greatest reduction in pH-dependent cation exchange capacity occurred when N was supplied as ammonium sulfate. Soil acidification to pH values of 4.5 in the ammonium sulfate treatment did not affect maize yields and suggested that Al toxicity was not a limiting factor in this kaolinitic Alfisol.

A review of published data for lime trials in Inceptisols, Oxisols and Ultisols was made to refine lime factors used in NuMaSS for lime recommendations. The former singular lime factor was divided into two separate factors for soil Al saturation > and < 20%. The value of the lime factor for Al saturation > 20% is adjusted based on the whole soil ECEC and clay content. Long-term lime trial data on Inceptisols, Oxisols and Ultisols were also reviewed to develop an algorithm to predict residual lime effects on soil Al saturation %. This algorithm also provides the basis for estimating future cost benefits to subsequent crops after lime is applied.

Nitrogen - a new fertilizer N algorithm was developed for cotton using target yield and a N factor. The N factor accounts for N supplied by both the soil and fertilizers and the value differs between Histosols and other soil orders. Fertilizer N algorithms were developed for peach palm that account for N differences in plant accumulation, export in harvest and recycling in foliage due to yield level, stand densities, growth stages.

BNF contributions through the addition of residual N for 38 different leguminous cover crops were compiled from the literature and added to NuMaSS data bases. Nitrogen contributions from previous leguminous crops and attributes such as yield, harvest index and N content were also added to NuMaSS data bases for six cereal legumes and 39 pasture legumes.

Phosphorus - an algorithm was developed to estimate rock phosphate requirements in P deficient soils. Factors considered include crop rhizosphere acidification potential, rock phosphate type and soil property effects (namely extractable acidity and Ca saturation %) on rock phosphate solubility. The algorithm will be added to the developing Phosphorus Decision Support System and, thereafter, to NuMaSS.

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.

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 5 are listed according to their respective institutions:

University of Hawaii - Hu Li
North Carolina State University - Pedro Luna
Colorado State University - Dana Hoag
Understanding Systems, Inc., Raleigh, NC - Steve Pratt, Will Branch

Progress:

1. *Final release of NuMaSS 2.0*

Version 2.0 of NuMaSS was completed in September 2002, and distribution of the software CDs began in October 2002. The following programming changes were implemented for NuMaSS, version 2.0:

1. a. Interface

- Streamlined interface by reducing 18 tab pages as well as a number of input boxes.
- Added over 70 images of plant nutrient deficiencies and related previous crop diagnosis to these nutrient deficiencies.
- Added over 5 images of indicator plants.
- Added close to 500 records to the Crop_yield table. There are over 20 fields for each record. The table primarily provides default yield information and N data for the 18 crops considered by the system.
- Added agricultural regions to each country.
- The map became functional so that users can click on a country to pull up information in the "Geography" section.
- Enabled viewing of data base records within the program.

- Added multiple popup warning messages when there is a user input error.

1. b. Acidity Module
    - "Diagnosis" was upgraded to include Bayesian probabilities for soil acidity.
    - Reprogrammed "Diagnosis and Prediction" as distinct entities to ensure compatibility with Nitrogen and Phosphorus modules.
    - Developed algorithms for relations between soil pH and % Al saturation based on data from the tropics.
    - Assembled critical soil % Al saturation data for crop cultivars and diagnostic foliar Ca and Mg levels.
    - Expanded acidity module application for 4 additional soil orders in the U.S. Soil Taxonomy.
    - Revised lime factor algorithms in "Prediction" to account for soils with high and low activity clays.
    - Revised algorithms for adjustment of lime quality to account for different types of information available to users.
    - Developed algorithms for peach palm in "Diagnosis and Prediction" based on soil and plant Ca and Mg deficiencies.
    - Developed algorithms for "Economics" to estimate location-specific yield responses to liming for all crops.
    - Developed algorithms to estimate savings in lime due to organic inputs in "Economics."
    - Revised algorithms, based on analyses of long-term trial data in the tropics, to estimate future cost savings from applied lime in "Economics."

1. c. Nitrogen Module
    - "Diagnosis" was upgraded to include Bayesian probabilities for N.
    - Peach palm, cotton, and tuber algorithms were added to "Prediction."
    - Nitrogen economic algorithms were developed for all crops.
    - Developed algorithms to estimate savings for N due to organic inputs in "Economics."

1. d. Phosphorus Module
    - Included data from Mali, West Africa for sandy soils (5-12% clay) and improved data for soils with high clay content (60-80%) from S. America and S.E. Asia. This data is used to better estimate P critical level and P buffer coefficients.
    - Additional crops are now included in estimates of P requirement: cotton, potato, and peach palm.
    - Removal of some economic options and residual effects.

1. e. Economics Module
    - Since each module had its own economic section, the final "Economics" section had to be developed to accommodate the all three modules. The interface was dramatically changed to provide for integration of the three modules.
    - Extensive cost and benefit programming for the integrated response functions of the three nutrient modules was developed and implemented in NuMaSS. Although each amendment has an optimum rate, optimum rates may not be the best economic solution. A linear plateau model was the basis for the economic integration. Amendment amounts must satisfy the most limiting nutrient requirement before the amendment amounts for the other limiting conditions apply. In addition, amendment types (such as the types of fertilizer or lime sold), the quantities of the amendments, the price of the amendments, or

the amount of cash a producer may have available, can determine the amendment rate. Thus this section is critical in determining useable amendment rates based on prevailing market conditions.

Each nutrient response is based on an underlying linear-plateau production function, Y = min (a + bx, T) where "Y" is the yield, "a" is the intercept, "b" is the slope coefficient and "T" is the optimum yield. We are assuming the von Liebig law of the minimum response. This assumes that one nutrient is most limiting and it is only when that nutrient need is met that other nutrients contribute to yield. In order to do the economic analysis in NuMaSS 2.0, we have assumed that each nutrient is independent, although we recognize that this may not be true.

Return attributable for each of the inputs is based on the marginal value product compared to input cost. Marginal value product (MVP) is the output price (P) times the derivative of Y with respect to the input (b). In this case, the derivative is always equal to "b", and thus marginal value product is MVP=Pb. The most profitable level of each input is found where MVPx = Px.

- A response curve for the "Economic" section was developed. The response curve allows for a visual and numeric representation of the yield response due to each of the necessary amendment amounts.
- The profit (or loss) associated with varying amendment amounts can be determined using different economic strategies. Users can look at an array of fertilizer types, they can determine the amendment mixes that maximize their profit, they can determine amendment amounts if they have a limited amount of either cash or amendment amounts.
- Economic benefits of organic amendments were added. The amount of amendment that was replaced by the organic residue is reported, as well as the cost savings.

2. *Environmental Concerns*

Information on the downstream environmental concerns from excess N and P fertilization were placed into NuMaSS 2.0 (Help/Definitions/N or Help/Definitions/P). The two sections are entitled, Nitrogen (N) - Environmental Impacts and Management and Phosphorus (P) - Environmental Impacts and Management. In addition, if N or P exceed the amount of nutrients necessary due to the type of fertilizer used, excess application(s) of N and/or P are noted in the Economic section of NuMaSS 2.0.

3. *Predicting Residual Nutrient Value*

Nitrogen can be supplied through residual effects of organic amendments, leguminous cover crops, or forest fallow. Residual N contributions for 38 different leguminous cover crops were compiled. The amount of N contributed from each specific green manure is adjusted through determining the vigor of leguminous cover crop growth. In addition, N contributions from 4 animal manures, 17 plant residues, and compost are available in the system. The user can either enter specific values for the %N content or defaults are supplied. The amount of N fertilizer is reduced by the contributions of these residual nutrient values. The user is alerted not only to the amount of N contributed from these other sources, but also the economic benefit of the organic amendments.

4. *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. Reports on travel events, workplans, workshops, annual progress and surveys are produced in Acrobat Reader file format (*.pdf) and posted on the website for downloading by interested viewers. Project participants in both the U.S. and overseas are notified via an e-mail listserver, whenever new information is posted on the website. The FTP site on the project's server expedites the exchange of NuMaSS software files among programmers at N.C. State and Hawaii universities.

Version 2.0 of NuMaSS can be downloaded from the project's website. The size of the downloadable software file is about 16.5 Mb; this will discourage many users from attempting the download, unless they have access to a fast network connection.

5. *Distribution of NuMaSS 2.0 Software CD*

Over 300 copies of the software CD have been distributed thus far. Recipients included all members of the project's extensive evaluation network, participants to all of the project's international workshops, members of the SM-CRSP ME, BOD, TC, EEP and other projects, and others who expressed interest in receiving a copy of the final version of the software. In addition to the software, the CD also contains an installation and user's guide manual (SM-CRSP Technical Bulletin No. 2002-02) in pdf file format.

External Funding and Support

$3,062 from the Management Entity of the Soil Management CRSP to cover half of the costs in producing 1000 copies of the NuMaSS software CD.

Travel and Meetings Attended

- Ares, A., L. Hossner, D. Osmond, F. Smith and J. Smyth. Travel to participate in the Latin American Regional Workshop on NuMaSS, Guápiles, Costa Rica, 6 -10 January, 2002.
- Smyth, J. and R. Yost. Travel to participate in the Asian Regional Workshop on NuMaSS, Maligaya, Philippines, 21 - 24 January, 2002.
- Kablan, R., F. Smith, J. Smyth and R. Yost. Travel to participate in the African Regional Workshop on NuMaSS, Lomé, Togo, 12 - 15 March, 2002.

Relevant Publications, Reports and Presentations at Meetings

Osmond, D.L., T.J. Smyth, R.S. Yost, D. L. Hoag, W.S. Reid, W. Branch, X. Wang and H. Li. 2002. Nutrient Management Support System (NuMaSS), v. 2.0. Soil Management Collaborative Research Support Program, Technical Bulletin No. 2002-02, North Carolina State University, Raleigh, NC.

Osmond, D.L., T.J. Smyth, R.S. Yost, D. L. Hoag, W.S. Reid, W. Branch, X. Wang and H. Li. 2002. Nutrient Management Support System (NuMaSS), v. 2.0, Software Installation and User's Guide. Soil Management Collaborative Research Support Program, Technical Bulletin No. 2002-02, North Carolina State University, Raleigh, NC. 32p.

Smyth, T.J., R.S. Yost, D.L. Osmond and F. Smith. 2002. Report on Regional Workshops in Asia, Africa and Latin America for Evaluation of Pre-Release Versions of the Final NuMaSS Software. 16p. (http://intdss.soil.ncsu.edu/download/documents/Regional_Workshop_Report_YR5.pdf)

Osmond, D.L., T.J. Smyth, R.S. Yost, D.L. Hoag, W.S. Reid, W. Branch, X. Wang and H. Li. 2002. Nutrient management software for the tropics: NuMaSS. *In* Annual Meeting Abstracts, 10-14 Nov. 2002, Indianapolis, IN. Amer. Soc. Agron., Crop Sci. Soc. Amer., Soil Sci. Soc. Amer., Madison, WI.

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.

Lead Investigators and Contributors

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 and Frank Hons (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; Costa Rican Ministry of Agriculture/'Los Diamantes' Experiment Station - Antonio Bogantes;

Institute d'Economie Rurale, Mali - Mamadou Doumbia, Aminata Sidibe, Adama Bagayoko, Mamadou Diarra, Kamidou Konare (Sotuba Station); Adama Coulibaly, Oumar Coulibaly, Birama Coulibaly, Diakalia Sogodogo and Zoumana Kouyate (Cinzana Station)

Philippine Rice Research Institute/IRRI - Teodula Corton, Santiago Obien, Josephina Lasquite, Miguel Aragon and Madonna Casimero (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).

Progress

1. *Costa Rica*

1. a. N fertilization field trial - (supervision by Eloy Molina, Alfredo Alvarado, Rafael Salas, Jimmy Boniche of UCR and Antonio Bogantes of MAG with assistance from Shaw Reid, Michael Wagger, Deanna Osmond and Jot Smyth) The second and final year of the field trial to evaluate peach palm response in heart-of-palm ('palmito') production to fertilizer N rates was

completed in June 2002. The experiment began in May 2000 in a 5-year stand at MAG's "Los Diamantes" Experiment Station on a soil classified as Aquandic Dystrudepts. Fertilizer N treatments include 0, 50, 100, 200 and 400 kg ha^{-1} as NH_4NO_3. A treatment with 100 kg N ha^{-1} as urea is also included for comparison of N sources. Foliage and stem residues from heart-of-palm harvests are left in the field as mulch in all these treatments. An additional zero-N treatment is also included where crop residues are removed at each harvest to provide comparisons between N contributions from native soil N reserves and crop residues. All N fertilizers and blanket rates of P, K and Mg are surface-applied in bands between plant rows as split-applications every 60 days. Each plot contains four 10-m plant rows and treatments are arranged in a randomized complete block design with three replications. Palmitos were harvested at 4-week intervals throughout the entire year when offshoot basal stem diameters reached approximately 9 cm.

Total number of palmito harvested for each year are shown in Figure 1 as a function of applied fertilizer N. Yields for all treatments, except for 200 kg N ha^{-1} as NH_4NO_3, were higher in year 2 than in year 1. Within both years, yields for a given treatment relative to the other treatments were also similar - except for 200 kg N ha^{-1} as NH_4NO_3. The unusually low yield in year 2 for the treatment with 200 kg N ha^{-1} could not be attributed to outliers among replicates. Plant N data, reported in the following, also does not support the low yields obtained with this treatment. Nevertheless, differences in yields between years 1 and 2 place fertilizer N requirements for maximum palmito yield somewhere between 193 and 400 kg N ha^{-1} yr^{-1}. Results in Figure 1 also indicate (1) no yield differences between sources (NH_4NO_3 vs. urea) of surface-applied fertilizer N and (2) an average yield reduction of 7% in the zero-N treatment when N recycling from the forage and stem residues is prevented by their removal from the field at each harvest.

Yields without residues or fertilizer N corresponded to 70% and 61% of the maximum in years 1 and 2 respectively. These data, in combination with plant N uptake data (Tables 1 and 2), indicate good reserves and supply of native soil N for peach palm in these Dystrudepts of Costa Rica.

Dry weights and N content of cut foliage, exported palmito, total harvested biomass and standing vegetation for each treatment are shown in Tables 1 and 2 for the respective crop years 1 and 2. Standing vegetation was estimated by destructively sampling 2 plants in border rows of each plot after the final harvest date in each crop year. Standing vegetation provides an estimate of the aboveground biomass that is a relatively constant value in mature stands and is composed of developing offshoots which replenish harvested stems.

Total harvested dry matter, averaged across treatments, was in the range of 13-16 t ha^{-1} for the two crop years. Only 10-13% of the harvested dry matter was exported as hearts-of-palm; foliage accounted for 70-80% of the harvested biomass which remained in the field as a surface mulch. Mean values for standing vegetation ranged from 6.8 to 7.3 t ha^{-1} between crop years.

Nitrogen accumulated in the harvested biomass, averaged across treatments, ranged from 248 to 270 kg ha^{-1} between crop years. Of this total, only 4-9% was exported in palmitos and foliage accounted for 82-83% of the N in harvest residues that remained in the field. Mean values for N uptake in standing biomass ranged from 128 to 151 kg ha^{-1} between crop years 1 and 2.

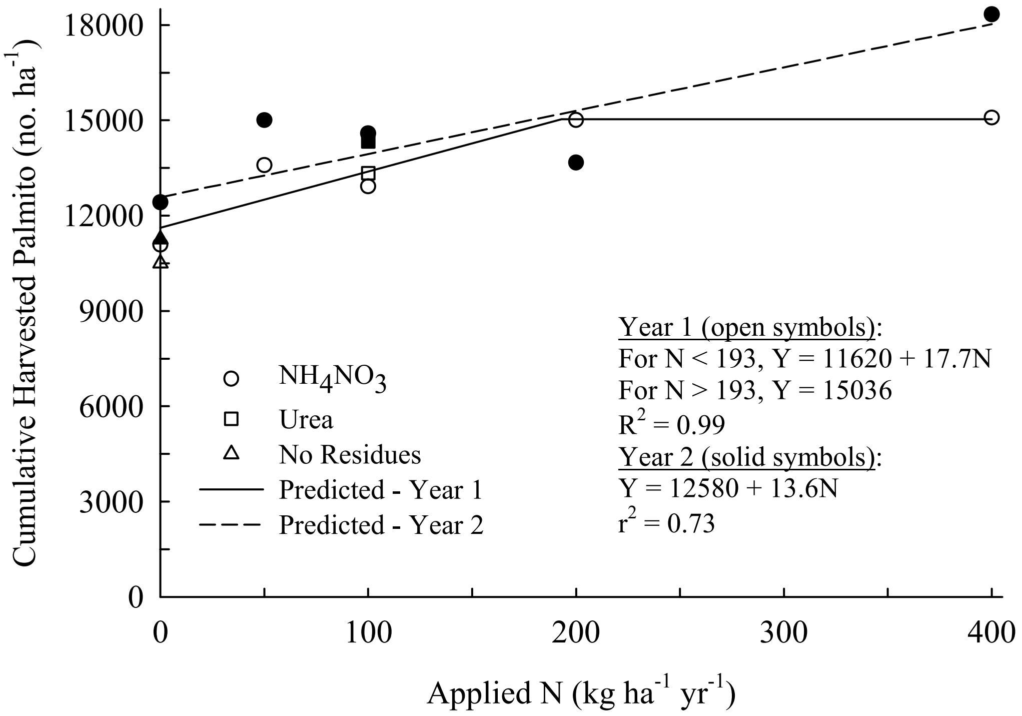

Figure 1. Harvested heart-of-palm yields as a function of N rates, N sources and foliage and stem residue management during two consecutive years for a 5-year stand in an Aquandic Dystrudepts of Costa Rica.

Predicted N release from foliage left as a surface mulch after each harvest is indicative of the potential recycling of N within the system during a crop year. Nitrogen release from foliage was estimated with equations developed from litter bag decomposition studies in prior field trials in Costa Rica. Development of the prediction equations was described in the project's annual report for 1999-2000 (http://intdss.soil.ncsu.edu/download/documents/IntDSS_YR3_Rept_Obj1.pdf). Treatment means for % of foliage N released during each year ranged from 67 to 81% between crop years. Apparent N recovery from fertilizer N was estimated for each crop year, using data from Tables 1 and 2. Since the experiment did not contain labeled N fertilizer, the standard assumption of constant native soil N supply across all fertilizer N rates was used. Nitrogen supply from native soil N and recycled soil N via foliage residues was estimated as the N uptake in total harvested biomass for the treatment with zero-N where residues were maintained in the field. Fertilizer N recycled during the year through decomposition of harvested foliage was estimated as the difference in predicted foliage N release between each fertilizer N treatment and the treatment with zero-N where residues were maintained in the field. Likewise, native soil N uptake in the standing vegetation was estimated as the N taken up by the zero-N treatment with residues.

Table 1. Mean dry weights and N uptake for cut foliage, exported palmito, total harvested biomass and standing vegetation, and predicted N release from foliage residues for each treatment during the first crop year of the experiment.

	DRY MATTER					N ACCUMULATION					PREDICTED
APPLIED	HARVESTED			STAND-		HARVESTED			STAND-		HARVESTED FOLIAGE
N	FOLIAGE	PALMITO	TOTAL	ING	TOTAL	FOLIAGE	PALMITO	TOTAL	ING	TOTAL	N RELEASE [c]
kg ha^{-1}	kg ha^{-1}					kg N ha^{-1}					kg N ha^{-1} yr^{-1}
0	7250	1277	11908	6161	18069	117.8	9.1	155.1	92.6	247.7	79.3
0[a]	6652	1225	11000	7440	18440	115.4	8.7	150.7	97.4	248.1	(73.3)
50	9342	1634	15406	8912	24318	173.9	11.2	228.1	103.1	331.2	118.3
100	8661	1574	14405	5771	20176	159.9	10.7	217.0	118.0	335.0	113.4
100[b]	9975	1839	16589	5628	22217	279.5	11.0	270.7	106.6	434.6	157.0
200	10346	1824	17106	9280	26386	289.9	12.4	348.9	188.8	537.7	193.3
400	8823	1604	14477	9572	24049	230.6	12.4	363.4	188.2	551.6	180.7

[a] Denotes the only treatment where foliage and stem residue were removed from the field at each harvest date; in all other treatments residues were left as a mulch.

[b] N source was urea; in all other treatments N source was NH_4NO_3.

[c] Estimated cumulative N release from cut foliage for all harvests using prediction equations developed from litterbag decomposition studies in prior field trials in the same region of Costa Rica.

Table 2. Mean dry weights and N uptake for cut foliage, exported palmito, total harvested biomass and standing vegetation, and predicted N release from foliage residues for each treatment during the second crop year of the experiment.

	DRY MATTER					N ACCUMULATION					PREDICTED
APPLIED	HARVESTED			STAND-		HARVESTED			STAND-		HARVESTED FOLIAGE
N	FOLIAGE	PALMITO	TOTAL	ING	TOTAL	FOLIAGE	PALMITO[c]	TOTAL	ING	TOTAL	N RELEASE [c]
kg ha^{-1}	kg ha^{-1}					kg N ha^{-1}					kg N ha^{-1} yr^{-1}
0	8865	1370	14752	4033	18785	170.0	20.7	229.4	81.6	311.0	134.1
0	7047	1119	11350	5686	17036	143.6	17.4	186.4	116.4	302.8	(143.6)
50	10409	1639	16711	5112	21823	203.1	24.2	279.9	106.5	386.4	161.8
100	9877	1624	15935	5825	21760	196.9	25.8	258.6	133.2	391.8	156.6
100[b]	9686	1644	15964	5944	21908	210.9	27.2	276.7	140.5	417.2	167.4
200	8982	1496	14730	11576	26306	213.9	26.7	282.1	252.7	534.8	164.7
400	12682	2069	20752	12706	33458	287.7	33.3	374.2	224.9	599.1	228.7

[a] Denotes the only treatment where foliage and stem residue were removed from the field at each harvest date; in all other treatments residues were left as a mulch.

[b] N source was urea; in all other treatments N source was NH_4NO_3.

[c] Estimated cumulative N release from cut foliage for all harvests using prediction equations developed from litterbag decomposition studies in prior field trials in the same region of Costa Rica.

The relations between apparent fertilizer N recovery and rates of applied NH_4NO_3-N treatments are shown in Figure 2 for both crop years. Data for the treatment with 400 kg N ha^{-1} in year 1 were excluded, because there was no yield response above 200 kg N ha^{-1} (Figure 1). All treatments, except for 200 kg N ha^{-1} in year 2, were adequately described by a linear relation with a zero intercept; nevertheless, this outlier was included in the regression equation. The slope of the equation provides an estimate of 57% for fertilizer N efficiency over the two crop years of this mature peach palm stand.

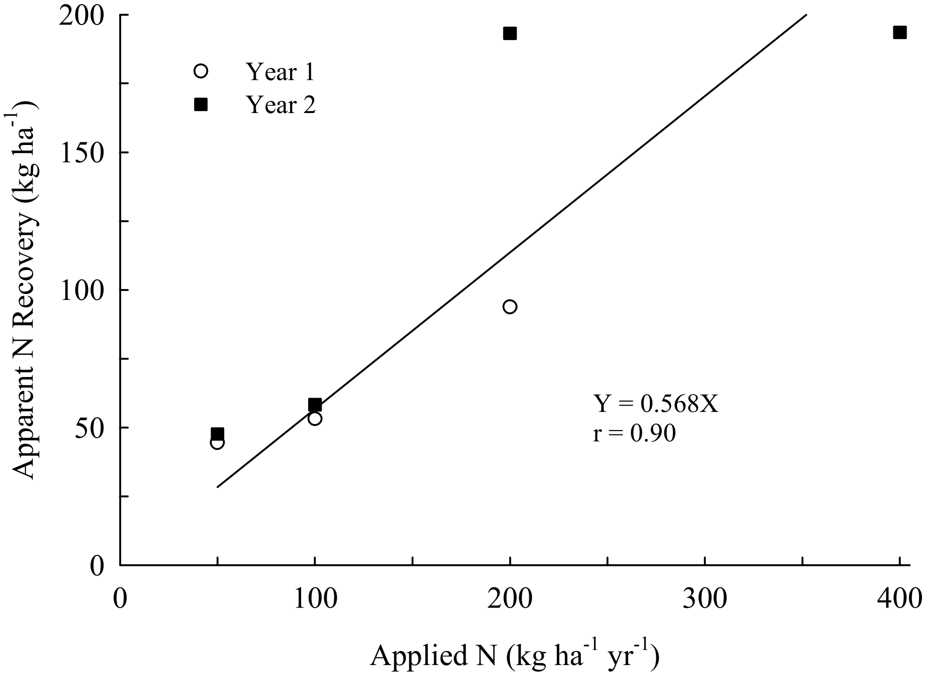

Figure 2. Apparent fertilizer N recovery by a mature peach palm stand during two consecutive years of harvest for heart-of-palm production with variable rates of NH_4NO_3 on an Aquandic Dystrudepts in Costa Rica.

The 3rd and 5th leaves (counting from youngest to oldest) were sampled periodically, during both crop years for N content, to evaluate their potential use in diagnostic tissue analysis. Correlations between % leaf N and relative palmito yield were significant in both years with only the 3rd leaf. However, relationships with relative yield differed between crop years (Figure 3). Data for year 1 suggested a critical leaf N level of 2.72% for the yield plateau, whereas data for year 2 suggested a linear increase in leaf N from 2.5 to 3.3% across the entire range of fertilizer N rates.

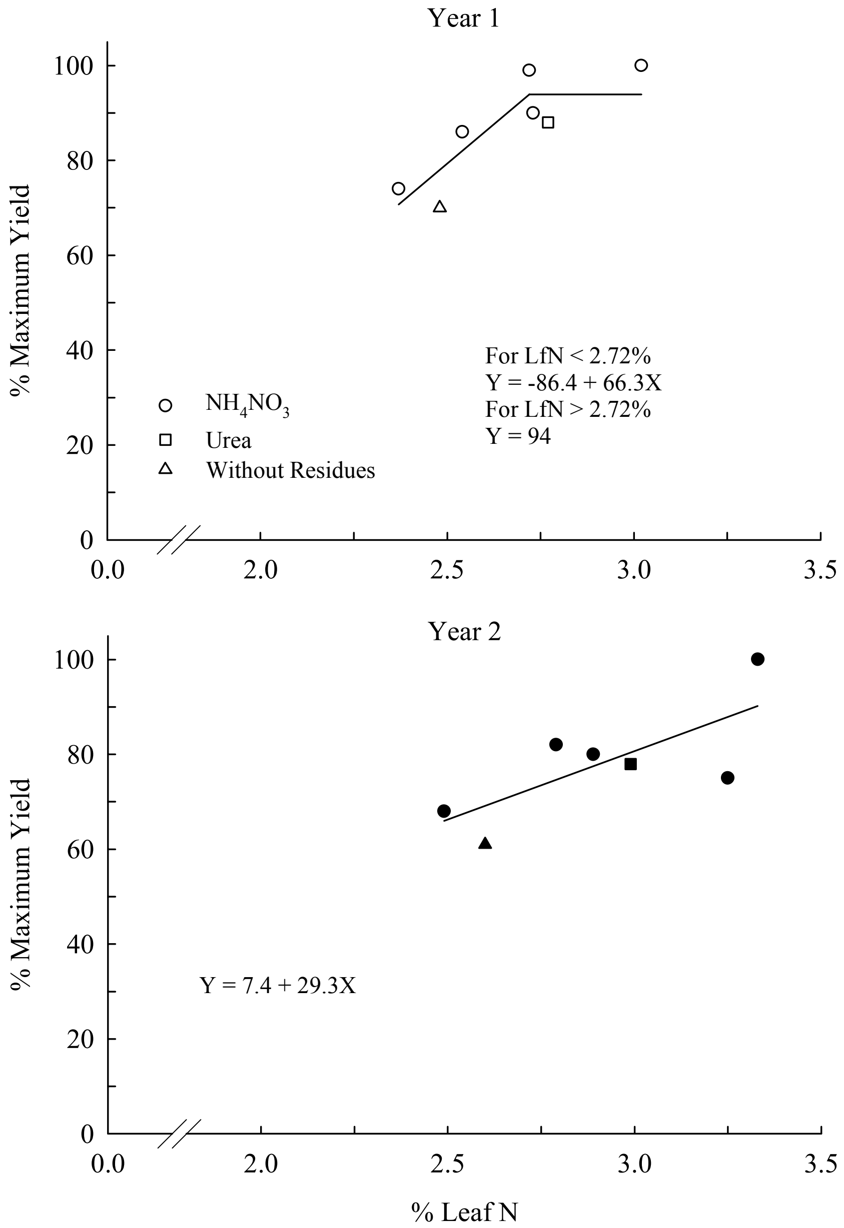

Figure 3. Relations between % N in the 3rd leaf and relative palmito yield during two consecutive crop years for a mature peach palm stand in Costa Rica.

1. b. <u>P fertilization field trial</u> - (supervision by Alfredo Alvarado, Eloy Molina, Rafael Salas, Jimmy Boniche and Danilo Alpizar of UCR, and Antonio Bogantes of MAG, with assistance from Adrian Ares and Russ Yost) Although heart-of-palm plantations are regularly fertilized in the main production regions of Latin America, there is little information on the rates of P fertilization and diagnostic methods for P sufficiency/deficiency. A heterogeneous spatial distribution of roots and nutrients in soils is an additional complicating factor for nutrient analysis in perennial crops. In these crops, foliar analysis may be more suitable for diagnosis

than soil tests. Foliar analysis, however, has not always been useful in predicting perennial crop responses to fertilization because nutrient concentrations are affected by factors such as leaf position within the crown, sample position within the leaf, stand and foliage age, nutrient interactions and climatic variations. Therefore, diagnosing nutrient status in peach palm may require methods that are designed to reflect the particular characteristics of perennial plants in nutrient acquisition and recycling.

A field fertilization trial was carried out in Costa Rica to determine peach palm response to controlled P additions and the value of extractable soil P by two methods (Modified Olsen and Mehlich 3), and different tissues (3rd and 5th leaf, petiole) in diagnosing P sufficiency/deficiency. Results from this trial and other complementary experiments were applied to refine the diagnostic and prediction phases in NuMaSS.

The experimental site was located in Caño Negro, San Carlos, at 200 m.a.s.l. Mean annual rainfall in Santa Clara (nearby Caño Negro) at 171 m.a.s.l. is 3171 mm and mean annual temperature is 25.5 °C. The soil has been tentatively classified as Inceptisol, soil clay content varied between 29 and 57%, and pH between 4.2 and 4.4 (Table 3). Initial extractable P (Modified Olsen) was 2.7 mg/kg at 0-5 cm depth and 1.7 mg/kg at 5-20 cm. A preliminary survey indicated that foliar P values were low (0.13-0.15%) in reference to tentatively proposed critical levels. Initial spacing of the peach palm stand was 2 x 0.5 m (10,000 plants/ha).

Table 3. Characteristics of the experimental site in Caño Negro, Costa Rica.

Block	**Depth**	**OM**	**Clay**	**pH**	**Ca**	**Mg**	**K**	**Acidity**	**ECEC**	**P**
	cm	----- % -----			-------------------- $\text{cmol}_c\ l^{-1}$ --------------------					mg/kg
1	0-5	3.5	50	4.3	9.9	2.7	0.3	2.4	15.3	2.5
	5-20	4.1	52	4.3	8.1	2.9	0.1	2.9	14.1	1.3
2	0-5	5.1	29	4.3	8.3	2.3	0.2	6.7	17.6	2.8
	5-20	4.2	30	4.4	8.8	2.9	0.1	2.5	14.4	1.4
3	0-5	5.3	51	4.3	9.1	2.8	0.2	3.4	15.5	2.5
	5-20	3.9	49	4.3	8.7	3.0	0.1	3.2	15.2	1.4
4	0-5	5.7	56	4.2	8.5	2.6	0.4	2.4	13.9	3.1
	5-20	4.0	57	4.2	8.0	2.6	0.2	2.1	12.9	2.5

After tending the four experimental blocks, soil samples were taken in each block and the P buffer coefficient was determined in the laboratory. The amount of fertilizer needed to raise extractable P to 5, 10 and 20 mg/kg (treatments derived from soil conditions) and to cover P crop requirements assuming a P absorption efficiency of 25 and 75%, respectively (treatments derived from crop uptake) was then calculated. Treatments were 0, 3.9, 7.8, 14.4, 21 and 47.7 kg P/ha. During the first year, P was applied as diammonium phosphate split into two applications six months apart. A blanket fertilization of N (250 kg/ha including N applied as DAP), K (124,5 kg/ha), Mg (36,1 kg/ha) and S (60 kg/ha) was also made. Potassium, Mg and S were applied as K-Mag (0-0-22-18-22). The blanket fertilization was done in July 1999 and P was applied in September 1999. The study plots were arranged in a completely randomized block design with four replicates. Measurements were taken in 50 m^2-plots. In the second and third years, a doubled P dose was applied as KH_2PO_4. Also, soil samples were taken from the crop alleys in addition to the standard sampling at 30-40 cm from the plant rows.

By convention, the spear (youngest) leaf of peach palm is numbered as zero. Phosphorus concentration in the 3rd and 5th leaf were measured monthly during the first two years and every four months during the third year. Heart-of-palm yield, number of heart-of-palms and number of new shoots were measured monthly from August 1999 to July 2002.

Initially, the P concentration in the 3rd leaf was marginally deficient relative to the tentatively proposed critical levels. After applying the blanket fertilization and imposing the P fertilization treatments, the P concentration in the 3rd and 5th leaf dropped drastically (Figure 4). Later, the P concentration in the 3rd and 5th leaf significantly increased in all treatments including the control. During years 1 and 2 of the experiment, foliar P levels were similar among treatments and neither related to extractable soil P nor to applied P.

Extractable soil P varied more among treatments and dates than foliar P (Figure 5). During year 1, extractable soil P concentrations were lower than those expected from the soil buffer coefficients determined in the laboratory. More P was extracted with the Modified Olsen method than with Mehlich 3 (data not shown). Extractable P at 5-20 cm depth was less variable than extractable P at 0-5 cm (Figure 5). During year 2, after doubling the applied P doses, a steep gradient in extractable P at both depths was established. Differences in extractable P among treatments decreased over time and became insignificant at 5-20 cm depth at the end of the second year.

During year 1, heart-of-palm yield varied between 14785 kg (fresh weight) in the control to 16238 kg in the treatment with 21 kg P/ha, without significant differences among treatments (p=0.47) (Table 4). Variation between blocks was considerable with a maximum CV of 24%. During the second year, heart-of-palm yields varied between 12109 kg for the control and 13561 kg for the treatment with 95.4 kg P/ha. Variation between blocks decreased with a maximum CV of 15%. The effect of applied P on heart-of palm yield was significant (p=0.08). This effect was also significant on the cumulative yield in years 1 and 2 (p=0.06). The cumulative yield for the three years of the experiment, was only about 9% lower in the control than in the treatment receiving the highest doses of P (Table 5).

If extractable soil P values at 0-5 cm are averaged for the year 2 (which had relatively stable extractable soil P), the soil P critical levels to reach 90% of maximum heart-of-palm yield would be around 23 mg/kg for Modified Olsen and 17 mg/kg for Mehlich 3. These levels could be the consequence of increasing soil P because of increased P applications and may not indicate a causal relationship between extractable soil P and growth response in peach palm.

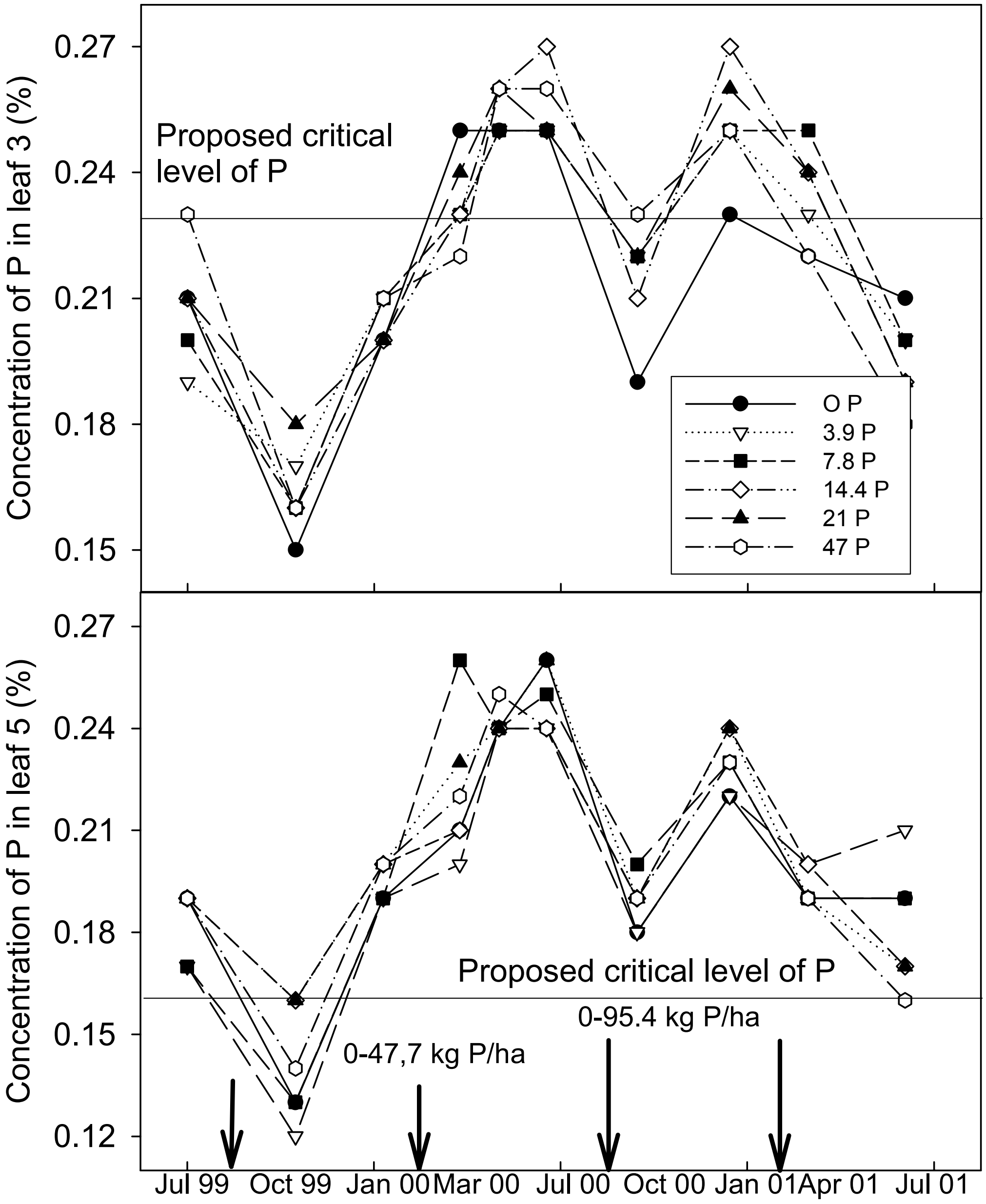

Figure 4. Variation in foliar P in two proposed diagnostic leaves for peach palm under heart-of-palm production in Costa Rica. Arrows indicate timing for application of two ranges of P rates during the experiment.

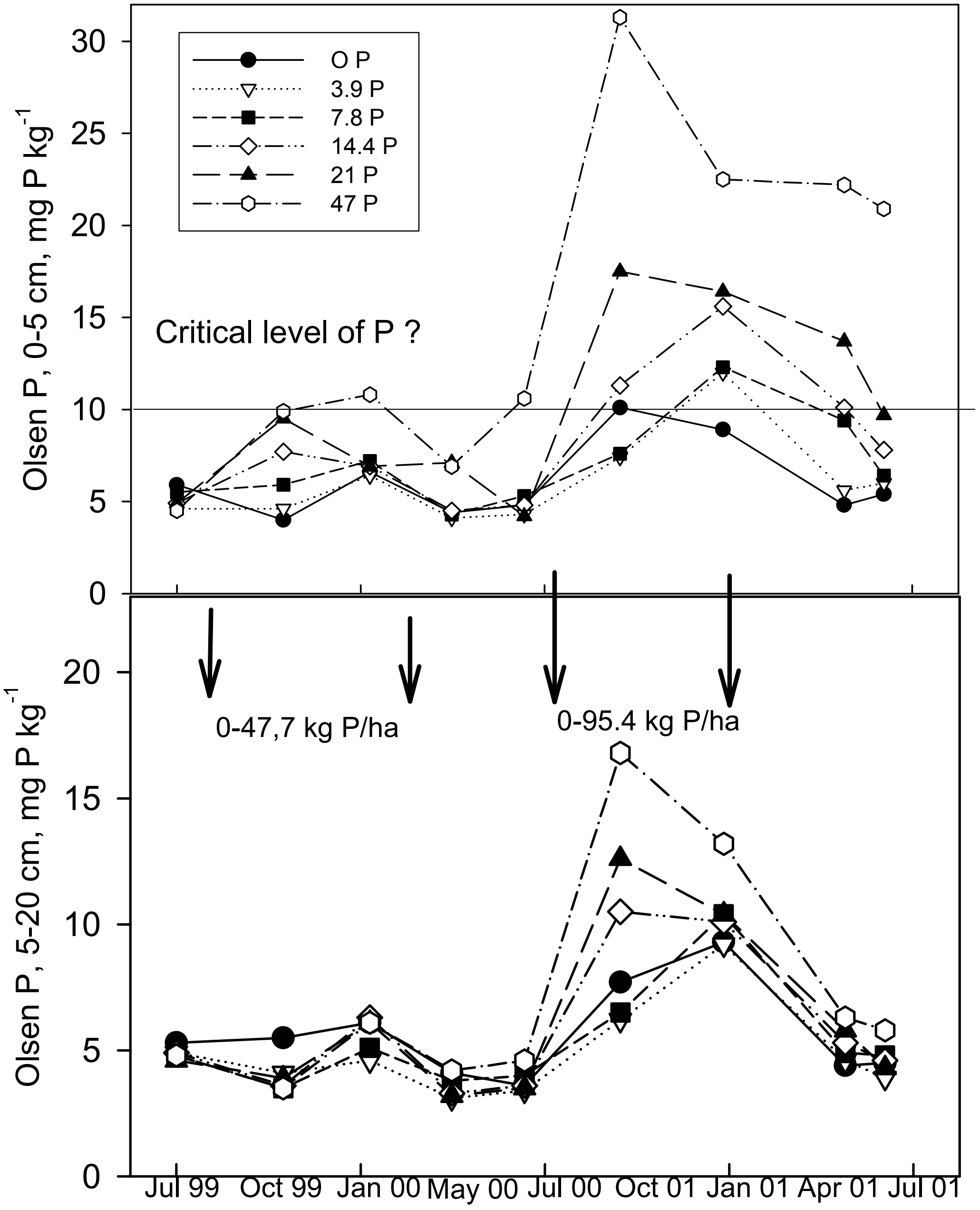

Figure 5. Variation in modified Olsen extractable soil P during an experiment with heart-of-palm production from peach palm in Costa Rica. Arrows indicate time of application for two ranges of fertilizer P rates.

Table 4. Heart-of-palm yields during three consecutive years of the P fertilization trial in Caño Negro, Costa Rica.

Year 1		Year 2		Year 3	
Applied P	**Yield**	**Applied P**	**Yield**	**Applied P**	**Yield**
kg/ha					
0	14785±3144	0	12109± 993	0	12107±1404
3.9	14840±2754	7.8	12961±1068	7.8	12750±1084
7.8	15857±1805	15.6	12294±1027	15.6	13937± 906
14.4	15152±3667	28.8	11814± 478	28.8	13381±1940
21.0	16238±2573	42.0	12882± 530	42.0	13300± 997
47.7	15947±1878	95.4	13561±1982	95.4	12738± 955

Table 5. Cumulative heart-of-palm yields and applied P for three years in the in the field trial at Caño Negro, Costa Rica.

Applied P	**Yield**
----- kg/ha -----	
0	39001
19.5	40551
39.0	42088
72.0	40347
105.0	42420
238.5	42246

The response in heart-of palm yields in the high-plant density plantation of peach palm was gradual and less than predicted based on the initially soil extractable P values. The cumulative yield for the three years of the experiment, was only about 9% lower in the control than in the treatment receiving the highest doses of P. During the first year, P additions were not able to raise extractable P levels to those expected from the P buffer coefficients. Only during the second year, an increased P application established a broad gradient in soil P extractable levels among treatments.

Standard measures of extractable P in soil seemed of limited value to diagnose response of peach palm to P fertilization and alternative methods (e.g., organic P) could be more useful for diagnosis. Australian researchers have advocated the use of solution P extracted with 0.01 M $CaCl_2$ as diagnostic method for woody species in the nursery and field (Smethhurst, 2000). In an experiment with peach palm in the Amazon region, however, solution P collected with ceramic suction cups was very low and too variable to be a good index of P availability (Schroth, 2000).

Literature cited:

Schroth, G.R., Seixas, L.F., da Silva, L., Teixera, W.G., Zech, W. 2000. Nutrient concentration and acidity in ferralitic soil under perennial cropping, fallow and primary forest in central Amazonia. European Journal of Soil Science 51: 219-231.

Smethurst, P.J. 2000. Soil solution and other soil analyses as indicators of nutrient supply: a review. Forest Ecology and Management 138: 397-411.

1. c. Field testing the diagnosis of N and P constraints by NuMaSS for peach palm in Andisols and Ultisols of Costa Rica (supervised by Alfredo Alvarado, Jimmy Boniche and Danilo Alpizar of UCR with support from Adrian Ares, Deanna Osmond, Jot Smyth and Russ Yost). The intent of the Diagnosis section for the NuMaSS software is to indicate whether soil acidity, N or P constraints exist in a specific site for the intended crop. The determination is based on available information about soils, previous crop performance and land management, plant nutrient deficiency symptoms and indicator plants. Bayesian conditional probability values, derived from surveys of nutrient management experts throughout the tropics, are associated with each diagnostic factor. The final diagnoses for acidity, N or P constraints are based on the cumulative probability for information provided on all factors.

On-farm trials were conducted in Costa Rica to evaluate the initial diagnosis by NuMaSS of soil N and P constraints for the intended crop of peach palm in production of heart-of-palm. Trial sites consisted of six peach palm stands in the Caribbean region of Costa Rica. Soils at each half of the sites were classified as either Andisols or Ultisols. After the initial diagnosis of N and P constraints, heart-of-palm yield response to fertilizer inputs were monitored at each site for 30 consecutive weeks. General characteristics for peach palm stands and their prior management at each site are shown in Table 6. Stand age among sites ranged from 2 to 11 years and stand

Table 6. General characteristics and prior management of peach palm stands at each on-farm test site for NuMaSS Diagnosis in Costa Rica.

Soil		**Stand**		**Prior**	**Pests and**	**Prior**	**Nutrient**
Order	**Site**	**Age**	**Density**	**Yield**	**Diseases**	**Fertilization**	**Deficiencies**
		yr	plant/ha	stems/yr		/ha/yr	
Andisol	1	3	6975	no record	Anthracnosis	0.8 t lime, N, P, K, Mg, S	N, K, Mg
Andisol	2	4	4450	7000	Anthracnosis, rodents	1 t lime, 600 kg 18-5-15-6, 540 kg urea	N, Mg
Andisol	3	9	6300	13000	Anthracnosis, rodents	lime	N, Mg
Ultisol	1	3	6800	no record	Anthracnosis	0.8 t lime, 200 kg urea	N, K, Mg
Ultisol	2	2	5900	no record	None	0.7 t lime, 120 kg NH_4NO_3	N, K, Mg
Ultisol	3	11	5263	no record	Anthracnosis, rodents	None for last 5 years	N, K, Mg, Ca

density ranged from 4450 to 6975 plants ha^{-1}. Most fields had received lime and N fertilizers during the previous year. Nutrient deficiency symptoms for N and Mg were present in all fields. Surface soil and diagnostic leaf samples were collected and analyzed during the initial diagnosis of each site (Tables 7 and 8). Diagnosis for soil acidity, N and P constraints for peach palm, using the data in Tables 6-8, are summarized for each site in Table 9. All sites were diagnosed as deficient in nitrogen and magnesium. Two of the sites on Ultisols were also diagnosed as deficient in Ca. All three sites in Andisols were diagnosed as not having a P deficiency (cumulative probability values of 0.32-0.39). Probability values for P diagnosis of sites in Ultisols was in the uncertainty range (0.54-0.58) between presence and absence of a deficiency.

Table 7. Surface soil characteristics at each diagnosis test site for peach palm prior to establishment of the fertilizer treatments.

		pH		**KCl-Extractable**				**Al**	**Mod. Olsen**			**Org.**	**Text.**
Soil	**Site**	**H_2O**	**NaF**	**Ca**	**Mg**	**K**	**Al**	**Sat.**	**P**	**Cu**	**Zn**	**Mat.**	**Class[a]**
				---------- cmol$_c$ L^{-1} ----------				%	------- mg L^{-1} -------			%	
And.	1	5.3	11.6	1.5	0.5	0.2	0.5	19	3.0	5.4	1.9	14.0	S
	2	5.6	11.4	5.9	1.0	0.2	0.2	3	12.5	3.9	0.6	9.2	LS
	3	4.5	9.9	3.9	0.3	0.2	1.5	25	7.0	26.4	6.8	8.0	SL
Ult.	1	3.8		1.4	0.2	0.2	1.8	50	5.4	28.7	3.8	4.3	C
	2	4.0		3.1	0.6	0.2	1.6	29	5.7	22.8	5.6	5.1	CL
	3	3.7		0.9	0.3	0.2	3.9	74	6.2	22.4	4.6	4.8	SC

[a] S=sand, LS=loamy sand, SL=sandy loam, C=clayey, CL=clay loam, SC=sandy clay.

Table 8. Foliar analysis (3rd most recent leaf) for peach palm stands during diagnosis assessment and prior to establishment of the fertilizer treatments.

Soil	**Site**	**N**	**P**	**Ca**	**Mg**	**K**	**S**	**Cu**	**Mn**	**Zn**	**B**
		------------------------------ % ------------------------------						--------------- mg kg^{-1} ---------------			
And.	1	2.45	0.22	0.69	0.25	0.58	0.45	59	89	60	25
	2	2.58	0.22	0.45	0.27	1.03	0.27	15	56	26	31
	3	3.05	0.22	0.59	0.16	1.37	0.50	80	104	86	19
Ult.	1	2.41	0.22	0.69	0.26	1.05	0.48	8	213	48	20
	2	2.67	0.22	0.55	0.30	1.23	0.47	5	191	43	13
	3	2.16	0.22	0.57	0.30	1.51	0.58	5	125	60	15

Three treatments were established at each site in 40-m^2 plots with three replications: a) control with no nutrients added, b) 133 kg N ha^{-1} (as NH_4NO_3) and c) 133 kg N ha^{-1} plus 29 kg P ha^{-1} (as triple superphosphate). Given the widespread occurrence of plant deficiency symptoms and the

Table 9. Summary of NuMaSS Diagnosis for peach palm stands at each test site.

		Soil Nutrient Limitation		
Soil	**Site**	**Acidity**	**N**	**P**
Andisol	1	Mg deficiency	yes	no
	2	Mg deficiency	yes	no
	3	Mg deficiency	yes	no
Ultisol	1	Mg deficiency	yes	no
	2	Mg deficiency Ca deficiency	yes	no
	3	Mg deficiency Ca deficiency	yes	no

diagnosis of a probable Mg deficiency, the N and N+P treatments also received 40 kg of Mg ha^{-1} as $MgSO_4$. All fertilizers were applied in four equal fractions on a bi-monthly basis starting in December 2001. Heart-of-palm were harvested at 7, 12, 17, 21, 25 and 30 weeks after the initial fertilizer application.

There were no significant differences between sites on Andisols and Ultisols in the cumulative number or the total fresh weight of hearts-of-palm harvested during the 30 weeks of the trials. Cumulative heart-of-palm yields, averaged across sites and treatments within soils, were 4824 stems ha^{-1} for Andisols and 6674 for Ultisols. Single-degree-of-freedom contrasts for treatment means indicated that there were significant differences in both yield variables between the control treatment and the mean of the N and N+P treatments. However, there were no differences between the N and N+P treatments. Mean heart-of-palm yields for treatments averaged across soils were 4808 stems/ha for the control, 6297 stems/ha for N and 6142 stems/ha for N+P (Table 10). Although yield differences among treatments were not significantly different between Andisols and Ultisols, there was a trend for increased yields with P fertilization in the Andisols. Results for these trials suggest that the likelihood of N and P limitations for heart-of-palm production were properly diagnosed by the NuMaSS software.

Table 10. Cumulative number of stems and total fresh weight harvested over 30 weeks for heart-of-palm production at six sites on Andisols and Ultisols in Costa Rica.

			HARVESTED HEART-OF-PALM	
SOIL	**SITE**	**TREATMENT**	**STEMS**	**FRESH WEIGHT**
			number/ha	kg/ha
Andisol	1	Control	5083	3867
		N	6167	4879
		N+P	4917	4060

			HARVESTED HEART-OF-PALM	
SOIL	**SITE**	**TREATMENT**	**STEMS**	**FRESH WEIGHT**
			number/ha	kg/ha
	2	Control	3667	2277
		N	3333	2160
		N+P	4417	3294
	3	Control	3167	2131
		N	5583	3852
		N+P	7083	5002
	Andisol Means	*Control*	*3972*	*2758*
		N	*5028*	*3631*
		N+P	*5472*	*4119*
Ultisol	1	Control	7222	5414
		N	10222	7706
		N+P	9222	7053
	2	Control	3833	2706
		N	4583	3269
		N+P	6917	5204
	3	Control	5877	4035
		N	7895	5711
		N+P	4298	341
	Ultisol Means	*Control*	*5644*	*4052*
		N	*7567*	*5562*
		N+P	*6812*	*5333*
	Treatment Means Across Soils	*Control*	*4808*	*3405*
		N	*6297*	*4596*
		N+P	*6142*	*4726*

Additional diagnostic P measurements were also taken on two of the trial sites - Andisols Site 3 and Ultisols Site 1. Petioles and blades of the 3rd and 5th leaves, and portions of peach palm basal sections (rhizome and fibrous tissue below the stem) were collected within each of the three replications of the N and N+P treatments prior to their fertilization.

The sampling of portions of the basal sections (done with a tree increment borer) proved to be technically difficult and impractical. Samples were small and contained a great proportion of soil. Instead of a largely continuous mass of plant tissue, the basal section appeared as a entanglement of intermixed plant tissue and soil material which does not offer steady resistence to the borer penetration and allow a clean, large sample to be taken. Sampling of petioles did not offer such difficulties and were faster than leaf blade sampling.

In the Andisol, mean cumulative heart-of-palm yields for 30 weeks were 5583 and 7083 stems ha^{-1} for the N and N+P treatments, respectively (Table 10). The yields for the N and N+P treatments were not significantly different but results suggested an incipient response to P. There was a trend to increased P concentrations in the plant tissues for the N+P treatment compared to the treatment with only N. This trend was more marked for the petiole of the 5th leaf (+55%) and the basal section (+77%) (Table 11).

Table 11. Phosphorus concentrations in different plant tissues and percent differences between N and N+P treatments for the diagnosis field trials on Andisol Site 3 and a Ultisol Site 1 in the Atlantic Region of Costa Rica.

	Treat-	**P Concentration**				
Site	**ment**	**3rd Leaf**	**5th Leaf**	**Petiole 3rd leaf**	**Petiole 5th leaf**	**Basal section**
		-------	-------	------- % -------	-------	-------
Andisol	N	0.224	0.257	0.096	0.084	0.073
	N+P	0.257	0.311	0.121	0.129	0.129
Change w/ added P		15%	21%	26%	55%	77%
Ultisol	N	0.319	0.327	0.135	0.175	0.123
	N+P	0.300	0.351	0.157	0.207	0.158
Change w/ added P		-6%	7%	16%	18%	28%

In the Ultisol, heart-of-palm yields were similar for the N and N+P treatments (about 10,000 stems ha^{-1}). The trend to increased P concentrations in plant tissues was less marked than for the Andisol, but the relative differences in P increase were also higher for the petiole of the 5th leaf and the basal section (Table 11).

Foliar P concentrations in both the 3rd and 5th leaf varied widely over time in the P trial at Caño Negro (Figure 4) and were not related to added P. Concentration of P in the petiole may be a better indicator but more research is needed. In addition to the results reported here, the range of P concentration in petioles and basal sections was 0.15-0.42% and 0.20-0.50%, respectively, while foliage P only varied between 0.25 and 0.36% in four stands of peach palm growing in Costa Rica on soils with modified-Olsen P ranging from 7 to 38 mg/kg.

1. d. Determining the soil test critical P level for peach palm seedlings in Ultisols and Andisols of Costa Rica (supervision by Alfredo Alvarado, Eloy Molina, Jimmy Boniche and Danilo Alpizar of UCR, Antonio Bogantes of MAG, with support from Fred Cox) Soil test information is needed for each crop considered in NuMaSS to be able to calculate the quantity of fertilizer required. A critical level for P is needed for peach palm grown on both Ultisols and Andisols. The objectives of this study were (1) to determine the critical soil test P level for peach palm seedlings and (2) to compare the P buffer coefficient found in a greenhouse study with that of a prior laboratory determination.

Ten soils low in P were collected on a transect from Turrialba to between Pital and Los Chiles and analyzed for physical and chemical properties. The samples were coded 0 to 9, the first five being Andisols and the last five Ultisols. Location coordinates are shown in Table 12.

Table 12. Locations of the 10 soils used in the greenhouse.

Soil Code	Location	Order	Latitude	Longitude
0	Indaco	Andisol	10º 22´ 16.9´´	83º 56´ 37.9´´
1	Venecia	Andisol	10º 21´ 1.931´´	84º 17´ 46.82´´
2	Diamantes-P	Andisol	10º 14´ 18.5´´	83º 46´ 11.6´´
3	Diamantes-C	Andisol	10º 15´ 25.8´´	83º 46´ 24.5´´
4	Guaria	Andisol	10º 09´ 27.6´´	83º 48´ 27.9´´
5	Chiles 17	Ultisol	10º 58´ 34.4´´	84º 44´ 52.5´´
6	Chiles 18	Ultisol	10º 58´ 37.3´´	84º 45´ 05.7´´
7	Chiles 21	Ultisol	10º 59´ 14.2´´	84º 44´ 29.4´´
8	Aragonez	Ultisol	10º 31´ 41.9´´	84º 23´ 45.37´´
9	Berrocal	Ultisol	10º 32´ 29.9´´	84º 23´ 53.5´´

Samples of the soils were mixed 1:1 with quantities of P (0, 35, 70, and 140 $\mu g/cm^3$), dried, and extractable P determined with both Modified Olsen and Mehlich 3. The laboratory P buffer coefficient was calculated and the quantity of P required to raise the soil test P level to 10 $\mu g/cm^3$ was determined. Using this quantity as unity, or "X", fertilizer P amounts could be calculated for the following treatments: 0, 0.25X, 0.5X, X, 2X, and 4X.

A greenhouse experiment was initiated in September 2000 on the Richard Garon farm in the La Leona area near Guapiles, Costa Rica. Soil, 3.6 dm^3, was mixed with a rate of powdered $Ca(H_2PO_4)_2.H_2O$ for each treatment. Peach palm seedlings from the Diamantes Experiment Station were transplanted into the soil and watered. Each pot was in a tray to hold any leachate. Initial plant height was measured. Other fertilization and disease control measures were applied as needed during the course of the study. There were 5 replications for 7 of the soils and at least 4 reps on the other 3 soils.

In April 2001 the leaves were counted, the plants were photographed, measured for height, cut just above the soil surface, and weighed. The roots were removed from the soil, photographed, and observed, then the soil mixed and sampled. After drying, the plants were weighed again, ground and the plant and soil samples analyzed for P. Soil P was extracted with both Modified Olsen and Mehlich 3 solutions. The Mehlich 3 values were exceptionally low and will not be reported here.

The soils were selected to be low in P and ranged between 2.4 and 7.6 μg P/cm^3 (Table 13). These were the base levels used to calculate the rates of applied P. The clay content of the Ultisols ranged between 54 and 72%, the amorphous or oxalate-extractable Al of the Andisols ranged between 1.86 and 3.18%, and other chemical properties are also shown in Table 13.

The P buffer coefficients determined by Modified Olsen on the laboratory samples are shown in Table 14. The coefficients for the Andisols ranged from 0.088 to 0.162 and are less than those for the Ultisols which ranged from 0.111 to 0.221. This indicated somewhat greater retention of P in forms not extractable with Modified Olsen for the Andisols than the Ultisols. The predicted soil test P at the intercept, or that predicted for the zero application rate of P, is also given in Table 14. This should be a better estimate of the original level of P in each soil as it is based on numerous observations. It is greater than the initial level of P in the soil used to calculate the rate of P applied, shown again in this Table for reference. The mean of the 10 soils is 7.87 μg P/cm^3 by regression and 4.96 μg P/cm^3 for the single initial samples.

Photographs of the pots, trays, and transplants were shown in my September 2000 trip report which may be found at: http://intdss.soil.ncsu.edu/download/trip_reports/Cox_TripRpt_900.pdf. The transplants were somewhat N deficient at the time, but this was corrected by fertilization. There was also considerable variability among the transplants, both in size and variety. Most were spineless (Putumayo from Peru) but some had spines (Turrique from Costa Rica). The measurements of height at transplanting showed than one replication had taller plants than the rest. This continued throughout the study, but use of this factor as a covariable with other measurements of yield, such as dry weight and number of leaves, showed no improvement in the analysis of variance, thus its use will not be reported.

Photographs of the plants at harvest were shown in my April 2001 trip report which may be found at: http://intdss.soil.ncsu.edu/download/trip_reports/Cox_CRica_0401_Trip.pdf. The average of the five replications for a soil was selected for each picture, but considerable variation is still shown. There was an increase in growth with an increase in rate of P applied in several of the soils. However, in two of the soils (2 and 7) growth appeared to increase, then decrease with increasing rate of P applied. Such a decrease cannot be explained.

At harvest after cutting the tops the roots were separated from the soil, observed, and photographed. Root growth was generally proportional to top growth. Roots from the larger plants had considerable growth along the top and sides of the pot, but only on the very largest were there many roots along the bottom of the pot. Thus often a hollow “cylinder” of fairly coarse roots were removed.

After mixing, the soil was sampled. Some of the soils were quite wet as the pots were in drainage pans which had contained considerable water. There was even an indication of reduction in the bottom of some of the pots. Such constant wetness would affect P availability.

The primary measurements to show response to P fertilization were dry weight and plant height, and to a lesser extent number of leaves. Analysis of variance of these factors as a function of P applied showed significant effects of soil and rate of P applied, and no interaction. However,

Table 13. Physical and chemical properties of the soils used in the greenhouse P experiment.

				KOH		**Oxalate**					**Modified Olsen**									
No	**Lab**	**Location**	**Order**[a]	**Al**	**Fe**	**Al**	**Fe**	**Clay**	**OM**	**pH**	**Ca**	**Mg**	**K**	**P**	**Cu**	**Fe**	**Mn**	**Zn**	**Ac**	**ECEC**
				------------------------ % ------------------------							-------- cmol$_c$ l^{-1} ---------			--------------- mg dm^{-3} ---------------					----- cmol$_c$ l^{-1} -----	
0	11002	Indaco	A	2.33	0.14	2.08	1.13	--	8.6	4.5	2.12	0.32	0.11	6.0	8.0	234	8.9	0.6	2.53	5.08
1	11003	Venecia	A	1.98	0.03	1.88	1.78	--	6.6	4.7	1.05	0.59	0.14	5.3	9.7	186	21.5	2.1	1.75	3.53
2	11071	Diamantes - P	A	1.60	0.03	1.86	0.88	--	7.9	5.3	4.29	0.96	0.15	4.1	3.5	67	2.0	0.2	0.38	5.78
3	11072	Diamantes - C	A	1.43	0.13	1.89	0.92	--	7.6	5.3	3.48	1.02	0.20	3.0	1.2	56	4.6	0.5	0.40	5.10
4	11073	Guaria	A	2.99	0.13	3.18	1.46	--	14.5	5.3	3.18	0.93	0.11	2.4	0.8	26	1.5	0.2	0.40	4.62
5	11321	Chiles 17	U	0.66	0.24	0.38	0.69	54	2.1	4.6	0.90	0.60	0.04	5.7	7.0	107	133.0	1.7	1.66	3.20
6	11322	Chiles 18	U	0.79	0.27	0.40	0.61	72	2.9	4.7	1.31	0.70	0.05	3.2	4.7	131	47.9	0.6	1.20	3.26
7	11323	Chiles 21	U	0.31	0.04	0.29	1.32	55	7.4	5.7	13.00	3.70	0.80	7.3	11.3	227	76.0	4.0	0.21	17.71
8	11609	Aragonez	U	0.61	0.24	0.69	0.87	72	6.3	4.6	3.79	0.64	0.55	7.6	15.3	568	39.9	3.3	0.69	5.67
9	11610	Berrocal	U	0.75	0.28	0.69	0.72	60	7.4	4.2	3.29	0.89	0.22	4.9	15.0	541	229.0	2.0	1.96	6.36

[a] A=Andisols, U=Ultisols.

Table 14. Modified Olsen P for an initial soil sample, P level of the check treatment and P buffer coefficient estimated by regression on samples prior to the greenhouse study, and P level of the check treatment and P buffer coefficient estimated by regression on samples after the greenhouse study.

	Lab Incubation			**After Greenhouse Study**		
Soil	**Mod. Olsen P**			**Mod. Olsen P**		
Code	**Observed**	**Regression**	**Slope**	**Observed**	**Regression**	**Slope**
	----- mg P dm^{-3} -----			----- mg P dm^{-3} -----		
0	6.00	6.97	0.125	5.30	9.08	0.074
1	5.30	7.41	0.088	10.45	9.60	0.045
2	4.10	8.51	0.124	7.56	7.45	0.044
3	3.00	9.45	0.162	9.74	8.64	0.050
4	2.40	5.99	0.122	4.11	5.28	0.054
5	5.71	4.45	0.111	7.52	7.65	0.034
6	3.22	4.81	0.162	8.07	7.96	0.038
7	7.34	10.57	0.180	8.10	11.19	0.123
8	7.60	9.94	0.221	9.62	13.14	0.149
9	4.90	10.63	0.200	6.42	9.40	0.045
Mean	4.96	7.87	0.150	7.69	8.94	0.066

further analysis showed that the Ultisols produced larger plants than the Andisols, and that there were some differences in the P rate effect among soils. Therefore, the results will be presented by regression of each dependent variable on the rate of P applied by soil.

Dry weight was increased by rate of P applied on 7 of the 10 soils (Table 15). Variability was high (cvs from 16 to 32%) and only a general linear effect could be noted. Soils 0, 1, 4, and 6 had highly significant effects of P applied.

Plant height was increased by rate of P applied on 5 of the 10 soils, namely 0, 1, 4, 5, and 6 (Table 16). In this case the cvs ranged from 22 to 39%.

Leaf number was increased by rate of P applied on 4 soils; 0, 1, 4 (trend), 6, and 9 (trend)(Table 17). The trend is significant only at the 10% level. The CVs ranged from 19 to 34%.

Modified Olsen extractable P did increase significantly with rate of P applied for all soils and the CV was more moderate, from 12 to 29% (Table 18). The slopes found are the estimate of the P buffer capacity at the end of the greenhouse study. These coefficients are also given in Table 14 for comparison with those before the greenhouse study.

Table 15. Relationship between dry weight and rate of P applied, significance of the slope, coefficient of variation, and mean for the 10 soils.

Soil **Code**	**Equation** **Dry Wt.=a+b(X)**	**Significance**	**CV**	**Mean Dry Wt.**
			%	g
0	20.2+0.048*Papplied	**	17	22.2
1	20.0+0.074*Papplied	**	27	25.4
2	21.0+0.008*Papplied	ns	27	21.5
3	28.0+0.011*Papplied	ns	25	28.6
4	21.9+0.026*Papplied	**	16	24.0
5	22.1+0.060*Papplied	*	26	25.2
6	20.6+0.065*Papplied	**	23	24.2
7	28.8-0.021*Papplied	ns	32	28.4
8	26.5+0.301*Papplied	*	30	30.6
9	22.7+0.096*Papplied	*	28	26.0

Table 16. Relationship between plant height and rate of P applied, significance of the slope, coefficient of variation, and mean for the 10 soils.

Soil **Code**	**Equation** **Plt Ht=a+b(X)**	**Significance**	**CV**	**Mean Height**
			%	cm
0	40.7+0.176*Papplied	**	26	48.0
1	39.6+0.166*Papplied	**	27	51.7
2	43.3+0.028*Papplied	ns	39	45.1
3	62.2+0.012*Papplied	ns	26	62.9
4	47.4+0.072*Papplied	**	22	53.2
5	48.0+0.172*Papplied	**	27	56.9
6	43.3+0.173*Papplied	**	29	52.9
7	67.0-0.103*Papplied	ns	30	65.1
8	64.8+0.363*Papplied	ns	25	69.7
9	58.1+0.081*Papplied	ns	30	60.8

Table 17. Relationship between leaf number and rate of P applied, significance of the slope, coefficient of variation, and mean for the 10 soils.

Soil Code	Equation Leaves=a+b(X)	Significance	CV	Mean Leaf Number
			%	
0	5.7+0.017*Papplied	**	19	6.4
1	5.5+0.012*Papplied	*	27	6.3
2	5.5+0.004*Papplied	ns	29	5.8
3	7.2-0.004*Papplied	ns	20	6.9
4	6.1+0.004*Papplied	+	15	6.5
5	6.1+0.004*Papplied	ns	26	6.3
6	4.0+0.022*Papplied	**	34	5.2
7	6.7-0.022*Papplied	ns	25	6.2
8	6.5_0.028*Papplied	ns	25	6.9
9	6.4+0.015*Papplied	+	21	6.9

Table 18. Relationship between Modified Olsen P and rate of P applied, significance of the slope, coefficient of variation, and mean for the 10 soils.

Soil Code	Equation Mod. Olsen P=a+b(X)	Significance	CV	Mean MOP
			%	µg/cm^3
0	9.1+0.074*Papplied	**	18	12.1
1	9.6+0.045*Papplied	**	17	12.8
2	7.5+0.044*Papplied	**	12	10.1
3	8.6+0.050*Papplied	**	22	11.4
4	5.3+0.054*Papplied	**	29	9.7
5	7.4+0.036*Papplied	**	14	9.2
6	8.0+0.038*Papplied	**	28	10.1
7	11.2+0.123*Papplied	**	17	13.5
8	13.1+0.149*Papplied	**	16	15.0
9	9.4+0.045*Papplied	**	22	10.8

Dry weight increased with an increase in Modified Olsen P on 4 of the soils; 0, 1, 4, and 5 (Table 19). The Cvs for this analysis ranged from 17 to 34%. There was little evidence that the response was linear, then plateaued, although the greatest weights were ordinarily at greater than 10 µg MOP/cm^3. This is one method of interpreting this highly variable data. Another method is to note the soil test level of the soils which showed a response to either applied P or MOP, but there are several of these soil test levels, as shown in Table 14. The initial estimates of MOP were very low and based on only one sample. The laboratory incubation estimates were greater, and would indicate that responses were expected on the Ultisols if MOP was less than 10 µg/cm^3. After the greenhouse experiment, the MOP determined by regression also indicated that responses were likely if the MOP were less than 10 µg/cm^3. However, similar statements cannot be made for the Andisols for either before or after the greenhouse study. This poses the question as to whether the Modified Olsen is the best extractant to use on the Andisols, or if there is a good extractant for P from Andisols.

Table 19. Relationship between dry weight and Modified Olsen P, significance of the slope, coefficient of variation, and mean for the 10 soils.

Soil Code	**Equation Dry Weight=a+b(X)**	**Significance**	**CV**	**Mean Dry Wt.**
			%	g
0	15.7+0.54*MOP	**	17	22.2
1	6.5+1.48*MOP	**	25	25.3
2	19.4+0.22*MOP	ns	27	21.6
3	33.9-0.47*MOP	ns	24	28.6
4	20.5+0.36*MOP	*	17	24.0
5	10.6+1.54*MOP	**	26	24.7
6	20.0+0.42*MOP	ns	28	24.3
7	29.1-0.12*MOP	ns	29	27.5
8	30.0+0.07*MOP	ns	34	30.6
9	19.0+0.64*MOP	ns	30	26.0

Plant P increased with an increase in MOP on 3 soils; 3, 4, and 5 (Table 20). If 10 µg MOP/cm^3 is considered as sufficient soil P, the plant P at this level and above would have been greater than 0.14%.

Phosphorus uptake increased with an increase in MOP in 5 soils, reflecting the effects of MOP on both dry weight and plant P (Table 21). The CVs ranged in this case from 22 to 45%.

The results of this study give some indication of a Modified Olsen critical P level for the Ultisols, but little for the Andisols. Variability was extremely high in this study for many reasons; the plants used varied in size and variety, the soils could have been screened finer and mixed more thoroughly, the fertilizer P could have been mixed more thoroughly with the soil, the plants were kept excessively wet at times, and there was no quality assurance/quality control on the soil testing process, so it is unknown how precise or accurate are the soil test data. The Modified Olsen is a standard procedure throughout much of Latin America, however, and should

Table 20. Relationship between Plant P concentration and Modified Olsen P, significance of the slope, coefficient of variation, and mean for the 10 soils.

Soil Code	Equation % Plant P=a+b(X)	Significance	CV	Mean Plant P
			%	%
0	0.131+0.0024*MOP	ns	39	0.160
1	0.150+0.0003*MOP	ns	29	0.153
2	0.132+0.0024*MOP	ns	39	0.156
3	0.116+0.0026*MOP	*	15	0.144
4	0.094+0.0043*MOP	**	18	0.136
5	0.123+0.0065*MOP	**	14	0.182
6	0.143+0.0024*MOP	ns	22	0.168
7	0.156+0.0002*MOP	ns	19	0.159
8	0.035+0.0022*MOP	ns	19	0.189
9	0.175-0.0008*MOP	ns	28	0.166

Table 21. Relationship between P Uptake and Modified Olsen P, significance of the slope, coefficient of variation, and mean for the 10 soils.

Soil Code	Equation P uptake=a+b(X)	Significance	CV	Mean P Uptake
			%	μg/pot
0	1.75+0.150*MOP	+	45	3.57
1	1.24+0.201*MOP	**	22	3.84
2	2.68+0.063*MOP	ns	43	3.32
3	3.96+0.025*MOP	ns	33	4.24
4	1.79+0.154*MOP	**	22	3.27
5	0.37+0.45*MOP	**	22	4.46
6	2.39+0.161*MOP	*	34	4.05
7	3.60+0.068*MOP	ns	26	4.49
8	6.08-0.01*MOP	ns	27	5.94
9	3.41+0.081*MOP	ns	37	4.30

be the most reliable extractant, but it has been noted that soil test P varies more among laboratories using Olsen than among those using Mehlich 3 (Kleinman et al., 2001).

A second objective of this study was to compare the P buffer coefficient found in the laboratory with that found at the end of the greenhouse study. These values are given in Table 14; the mean of the 10 soils from the laboratory was 0.150 whereas after the greenhouse study it was 0.066, or less than half as much. The lower value for the latter may have been due to the much longer time and/or it may be associated with the extremely wet conditions used in the greenhouse study. It does appear that the coefficients found after the greenhouse study are exceptionally low.

With these few soils it does not appear that the buffer coefficients found for the Andisols are related to oxalate extractable Al nor are those for the Ultisols related to clay content.

Literature Cited -

Kleinman, P.J.A., A.N. Sharpley, K. Gartley, W.M. Jarrett, S. Kuo, R.G. Menon, R. Myers, K.R. Reddy, and E.O. Skogley. 2001. Interlaboratory comparison of soil phosphorus extracted by various soil test methods. Commun. Soil Sci Plant Anal. 32:2325-2345.

1. e. <u>Fifth year socio-economic survey</u> (conducted under the supervision of Frank Smith and Alfredo Alvarado) The evaluation focused on tracking and analysis of critical indicators of progress and impact in relation to conditions as previously documented in project years 1 and 3. The methodology includes surveys of project collaborators and beneficiaries, assessments of available records on nutrient management, and collection of critical market information. As part of this review, a meeting was held with representatives of all sectors of the peach palm ('palmito') industry. The meeting provided an opportunity for the project to disseminate preliminary research findings and to obtain feedback from participants.

The latest available data from SIM/CNP indicates f.o.b. prices for palmito continued to decline in the period January 1999 to August 2000 (Table 22). The principle buyer of Costa Rican palmito is France (3,656 tons in August, 2000). Sales to Spain, Canada, Israel and Chile were down 683 metric tons in August 2000, while sales to the U.S., Holland, Mexico and Denmark increased during the same period. Some improvement in the pricing conditions are expected in 2002 as international demand continues to grow and as other producing countries (Ecuador) have had to adjust to market factors.

The prices paid to independent farm producers continued to decline during the same period. Average unit prices in August 2000 were 39.77 colones, and the latest available information shows that the prices have continued the downward trend reaching 32.00 colones in May of 2001.

The internal demand for palmito in Costa Rica has strengthened. According to reports from CNP, the unit price for fresh palmito in local markets ranges between 300-350 colones. The local consumption of processed palmito has also increased via sales in various food stores.

Changing product standards - in the last couple years, the industrial standard unit for palmito has changed as follows:

- the minimum diameter for palmito stems has been reduced to 3cm from 7cm; and
- harvesting should be done when the flag leave is 30-70% open.

The change in the standard reflects the preference in the French market for tender, creamy palmito. The changing industrial standard has implications on harvesting frequency. Previously palmito was harvested every 15-30 days. Now harvesting frequency has been increased to 7 days. The implications of the revised industry standard have yet to be fully analyzed in terms of nutrition management and economics.

Product differentiation is likely in the future, as oriental markets prefer a product with sensory attributes similar to bamboo shoots. Some experts in the field are exploring the possibilities of "organic" palmito. At the present time there is no standard or institutional capacity for certification of "organic" processes. UCR/CIA experts report that there are insufficient "organic nutrient inputs" available to producers and therefore, fertilizer supplements are necessary to optimize economic efficiency.

Table 22. National production of palmito in Costa Rica.

			Export	
Year	**Area**	**Production**	**Volume**	**Value**
	hectares	---------- metric tons	-----------	million US$
1992	3500	17500	4492	7.9
1993	3822	19110	5843	10.5
1994	3930	20000	3600	6.1
1995	5750	21000	7856	15.5
1996	7370	34000	10986	22.0
1997	10200	86200		25.1
1998	12500	88889		26.3
1999	11005	72000	12078	22.0
2000	8000		10991	24.9
2001	8895			
2002 est.	7500			

Source: SEPSA, http://www.infoagro.go.cr/estadisticas/act_productiva/palmito.html

Demand for technical services - The declining trend in the number of clients seeking soil and plant analysis is a clear response to the deepening "crisis" in palmito (Table 23).

Table 23. Number of soil and plant analyses performed for clients between 1998 and 2000*.

		Number of Analyses		
Year	**No. of Clients**	**Soil**	**Plant**	**Total**
1998	16	33	27	60
1999	8	54	4	58
2000	4	28	0	28

*Based on information obtained from two of the principle laboratories (Cafesa and UCR)

Project research and analysis by CIA/UCR have produced intermediate (preliminary) fertilizer recommendations targeting specific conditions common within the area as shown in Table 24. These recommendations for N and P fertilizers and lime have decreased considerably as project research data replaced recommendations based solely on average local practices. At the start of this project in 1997, annual fertilization rates in kg ha^{-1} were in the order of 200-400 for N, 22-44 for P and 50-83 for K and 500-2000 for lime.

Table 24. Preliminary adjustments to fertilizer recommendations for peach palm by the UCR/CIA soil and plant testing lab ((Eloy Molina, 2000).

Nutrient	Amount	Source	Application
	kg ha^{-1}		
		Soil with moderate fertility, no acidity problems and moderate K	
N	250	10-30-10	6/year: 1 of 10-30-10, 2 of 26-0-26 and 3 of ammonium nitrate
P	22	26-0-26	
K	83	Ammonium nitrate	
		Soils with moderate - high fertility, no acidity problems and low in K	
N	250	10-30-10	6/year: 1 of 10-30-10, 3 of 26-0-26 and 2 of ammonium nitrate
P	22	26-0-26	
K	124	Ammonium nitrate	
		Soils with low fertility, acidity problems and low in Mg and P	
N	250	18-3-10-8-0.4	6/year: 3 of 18-3-10-8-0.4, 1 of 10-30-10 and 2 of 26-0-26 + ammonium nitrate
P	22	10-30-10	
K	62	Ammonium nitrate	
Mg	36		
		Soils with low fertility, acidity problems and low in Mg, K and P	
N	250	18-5-15-6-0.7	6/year: 4 of 18-5-15-6-0.7 and 2 of ammonium nitrate
P	22	Ammonium nitrate	
K	124		
Mg	36		
		Fertile soils	
N	300	Ammonium nitrate Urea Lime-Ammonium nitrate	6/year: 2 of ammonium nitrate, 2 of urea and 2 of lime-ammonium nitrate

Lime and fertilizer N and P recommendations for peach palm by NuMaSS have a Diagnosis, Prediction and Economics component. The Diagnosis component seeks to determine whether acidity and N or P deficiencies exist. Diagnosis uses soil and plant analytical data, if available, but also considers location, prior production, management history and presence-absence of nutrient deficiency symptoms and indicator plants in the peach palm plantation. Rather than basing lime and fertilizer recommendations on existing ranges of values from soil test results, NuMaSS recommendations also includes considerations about the stage of crop development (plantation age), the targeted yield level and the economic marginal value product for the nutrient inputs. For an effective use of the NuMaSS software in its soil-plant testing programs, the UCR/CIA labs will need to revise the questions and types of information they collect from clients who submit samples for their recommendation services. In return, however, they can provide better service to their clients including multiple recommendations for different scenarios of input/output costs, available nutrient sources and desirable yield levels.

Survey of palmito specialists in Costa Rica - The workshop was announced in the newsletter of the Costa Rican Soil Science Association (ACCS), and participants expressing interest in the event received an email or fax copy of the survey. In addition, personal invitations were made to 15 professionals that did not belong to ACCS but were heavily involved with palmito production in Costa Rica. Eight members of ACCS who completed the survey were invited to participate in the workshop along with the other 15 professionals. Twenty-one professionals participated in the workshop.

Respondents to the survey included two researchers, two farm owner/managers, a businessman (agricultural supplies) and an agricultural consultant. Their experience with palmito production ranged from 3 to 25 years. Except for the consultant and businessman all devoted considerable time to palmito (25-100%). The following are summaries of responses to various questions.

- Characterization of the farming system: most palmito plantations range from 4-10 years of age. Planting distances are 2x1 meters. Expected annual yields are 6000-12,000 palmitos/ha/year. The new industry standard for harvested palmito diameter implies more frequent harvesting and production of more than 12,000 palmitos/ha/year to achieve competitive levels. Weed control is primarily chemical but also combined (chemical and mechanical). Under normal conditions producers do not practice pest and disease control, however an emergent disease is forcing producers to use chemicals. Most plantations manage more than six shoots per plant. Drainage, if done, is superficial ditches. All plantations are without trees. Soil fertility is considered to be low to moderate.
- Basis for fertilizer recommendations: biological parameters are more often used than economic parameters as the basis for fertilizer recommendations. Soil analysis is most important. Other parameters in descending order of importance are price of fertilizers > rainfall distribution = deficiency symptoms > farmgate price of palmito > type of farmer (big/small) > foliar analysis = actual or future production.
- Ordering of nutrient importance: nitrogen is ranked as first priority followed by K > Mg > Ca = P > B = Zn.
- Fertilizer recommendations for palmito plantations in Costa Rica: Table 25 provides current fertilizer recommendations and practices of the principal government agencies, fertilizer companies and representative farm managers in Costa Rica. Within the ranges indicated, it should be understood that recommendation for poorer soils are in the upper end of the range and recommendations for better soils are in the lower portion of the range. The values are consistent with the international literature as reviewed by Molina (2000).
- Recommendations for fertilizer in palmito nurseries: nutrient management during the first stage of growth is critical for healthy plant development. Most professionals didn’t have specific knowledge or recommendations about fertilizer applications for recently transplanted palmito plants. Only two participants responded saying they used between 5-10 g/plant/month of a complete fertilizer formula (18-5-15-6-2 or 12-11-18-3-8). The research of the project is laying the foundation for criteria and application rates for nursery plants.

Table 25. Nutrient recommendations for palmito in Costa Rica.

Source	N	P	K	Lime	Mg	S
	------------------------------ kg ha^{-1} year^{-1} ------------------------------					
MAG (1)	200-250	9	133-166	400-500		
MAG (2)	100-150	9-18	83-124	500		
Fertilizer Company 1	180	18-31	58-100	3000	18-30	20
Fertilizer Company 2	200-250	22-26	124-207			
Farmer	250	26	116			
Range	*100-250*	*9-31*	*58-207*	*400-3000*	*18-30*	*20*

- Relation between soil orders and fertilizer recommendations: most participants provided no specific comments related to the three principle soil orders in Costa Rica (Andisols, Inceptisols and Ultisols). However, two participants responded as follows: Andisols are considered to have moderate fertility with large requirements of P and K. For Inceptisols with a sandy texture, split N applications are required. Clayey Ultisols are considered to have low fertility and need liming, P, and drainage.
- Determination of critical levels for nutrients in soil and foliar analysis: for soil sampling most participants considered samples from 0-20cm the most appropriate. For foliar sampling, all considered the third leave to be the best. Only one person provided soil critical levels (pH = 5.5, Al = 0.5, Mg = 4.0, K = 0.2, Ca = 4.0, expressed in cmol(+)/100g and P = 10, Zn = 3 expressed in ppm). Only one participant provided foliar critical levels (N = 2.3, P = 0.1, K = 1.5, Mg = 0.3 all expressed in percent).
- Parameters used to evaluate fertilization in palmito: the most important parameter to evaluate the results of nutrient recommendations is the general health and appearance of the plantation and yield (palmitos/ha). Other criteria included the number of harvested palmitos needed to fill a box. One participant mentioned use of the internal rate of return as part of the analysis.
- Estimates of palmito tolerance to soil acidity: most participants reported tolerance up to Al saturation values of 21-40%.
- Recommendations for liming in palmito: the lime recommendation currently used seeks to reduce the Al saturation to 21 %. Dolomite is the most frequently recommend type of liming material, but calcitic limestone and calcium hydroxide are also recommended. Except for one, all recommend the lime to be applied by the broadcast method. Depending on the amount of lime recommended the frequency of application would be either once a year or every two years (for large amounts).
- Knowledge of existing literature related to nutrient management in palmito: the best known references were the ones published in Spanish.

- Needs for additional information on nutrient management in palmito: individual participants wanted to know about one or more of the following - soil critical levels, foliar critical levels, export of N, P & Mg, nutrient recycling, nursery fertilization, better soil maps.
- Production Expectations: most participants expected the levels of production to decline in the next several years. The more optimistic view was that the current levels of production would be maintained. It is further expected that the small-scale producers will be most affected. Some processing plants have been closed, and others are likely to be closed in the near future.
- Price Expectations: most participants foresee a slight increase in prices in 2002 as a result of a better quality product and the elimination of least competitive producers.
- Principle risks: most participants identify market conditions and policies as the greatest constraints to sector growth. Plantation diseases could also become a problem.
- Future prospects for palmito producers: small farmers were considered to be at the greatest risk. Their future prospects are estimated to be poor to medium. Medium and larger scale producers have somewhat better prospects ranging from medium to good.

The timing of the workshop was excellent, because palmito producers are now facing critical economic conditions and the information provided may help producers to alleviate their costs of production and better withstand the pressures of global competition. The research and technical support on soil fertility for palmito is essential to revitalize and give encouragement to producers. Regular annual workshops are vital to keep everyone informed about advances in knowledge.

The project is a good example of what is needed: long-term research that is comprehensive, field-oriented, and environmentally appropriate. The project is based on criteria and key fertility parameters necessary to develop a complete fertility management system. Some of the results presented reconfirm prior research and current management practices, while other research results are new. For example, many farmers in the past three years have started to split the N fertilizer applications as is consistent with the project's recommendation.

All the research components contribute knowledge that will enable farmers to reduce costs of production. In cases of nutrient recycling, for example, the information can be used to design an organic farming system for palmito, which will provide an opportunity to receive a premium price in international markets. Given the preliminary results showing accumulation of carbon in palmito plantations, participants mentioned that producers may qualify for future benefits (e.g., emission abatement subsidy or other instruments) under the national environmental services program, "Servicios Ambientales", or international programs. The results presented also allow producers to synchronize fertilizer applications with plant needs and thereby reduce contamination and improve fertilizer use efficiency. The allometric equations developed will help producers to better predict yields and economic returns to palmito. Some of the results can be further improved by adding new research elements such as: alternative N sources (urea, organic); using other criteria (Al saturation); relating research findings to costs of production; additional experiments in the field (liming). Further interpretation of the research findings are needed, particularly in relation to their implications for future impact.

In the future, participants would like to see research findings on K and minor elements, better site characterization, drainage and soil classification need more consideration, the relation between nutrition and diseases, nutrition and plant density or spatial arrangements.

Partial findings and implications from collaborative research -

- Efficiencies in N utilization can be improved with the result that costs of production can be reduced and N pollution can be reduced.
- Recommendations can be adjusted for plantation density and age (establishment, rapid growth, mature) resulting in greater efficiencies in fertilizer use.
- Carbon accumulation in the palmito plantation contributes to plantation sustainability and C sequestration
- Understanding the rate of release of nutrients from palmito field residue under conditions of high and low rainfall allows producers to adjust downward the need for chemical nutrient supplements and reduce costs of production. The latter is especially critical for low-income producers.
- Target recommendations for fertilization to palmito plantations of different varieties and rainfall conditions.
- Target the P requirements of palmito in different soil orders and during different stages of plantation growth. P supplementation is indispensable in the early growth.

Capacity building continues to be an essential part of the development process. Many of the technical problems are being managed with improved methods and coordination between professionals.

Conclusions -

- Research is generating findings valued by farm producers and agricultural professionals.
- New knowledge will enable farmers to achieve greater efficiencies in palmito production and better withstand the competitive pressures of the international markets.
- Improved nutrient management will reduce non-source N pollution of water resources and protect environmental resources.
- The value of the project's impacts cannot be fairly assessed in the current context of an economic downturn for the targeted commodity.

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Molina, E. 2000. Manual de suelos y nutricion de pejibaye para palmito. Associacion Costarricense de la Ciencia del Suelo, San Jose, Costa Rica. 42p.

2. *Mali*

2. a. On-farm evaluation of NuMaSS soil nutrient diagnosis and recommendations (Mamadou Doumbia, Aminata Sidibe, Adama Bagayoko, Mamadou Diarra, Hamidou Konare of IER and Lloyd Hossner, Frank Hons, Anthony Juo, and Hamid Shahandeh of Texas A&M University) On-farm studies were conducted to test recommendations from NuMaSS against a control, the standard fertilizer recommendation of Mali (Unique R.) and the 4-quadrant method of van Duivenbooden et al. (1996) (Quadrant R). These tests were implemented at Sotuba (sorghum, maize, and peanut), Cinzana (millet and sorghum) and Dougouba (millet). Soil and plant samples were collected from experimental units for both laboratory characterization and prediction of fertilizer application rates by the model NuMaSS. Recommendations from Quadrant R are based on a graphical analysis of annual crop response to fertilizer application. Recommendations are made for N, P, and K on the basis of yield goal, nutrient exports, nutrient recovery percentage, etc. (Table 26).

Table 26. Fertilizer (N, P and K) recommendations for millet, sorghum, maize and rice on the basis of yield goal, nutrient exports and nutrient recovery percentage (van Duivenbooden et al., 1996).

Nutrient	Millet	Sorghum	Maize	Rice
	---------- nutrient export (kg)/ 1000 kg of grain ----------			
N	34.6 (0.40)[a]	30.7 (0.35)	23.4 (0.36)	18.7 (0.39)
P	5.0 (0.17)	3.7 (0.15)	3.5 (0.12)	2.5 (0.12)
K	48.8 (0.38)	26.0	16.6 (0.34)	24.7 (0.34)

[a] Values in parentheses are recovery of applied nutrient by plant.

Applications rates of N, P, K, and lime for the different treatments for 1999, 2000, and 2001 are given in Table 27. Soil samples were taken at the end of the study to evaluate the residual effect of fertilizer recommendations on selected soil chemical properties.

Table 27. Fertilizer application rates for the different treatments tested in the 1999, 2000,2001 growing seasons.

		Crop			
Treatment	**Year**	**Maize**	**Sorghum**	**Millet**	**Peanut**
		---------------------------- kg ha^{-1} of fertilizers[a] ----------------------------			
Check	1999	none	none	–[b]	--
	2000	none	none	none	--
	2001	none	none	none	none
Unique R	1999	100 DAP, 150 urea	100 DAP, 50 urea	--	--
	2000	100 DAP, 150 urea	100 DAP, 50 urea	100 DAP, 50 urea	--

		Crop			
Treatment	**Year**	**Maize**	**Sorghum**	**Millet**	**Peanut**
		---------------------------- kg ha^{-1} of fertilizers[a] ----------------------------			
	2001	100 DAP, 150 urea	100 DAP, 50 urea	100 DAP, 50 urea	66 SSP
NuMaSS	1999	125 DAP, 200 urea, 1365 lime	125 TSP, 155 urea, 1500 lime	--	--
	2000	202 DAP, 378 urea, 750 lime	149 DAP, 233 urea, 1800 lime	88 DAP, 208 urea, 750 lime	--
	2001	176 urea, 747 lime	103 DAP, 83 urea	75 DAP, 152 urea, 750 lime	211 SSP, 750 lime
Quadrant R	1999	--	--	--	--
	2000	256 DAP, 466 urea, 488 K_2SO_4	65 DAP, 204 urea, 80 K_2SO_4	76 DAP, 196 urea, 384 K_2SO_4	--
	2001	256 DAP, 465 urea, 487 K_2SO_4	64 DAP, 203 urea, 78 K_2SO_4	76 DAP, 196 urea, 384 K_2SO_4	--

[a] DAP=diammonium phosphate, SSP= single superphosphate, TSP= triple superphosphate.

[b] Denotes years where crop and/or treatments were not tested.

Grain yield obtained from any fertilizer recommendation was significantly higher than that of the check in all years (Table 28). However, in two of three years, no significant difference was found between yields obtained using the 3 fertilizer recommendation systems. Sorghum and maize grain yields in 2001 produced by applying fertilizer rates predicted by NuMaSS, however, were significantly higher than those obtained from the other fertilizer recommendation types. All 3 recommendation schemes produced the same grain yield level of millet and peanut in 2001. The differential responses of sorghum and maize in 2001 might be attributed to the fact that only NuMaSS is correcting soil acidity (Table 29). In fact, both sorghum and maize are more sensitive to soil acidity than millet and peanut (Doumbia et al., 1993). Thus, the lime provided by NuMaSS had little effect on millet and peanut.

Table 28. Grain yields for maize, sorghum, millet and peanut as affected by the different fertilizer recommendations in 1999, 2000 and 2001.

		Crop			
Treatment	**Year**	**Maize**	**Sorghum**	**Millet**	**Peanut**
		---------------------------- kg ha^{-1} of grain[a] ----------------------------			
Check	1999	413 b	700 b	–[b]	--
	2000	131 b	680 b	600 b	--
	2001	1481 d	689 c	1125 b	482 c

Treatment	Year	Crop			
		Maize	Sorghum	Millet	Peanut
		---------------------------- kg ha^{-1} of grain[a] ----------------------------			
Unique R	1999	1582 a	1047 ab	--	--
	2000	403 a	1259 a	1440 a	--
	2001	296 c	1033 b	1396 ab	704 b
NuMaSS	1999	1624 a	1451 a	--	--
	2000	449 a	1397 a	1200 a	--
	2001	4963 a	1619 a	1625 a	963 a
Quadrant R	1999	--	--	--	--
	2000	440 a	1162 a	1042 a	--
	2001	3555 b	1208 b	1458 ab	--
Coefficient of Variability (%)	1999	47	33	--	--
	2000	108	14	12	--
	2001	19	10	8	18

[a] Treatments with the same letter, within a given crop and year, are not significantly different at p=0.05.

[b] Denotes years where crop and/or treatments were not tested.

Table 29. Effect of the different fertilizer recommendations on selected soil chemical properties after maize and millet harvest in 2001.

	Maize		Millet	
Treatment	**pH in H$_2$O**	**Bray 1 P**	**pH in H$_2$O**	**Bray 1 P**
		mg kg^{-1}		mg kg^{-1}
Check	4.1 c	34.8 b	4.2 b	9.5 a
Unique R	3.8 c	42.7 ab	4.2 b	14.7 a
NuMaSS	7.0 a	19.2 b	6.6 a	13.7 a
Quadrant R	5.5 b	64.5 a	4.1 b	20.9 a
CV (%)	7	35	7	47

The effect of different fertilizer recommendations on concentrations of selected nutrients in plant tissues of maize, sorghum and millet are given in Table 30 for the 2001 crop year. Fertilizer application increased N concentrations in sorghum and millet grain. The nitrogen concentrations of sorghum and maize leaves and shoots also tended to be increased by all recommendation systems, as was leaf potassium concentration of maize.

Table 30. Selected nutrient concentrations in grain, leaf and shoot tissues of maize, sorghum and millet crops in the 2001 growing seasonas affected by fertilizer recommendations.

		Grain			**Leaf**			**Shoot**		
Treatment	**Crop**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
		----------------------				%			----------------------	
Check	Maize	1.37	0.38	0.60	0.99b*	0.04b	1.43b	0.16b	0.03	1.45
	Sorghum	1.50b	0.60b	1.12a	1.13c	0.05a	0.50a	0.19c	0.10a	1.40a
	Millet	2.22b	0.37	0.56	2.05	0.12	2.12	2.21	0.05b	3.01
Unique R	Maize	1.77	0.48	0.77	1.33a	0.11ab	1.82a	0.28b	0.07	1.42
	Sorghum	1.96a	0.68ab	1.18a	1.25bc	0.11a	0.50a	0.58bc	0.04a	1.40a
	Millet	2.62a	0.45	0.69	2.42	0.13	1.79	1.73	0.15a	2.66
NuMaSS	Maize	1.90	0.50	0.73	1.50a	0.10ab	1.62ab	1.16a	0.02	1.17
	Sorghum	2.10a	0.74a	1.16a	1.46a	0.10a	0.40a	1.02a	0.01a	1.34a
	Millet	2.76a	0.43	0.56	1.92	0.15	2.01	2.40	0.10ab	2.63
Quadrant R	Maize	1.78	0.49	0.71	1.32a	0.16a	1.83a	0.75ab	0.06	1.29
	Sorghum	2.03a	0.74a	1.21a	1.34a	0.19a	0.50a	0.67a	0.04a	1.70a
	Millet	2.83a	0.43	0.61	1.99	0.17	2.20	1.56	0.12a	2.80
Coefficient of Variability (%)	Maize	9	13	13	8	33	11	36	127	12
	Sorghum	8	9	7	7	74	16	32	147	25
	Millet	7	15	18	18	17	20	24	30	12

* Treatments with the same letter, within a given plant tissue and crop, are not significantly different at *p*=0.05.

Literature Cited-

Doumbia, M.D., L.R. Hossner, and A.B. Onken. 1993. Variable sorghum growth in acid soils of Subhumid West Africa. Arid Soil Research and Rehabilitation 7:335-346.

van Duivenbooden, N., C.T. De Wit, and H. van Keulen. 1996. Nitrogen, phosphorus and potassium relations in five major cereals reviewed in respect to fertilizer recommendations using simulation modeling. Fertilizer Research 44:37-49.

2. b. On-farm evaluation of composted phosphate rock (Mamadou Doumbia, Aminata Sidibe, Adama Bagayoko, Mamadou Diarra, and Hamidou Konare of IER and Lloyd Hossner, Frank Hons, Anthony Juo, and Hamid Shahandeh of Texas A&M University) Soils of semiarid and subhumid Mali and other regions of West Africa are generally weathered, commonly acid, low in organic matter content, poorly buffered, and characterized by a dominance of kaolinite and sesquioxides Phosphorus is the most deficient and plant-growth limiting nutrient in these soils. This contrasts with the fact that in the Tilemsi Valley of Mali , there are more than 20 million tons of the most soluble phosphate rock (PR) in West Africa (Truong et al., 1978): Tilemsi PR. Two major constraints inhibit the direct agricultural use of Tilemsi PR: relatively low reactivity and fine powder form (Kamara et al., 1994). The objective of this study was to evaluate the effects of addition of Tilemsi PR during composting of organic wastes (manure, household waste, crop residue) on soil properties and millet grain yield. The hypothesis was that the composting process would increase the dissolution and plant availability of Tilemsi PR. The composted product was prepared using 1000 kg of organic material (dry weight basis), 100 kg of Tilemsi PR, and 12 kg of urea. Composting was conducted during the portion of the dry season from February through May. Water was applied weekly to maintain active composting. The Tilemsi PR-amended compost was compared to compost without addition of PR, and a control. Two replications of each treatment were applied to 12 collaborative on-farm sites in 2001. Millet was planted as the crop and grain was harvested to determine treatment effects. Soil samples were taken from each experimental plot following harvest to assess treatment effects on selected soil properties.

Addition of compost, and especially Tilemsi PR-amended compost, increased millet grain yield as compared to controls (Table 31). Averaged across sites, PR-amended compost increased yield by 65% compared to controls, while compost without PR increased yield by 35%. Long-term average millet yield in the Cinzana area where this study was conducted is 600 kg/ha (Doumbia et al., 1998).

Table 31. Mean millet yield as influenced by application of composts.

	Treatment		
Farmer - Village	**Control**	**Ordinary Compost**	**Composted PR**
	---------- millet yield, kg ha^{-1} ----------		
Bamoussa Traore-Cinzana	1363	1768	2473
Saouty Toure-Cinzana	800	1300	1600
Chaka Traore-Dilaba	950	1025	1125
Kassim Tangara-Cinzana	725	925	1075
Lassana Djire-Dougouba	869	1025	1375
Bourema Fofana-Dougouba	900	963	1250
Adama Sidibe-Cinzana	263	375	625

Farmer - Village	Control	Ordinary Compost	Composted PR
		---------- millet yield, kg ha^{-1} ----------	
Fousseyni Diarra-Cinzana	556	825	856
Oumar Traore-Dilaba	175	300	487
Bocary Coulibaly-Dilaba	175	963	388
Moussa Toure-Dilaba	388	413	550
Sinaly Djire-Dougouba	325	350	525
Mean	624 c	844 b	1027 a
Mean yield increase (%)		35 b	65 a
Level of Significance		$p < 0.01$	$p < 0.01$

The residual effects of the different treatments on selected soil properties are indicated in Table 32. Both compost and PR-amended compost significantly increased soil pH over controls. Application of compost or PR-amended compost significantly increased the residual soil pH from 4.2 to 4.7 and 4.8, respectively. The pH of compost-treated soils, however, are still within the strongly acidic range (pH < 5.5). Application of compost without PR did not significantly increase residual soil Bray-1 P concentration. However, application of PR-amended compost significantly increased the residual Bray-1 P level from 5.1 to 8.4 mg P kg^{-1}.

Table 32. Soil pH in water and Bray 1-extractable P as influenced by the residual effect of compost applications.

	pH in Water (1:1)			Bray 1 P		
Farmer	**Control**	**Ord. Compost**	**PR Compost**	**Control**	**Ord. Compost**	**PR Compost**
					------------------ mg kg^{-1} ------------------	
B. Traore	3.8	4.5	4.7	18.7	17.2	25.1
S. Toure	4.4	5.5	6.5	9.5	10.2	12.4
C. Traore	4.0	4.4	4.3	4.7	11.1	11.8
K. Tangara	4.3	5.5	5.7	2.3	2.1	6.4
L. Djire	4.0	4.4	4.3	7.1	6.9	8.1
B. Fofana	3.9	4.2	4.1	6.7	7.1	12.7
A. Sidibe	5.2	5.5	5.6	3.2	3.6	6.7

	pH in Water (1:1)			Bray 1 P		
Farmer	**Control**	**Ord. Compost**	**PR Compost**	**Control**	**Ord. Compost**	**PR Compost**
				------------------- mg kg^{-1} -------------------		
F. Diarra	3.8	4.3	4.3	2.5	2.6	3.5
O. Traore	4.4	4.5	4.5	1.1	2.9	3.7
B. Coulibaly	4.5	4.7	4.8	2.1	1.9	2.7
M. Toure	3.9	4.2	4.2	0.7	1.2	3.7
S. Djire	4.1	4.4	4.6	2.3	2.2	3.9
Mean	4.2 b	4.7 a[¶]	4.8 a	5.1 b	5.8 b	8.4 a
Significance		$p < 0.01$	$p < 0.01$		$p < 0.01$	$p < 0.01$

[¶] Letters after numbers are Duncan's multiple range test.

Linear regression of residual soil Bray 1-P vs. millet grain yield within each treatment resulted in the following:

- Control yield = 313.5 + 61.20 P $r^2 = 0.70$
- Compost yield = 415.5 + 74.56 P $r^2 = 0.71$
- PR-Compost yield = 291.1 + 87.74 P $r^2 = 0.88$

The results suggested that phosphorus from PR-amended compost was more plant available and/or in greater quantity than that from normal compost which was more available than that from native soil phosphorus. Addition of native rock phosphate during composting of waste appeared to be an excellent method of increasing soil phosphorus and millet yield.

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Truong, B., J. Pichot, and P. Beunard. 1978. Caractérisation et comparaison des phosphates tricalciques d'Afrique de l'Ouest en vue de leur utilisation directe en agriculture. Agron. Trop. 33:136-145.

2. c. <u>Cowpea and millet yield response and interactions among N, P, and lime rates</u> - (Mamadou Doumbia, Aminata Sidibe, Adama Bagayoko, Mamadou Diarra, Hamidou Konare of IER, and Lloyd Hossner, Frank Hons and Hamid Shahandeh of Texas A&M University and Daniel Israel of North Carolina State University) Research on soils of the semiarid and sub-humid zones of West Africa in the last four decades has provided evidence that P is the most deficient and growth limiting nutrient in these soils (Scott-Wendt et al., 1988; Manu et al., 1991; Buerkert et al., 2001). Sanchez et al. (1997) reported that in the Sahel, P is the most limiting nutrient to millet growth. Millet generally does not respond to N fertilizer until the P requirement is first met (Bationo et al., 1986).

Aluminum toxicity and Ca deficiency are also common problems in these soils. Aluminum toxicity has been associated with variable millet and sorghum growth and establishment in semiarid West Africa and Mali (Scott-Wendt et al., 1988; Manu et al., 1991; Doumbia et al., 1998). Although Al toxicity has been identified as a plant growth-limiting factor in semiarid West Africa, Ca deficiency has not been recognized as a problem. In many highly weathered acid soils of West Africa, however, an inverse relationship exists between exchangeable Al and Ca. Kouyate et al. (2000) described how continuous cropping, use of chemical fertilizers, and lack of sound soil management practices on poorly buffered kaolinitic Alfisols and clayey Inceptisols in the semi-arid Niger River valley of Mali have accelerated declines in soil pH, exchangeable Ca and Mg, and crop yield.

This "core" experiment was conducted with both cowpea and millet on a sandy soil of the Cinzana Research Station in Mali. The objective of the study was to test predictions for N, P, and lime for both crops on sandy Alfisols of the African Sahel using the NuMaSS model and to suggest necessary refinements to the model. The experiments were conducted from 1998 through 2001. Millet and cowpea were alternated in the cropping sequences. Surface soil properties were used to predict needed application rates of N, P, and lime by the NuMaSS model (Tables 33-36). Results for 1998 and 1999 were previously reported and will not be discussed. Results for all four years are reported here, however, for completeness and continuity. The P variable in both the millet and cowpea core experiments was essentially eliminated when the P level in all plots was erroneously adjusted to the NuMaSS recommendation prior to the 1999 cropping season. Lime was not applied before the 1999 cropping season for either experiment since soil pH values were at desirable levels in the respective lime treatments.

Table 33. Chemical properties of the Haplustaf soil at the Cinzana Research Station, Mali, before planting the "millet core experiment" in 1998.

Chemical	**Soil Depth, cm**				
Property	**0-7.5**	**7.5-22.5**	**22.5- 45**	**45-75**	**LSD 0.05**
Bray 1 P, mg/kg	11.0	5.5	-	-	1.2
pH in H2O	5.6	4.8	4.6	4.7	0.22
Exch. Acidity, cmol/kg	0.49	0.44	0.65	0.60	0.11
Exch. Ca, cmol/kg	0.18	0.30	0.34	0.51	0.24
Exch. Mg, cmol/kg	0.16	0.11	0.24	0.23	0.04
Exch. K, cmol/kg	0.20	0.08	0.08	0.09	0.03
ECEC, cmol/kg	1.03	0.94	1.32	1.43	0.24
Carbon, %	0.36	-	-	-	-

Table 34. Rates of Diamou lime, P and N applications in the "millet core experiment" based on the NuMaSS model.

Treat-	1998			1999			2000			2001		
ment	Urea	TSP	Lime	Urea	TSP	Lime	Urea	TSP	Lime	Urea	TSP	Lime
						--- kg ha^{-1} ---						
N0P0L0	0	0	0	0	41	0	0	0	0	0	0	0
N2P0L0	0	0	1800	0	35	0	206	0	0	0	0	0
N2P1L2	0	31	1800	0	39	0	168	14	755	0	58	0
N2P2L2	0	62	1810	0	35	0	207	44	755	0	45	0
N2P2L0	0	62	0	0	35	0	192	40	0	0	133	0
N2P2L1	0	62	900	0	28	0	149	60	378	0	81	250
N2P1L1	0	31	900	0	15	0	203	34	378	0	60	750
N0P2L2	0	62	1800	0	10	0	0	3	0	0	93	500
N1P1L2	0	62	1800	0	0	0	92	12	0	0	81	500
N1P1L1	0	31	900	0	17	0	98	75	0	0	55	750

Table 35. Chemical properties of the Haplustaf soil at the Cinzana Research Station, Mali, before planting the "cowpea core experiment" in 1998.

Chemical	**Soil Depth, cm**				
Property	**0-7.5**	**7.5-22.5**	**22.5-45**	**45-75**	**LSD 0.05**
Bray 1 P, mg/kg	11.8	6.6	-	-	1.4
pH in H2O	5.4	4.7	4.7	4.5	0.10
Exch. Acidity, cmol/kg	0.62	0.60	-	-	0.15
Exch. Ca, cmol/kg	0.29	0.76	0.78	0.69	0.11
Exch. Mg, cmol/kg	0.26	0.31	0.41	0.50	0.04
Exch. K, cmol/kg	0.18	0.12	0.10	0.9	0.02
ECEC, cmol/kg	1.37	1.79	-	-	0.16
Carbon, %	0.26	-	-	-	-

Millet and cowpea yields in the "millet core experiment" are presented in Table 37. Several of the millet treatments in 2000 resulted in grain yields equal to or greater than the Malian national target yield of 1000 kg millet grain/ha. Although not significant, added P tended to increase millet yield in 2000. Yields were low in the following cowpea crop in 2001, with no significant treatment effects observed.

Table 36. Rates of Diamou lime, P and N applications in the "cowpea core experiment" based on the NuMaSS model.

Treat-ment	1998			1999			2000			2001		
	Urea	TSP	Lime	Urea	TSP	Lime	Urea	TSP	Lime	Urea	TSP	Lime
	kg/ha^{-1}											
N0P0L0	0	0	0	0	45	0	0	0	0	0	0	0
N0P0L2	0	0	1800	154	28	0	0	0	0	62	0	0
N0P1L2	0	41	1800	154	32	0	0	36	0	103	33	0
N0P2L2	0	82	1800	154	0	0	0	46	0	151	59	0
N0P2L0	0	82	900	154	0	0	0	1.3	0	109	40	0
N0P2L1	0	82	900	154	45	0	0	24	0	114	60	0
N0P1L1	0	41	900	154	18	0	0	24	0	193	18	0
N2P2L2	0	82	1800	0	2.3	0	0	23	0	0	17	0
N0P2L2	0	82	1800	77	30	0	0	41	0	65	47	0
N0P2L2*	0	82	1800	0	8	0	0	51	0	0	28	0
N1P1L1	0	41	900	77	7	0	0	2	0	28	18	0

* The only treatment where cowpea stover was left as residue in the field.

Effects of treatments in the "millet core experiment" on soil chemical properties were determined after the 1998 through 2000 cropping seasons (Tables 38 and 39). Little credence was given to Bray-1 P values since a uniform application of P was made prior to the 1999 season. Lime did significantly increase soil pH, with lime addition increasing soil reaction above the critical pH of 5.5. Treatments without lime showed values below pH 5. Lime application also tended to increase soil concentrations of exchangeable Ca and Mg.

Cowpea and millet yields in the "cowpea core experiment" are presented in Table 40. Applications of lime and P had no effect on cowpea grain yield in 2000, perhaps because of low yield and high variability. Millet yield following cowpea in 2001 was little influenced by treatment, but yield did tend to increase at the higher lime and P rates.

Lime significantly increased soil pH of samples taken after the 2000 growing season (Table 41). As with the "millet core experiment", lime addition generally increased pH above 5.5, while treatments without lime exhibited pH values <5. Lime application, as would be expected, also tended to increase concentrations of soil exchangeable Ca (Table 42).

Table 37. Millet and cowpea grain yields in the "millet core experiment" as influenced by applications of lime, N and P recommended by the NuMaSS model.

	Crop and Year			
Treatment	**Millet 1998**	**Cowpea 1999**	**Millet 2000**	**Cowpea 2001**
	---------------------------- grain yield, kg ha^{-1} ----------------------------			
N0P0L0	1208 c	526 a	569 ab	238 a
N2P0L2	1542 bc	403 ab	437 b	330 a
N2P1L2	1523 bc	539 a	675 ab	340 a
N2P2L2	2310 a	433 ab	853 ab	410 a
N2P2L0	1477 bc	394 ab	800 ab	311 a
N2P2L1	1977 ab	456 ab	1012 a	294 a
N2P1L1	1546 bc	446 ab	1005 a	278 a
N0P2L2	1824 ab	446 ab	780 ab	245 a
N1P2L2	1884 ab	337 b	992 a	271 a
N1P1L1	1519 bc	380 ab	853 ab	301 a
Average yield	1681	436	797	302
CV (%)	18	21	33	29

Table 38. Soil extractable P and pH in the "millet core experiment" as influenced by applications of lime and P recommended by NuMaSS.

	Bray-1 P			**pH (H_2O)**		
Treatment	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**
	---------- mg kg^{-1} -----------					
N0P0L0	6.02 cd	8.33 b	11.14 ab	4.7 c	5.2 c	4.3 b
N2P0L2	5.72 cd	9.06 b	9.01 ab	5.0 abc	6.7 abc	6.4 a
N2P1L2	5.45 d	8.55 b	10.60 ab	5.0 abc	6.4 bc	5.9 a
N2P2L2	7.61 cd	8.93 b	12.38 ab	5.6 a	6.6 abc	5.8 ab
N2P2L0	6.62 bcd	9.49 ab	9.62 ab	4.9 bc	5.7 bc	4.9 ab
N2P2L1	7.41 bcd	10.25 ab	7.22 b	5.2 abc	6.3 bc	5.7 ab
N2P1L1	8.42 abc	12.01 ab	6.47 b	5.2 abc	6.4 bc	5.6 ab

	Bray-1 P			**pH (H_2O)**		
Treatment	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**
	---------- mg kg^{-1} -----------					
N0P2L2	9.25 ab	11.79 ab	18.01 a	5.4 ab	8.2 a	5.8 ab
N1P2L2	11.18 a	14.49 a	12.05 ab	5.3 abc	7.2 ab	6.2 a
N1P1L1	8.27 bcd	11.11 ab	6.83 b	5.4 ab	6.8 abc	5.4 ab
CV (%)	28	26	49	13	14	14

Table 39. Soil exchangeable Ca and Mg in the “millet core experiment” as influenced by applications of lime and P recommended by NuMaSS.

	Exchangeable Ca			**Exchangeable Mg**		
Treatment	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**
	-------------------------------------- $cmol_c$ kg^{-1} --------------------------------------					
N0P0L0	0.62 d	0.59 b	0.74 b	0.41 b	0.30 c	0.23 ab
N2P0L2	1.04 bcd	2.28 ab	1.77 ab	0.48 b	0.52 ab	0.29 ab
N2P1L2	0.80 cd	1.49 ab	2.18 ab	0.39 b	0.45 abc	0.34 ab
N2P2L2	1.72 a	2.22 ab	2.40 a	0.58 b	0.59 a	0.35 ab
N2P2L0	0.63 d	0.61 b	0.76 b	0.44 b	0.37 bc	0.22 b
N2P2L1	1.76 cd	0.94 b	1.42 ab	0.44 b	0.40 abc	0.28 ab
N2P1L1	1.24 abc	1.67 ab	1.61 ab	0.51 b	0.45 abc	0.32 ab
N0P2L2	1.50 ab	2.70 a	1.28 ab	1.19 a	0.49 abc	0.36 ab
N1P2L2	1.12 bcd	1.88 ab	1.85 ab	0.49 b	0.54 ab	0.38 a
N1P1L1	1.18 abc	1.93 ab	1.30 ab	0.55 b	0.60 a	0.32 ab
CV (%)	71	54	49	113	22	25

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Table 40. Cowpea and millet grain yields in the "cowpea core experiment" as influenced by applications of lime, N and P recommended by the NuMaSS model.

	Crop and Year			
Treatment	**Cowpea 1998**	**Millet 1999**	**Cowpea 2000**	**Millet 2001**
	---------------------------- grain yield, kg ha^{-1} ----------------------------			
N0P0L0	649 a	1123 b	420 a	667 b
N0P0L2	564 a	1469 ab	377 a	605 b
N0P1L2	606 a	1392 ab	488 a	691 b
N0P2L2	746 a	1586 ab	531 a	938 ab
N0P2L0	777 a	1534 ab	438 a	753 ab
N0P2L1	658 a	1491 ab	549 a	586 b
N0P1L1	574 a	1509 ab	441 a	586 b
N2P2L2	678 a	1383 ab	494 a	938 ab
N0P2L2	790 a	1457 ab	543 a	1173 a
*N0P2L2	1129 a	1759 a	531 a	951 ab
N1P1L1	559 a	1247 b	407 a	728 ab
Average yield	702	1450	474	783
CV (%)	42	17	21	31

Table 41. Soil extractable P and pH in the “cowpea core experiment” as influenced by applications of lime and P recommended by NuMaSS.

	Bray-1 P			**pH (H_2O)**		
Treatment	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**
	-------------------- mg kg^{-1} --------------------					
N0P0L0	4.35 c	5.91 b	7.51 ab	4.7 d	4.9 b	4.0 d
N0P0L2	5.79 bc	7.79 ab	7.15 ab	5.6 a	6.9 ab	6.7 a
N0P1L2	6.77 abc	10.21 ab	5.55 b	5.3 abc	6.7 ab	6.5 ab
N0P2L2	10.30 ab	14.98 ab	8.62 ab	4.9 bcd	7.2 a	7.2 a
N0P2L0	9.92 ab	15.28 ab	11.21 a	5.6 a	5.0 b	4.6 d
N0P2L1	6.24 abc	5.74 b	6.99 ab	4.9 bcd	5.5 ab	5.3 bcd
N0P1L1	6.56 abc	8.98 ab	8.57 ab	4.9 bcd	5.5 ab	4.8 cd
N2P2L2	11.15 a	17.45 a	11.38 a	5.2 abcd	6.5 ab	6.8 a
N0P2L2	6.39 bac	8.98 ab	9.24 ab	5.6 a	7.5 a	6.0 abc
*N0P2L2	8.65 abc	12.68 ab	8.07 ab	5.5 ab	6.8 ab	6.3 ab
N1P1L1	8.15 abc	11.39 ab	11.88 a	5.3 abc	6.3 ab	6.0 abc
CV (%)	50	46	30	13	16	13

Table 42. Soil exchangeable Ca and Mg in the “cowpea core experiment” as influenced by applications of lime and P recommended by NuMaSS.

	Ca			**Mg**		
Treatment	**1998**	**1999**	**2000**	**1998**	**1999**	**2000**
	------ -------- ---- --------------------- cmol$_c$ kg^{-1} ---- ------- ---------- -------------------					
N0P0L0	0.44 d	1.41 c	0.67 e	0.17 a	0.06 ab	0.19 a
N0P0L2	1.29 a	2.30 a	3.30 a	0.05 b	0.04 ab	0.67 a
N0P1L2	0.78 abcd	1.50 abc	2.07 bc	0.10 ab	0.08 ab	0.34 a
N0P2L2	1.04 abc	1.99 abc	1.79 bcd	0.16 ab	0.12 ab	0.53 a
N0P2L0	0.49 cd	0.63 bc	0.94 de	0.08 ab	0.00 b	0.30 a
N0P2L1	0.58 cd	0.79 abc	1.01 de	0.13 ab	0.06 ab	0.22 a
N0P1L1	0.59 cd	0.78 abc	1.18 cde	0.06 ab	0.03 ab	0.25 a
N2P2L2	0.69 bcd	1.25 abc	2.22 b	0.06 ab	0.05 ab	0.40 a
N0P2L2	1.19 ab	2.27 ab	1.66 bcd	0.10 ab	0.05 ab	0.31 a

Treatment	Ca 1998	Ca 1999	Ca 2000	Mg 1998	Mg 1999	Mg 2000
	------ -------- ---- --------------------- cmol$_c$ kg^{-1} ---- ------- ---------- -------------------					
*N0P2L2	0.93 abcd	1.60 abc	1.78 bcd	0.17 a	0.17 a	0.39 a
N1P1L1	0.69 bcd	1.05 abc	1.78 bcd	0.09 ab	0.02 ab	0.34 a
CV (%)	74	63	31	112	132	69

2. d. Fifth year socio-economic survey (Mamadou Doumbia, Frank Hons and Frank Smith) As part of the fifth year of project activity, a survey was designed and conducted to monitor indicators of development processes and outcomes. The survey was intended to provide feedback to project leaders on the changing conditions in the field and relevant perceptions of the project's intended beneficiaries Prior surveys had produced baseline data in year one and intermediate data in year three.

The survey sample consisted of 81 farmers from five communities in the project service area. The sample included 32 farmers who had participated both in the baseline survey and field trials of the project. The sample also included 12 farmers who had participated only in the field trials; two farmers had participated in only the baseline survey; and two farmers that had not participated in either the baseline survey or field trials.

The survey included a set of questions that had been asked in the baseline survey as well as "new" questions to assess project impact and other issues of interest. The survey was designed and conducted as a structured conversation/interview with the farmer. The content and phrasing of the questions was decided in a group process involving an international scientist working in collaboration with local research and extension personnel. The field work was scheduled after the period of field preparation and planting to accommodate the needs of local farmers. As such the results are intended to provide the best possible description of current practices in soil management. The survey was conducted by experienced agriculture extension professionals with knowledge of the local area and bilingual (French and local language, Bambara). They were trained in use of the survey form and specifically they were instructed to follow a consistent phasing of the questions in the local language and to record relevant contextual information to aid with interpretation and understanding current practices. Later, the data from the survey forms were coded and entered into a computer spreadsheet by the local project leader.

Results: Farmer practices in the region vary. It is not clear whether this variance is stable or alternatively, that it reflects a process of transition from traditional methods to externally influenced methods. But clearly, farmer use of chemical fertilizer in 2001 was more extensive than in 1998 in spite of government imposition of taxes on fertilizer imports. Previous economic analysis (cited by local experts) has concluded that use of chemical fertilizers is inefficient. This has lead to an institutional emphasis on use of local sources of nutrients and organic matter for soil nutrient improvement.

All farmers in the sample indicated that they were satisfied with the work of the project whether they had participated or not (Table 43). Most farmers also claimed to have a good understanding the project impact on their own farm, whether they participated or not. This raises questions as to whether the uniformity of responses is the product of a response bias (e.g., to comment favorably) or that participants in the project were sharing knowledge gained with nonparticipants. There is some independent information that farmers are sharing knowledge gained both within their own village and with farmers of neighboring villages as well.

Table 43. Farmer perceptions of project impact.

Project Impacts	No Change	Decrease	Increase
on production	0	0	41
on manual labor	26	0	14
on farm revenue	6	0	35
on production costs	25	5	11
on risk	8	30	3

The survey results are somewhat disappointing in their failure to elicit or record more detail from farmers with regard to the reasons why farmers do what they do. This kind of qualitative data is not easily obtained, and in this survey the open-ended questions did not produce much in the way of detailed explanation. One may surmise, that the survey workers were insufficiently prepared to probe further a farmer's superficial response to a open-format question.
Conclusion: The interaction between project scientists and local farmers has produced a better understanding of local soil management practices and opportunities for farm productivity enhancement. The results suggest that the process of local participation in development activities has produced perceived benefits at the farm level. These benefits precede the release of the final version of the decision support tool, NUMASS. A full assessment of the project impact will require a follow-up study of the distribution, adoption and use of the NUMASS software.

3. *Philippines*

3. a. On-farm experiments to test diagnostic predictions and compare decision-aid predictions of nutrient requirements - (M. Casimero, M. Aragon, T. Corton, R. Escabarte, J. Lasquite, T. George, J. Quiton, A. Mataia, Q. Asuncion, B. Macarubbo and R.S. Yost) The general objective of the intensive testing was to validate and test the accuracy of the prediction component of the N, P and acidity modules of NuMaSS decision-aids. Specific objectives were to:

- Conduct factorial experiments that will support Level 0 (comparing yield predictions) testing of the acidity, phosphorus, and nitrogen modules of NuMaSS or equivalent N recommendation methodology, for alternative upland cropping systems;
- Collect the data for a Level 1 (both yield prediction and parameter) testing for a selected cropping system for P, acidity and N modules; and
- Develop management alternatives (crop and amendment combinations) that might be used in subsequent outreach testing locations throughout the non-irrigated rice-based systems in the Philippines.

The intensive testing of NuMaSS in the Philippines is a collaboration of Philippine Rice Research Institute (PhilRice), Department of Agriculture – Cagayan Valley Integrated Agricultural Research Center (DA-CVIARC), Department of Agriculture – Local Government Unit (DA-LGU) Ilagan, International Rice Research Institute (IRRI), and UH.

Experimental design and treatments: -The experimental design and treatments differed between the cereals and legumes, and therefore two experimental layouts, one each for the cereal (Table 44) and legume studies (Table 45), were established. The factorial experiment was laid-out in the randomized complete block design and consisted of 14 (cereal) and 16 treatments (legume) that were replicated four times. Replicates I and II were established in one site while replicates III and IV were set up about $^1/_2$ kilometer away.

Physico-chemical properties of the soil: The experimental crops were grown on a clayey soil with bulk density of 1.2 g cc^{-1} (Table 46). The soil was very acidic (pH 4.09), low in organic carbon (OC) (1.2 %), P (3.1 mg kg^{-1} Mehlich 1-P), exchangeable Ca (1.1 cmol$_c$ kg^{-1}) and Mg (1.1 cmol$_c$ kg^{-1}), but with proportionately high exchangeable K (0.3 cmol$_c$ kg^{-1}) and Al (4.6 cmol$_c$ kg^{-1}). Effective cation exchange capacity (ECEC) was low (6.8 cmol$_c$ kg^{-1}) and the Al saturation was high (58.6 %), typical of an Ultisol.

Planting: The sequence of crops grown in the experiments are shown in Table 47. Each plot for rice was 5 m (17 rows, 0.30 m apart) x 9 m. Rice seeds were drilled at 75 kg ha^{-1}. The corn plots measured 5 m (8 rows, 0.75 m apart) x 9 m (0.25 m between hills). The corn population density was reduced to 53,000 plants ha^{-1} after thinning, which was done immediately before the second application of N. For legumes, the plot dimensions were 5 m (11 rows, 0.5 m apart) x 9 m. The harvest area in each plot was 18.9 m^2 (9 middle rows x 7 m length) for rice, 21 m^2 (4 middle rows x 7 m) for corn, 17.5 m^2 (5 middle rows x 7 m) for the legumes.

Sampling and processing: Soil samples were collected before planting and after harvest at 0-15 cm soil depth from all treatment plots for both cereal and legume. Soil samples at 15-90 cm soil depth were collected after harvest in selected treatments for both crops. Samples were also collected during panicle initiation for rice and silking for corn (0-90 cm depth) in the selected treatment plots. The collected soil samples were air-dried, pulverized and sieved prior to laboratory analysis for soil pH, organic carbon, available P, and exchangeable bases and acidity. The results of laboratory analysis collected at 0-15 cm after harvest in each crop were the bases for the next cropping fertilizer recommendation.

Table 44. Factorial arrangement of treatments for cereals.

Treatment	N	P	Lime	Comparisons
1	N0	P0	L0	Complete check
2	N2	P2	L0	Lime check
3	N0	P2	L2	N check
4	N2	P0	L2	P check
5	N1	P2	L2	N resp. 3,5,7
6	N2	P2	L2	3,5,6,7–N; 4,8,6–P; 2,11,6 –Lime
7	N3	P2	L2	N extra, 6,7
8	N2	P1	L2	P resp. 4,8,6,9?
9	N3	P3	L2	P extra 7,9
10	N1	P1	L2	Low N & P; 5vs10; 8vs10
11	N2	P2	L1	Lime resp.: 2,11,6
12	N2	P2	see –>	Gypsum effects, L2 but 50%Ca as $CaCO_3$ +50% as $CaSO_4$
13	N2	P2	L0+5t GM	GM Lime effect 13,14 vs 2,
14	N2	P2	L1+5t GM	GM Lime effect 13,14 vs 2.

Table 45. Factorial arrangement of treatments for legumes.

Treatment	N	P	Lime	Comparisons
1	N0	P0	L0	Complete check
2	N0	P1	L1	Adequate lime, no N, low P
3	N0	P2	L1	Adequate lime, no N, adequate P
4	N0	P3	L1	Adequate lime, no N, high P
5	N0	P1	L2	High lime, no N, some P
6	N0	P2	L2	High Lime, no N, adequate P
7	N0	P3	L2	High lime, no N, high P
8	N1	P0	L1	Adequate lime, low N, no P
9	N1	P1	L1	Adequate lime, low N, some P;
10	N1	P2	L1	Adequate lime, low N, adequate P
11	N1	P3	L1	Adequate lime, low N, high P
12	N3*	P2	L2	Potential yield without BNF
13	N0	P2	L2	Gypsum effects, L2 but 50%Ca as CaCO3 +50%Ca as CaSO4 ; 4,
14	N0	P2	L0+5t 5M	GM effects 14,15 vs 3,6
15	N0	P2	L1+5t 5M	GM effects 14, 15 vs 3,6
16	N0	P2	L2	Non-nodulating reference

N3* – treatment designed to provide all N as combined N (T. George).

Table 46. Physico-chemical properties of the soil before the experiment

Chemical Properties	Value
Soil pH (1:1 soil-water ratio)	4.1
Organic Carbon (%)	1.2
Available P (ppm)	3.1
Exchangeable cations ($\mathrm{cmol_c\ kg^{-1}}$)	
K	0.3
Ca	1.1
Mg	1.1
Al	4.6
ECEC ($\mathrm{cmol_c\ kg^{-1}}$)	6.8
Al Saturation (%)	58.6
Soil Order	Ultisol
Physical Properties	
Soil Texture	Clay
Bulk density ($\mathrm{g\ cm^{-3}}$)	1.2

Table 47 . List of crop, varieties/cultivars tested in the core experiment, Ilagan, Isabela.

Year	Experiment	Crop/variety	Date Planted & Harvested
1998	Cereal	Rice (IR55423-1)	Sept. 14, 1998 – Jan. 13, 1999
1999	Cereal	Maize (AG8362)	June 17, 1999 – Sept. 29, 1999
		Rice (PSB Rc 3)	Oct. 26,1999 – Feb. 18, 2000
	Legume	Peanut (BPI Pn 9)	Jan. 11, 1999 – April 25, 1999
2000	Cereal	Maize (Cargill 818)	June 19, 2000 – Sept. 26, 2000
		Rice (IR55423-1)	Oct. 27, 2000 – Feb. 19, 2001
	Legume	Soybean (PSB Sy 2)	Dec. 31, 1999 – April 6, 2000
		Mungbean (UPL Mg 9)	June 20, 2000 – Sept. 17, 2000
2001	Cereal	Maize (Cargill 818)	July 3, 2001 – October 15, 2001
	Legume	Peanut (BPI Pn 9)	Jan. 16, 2001 – April 27, 2001
		Soybean (PSB Sy 2)	June 27, 2001 – October 12, 2001

Fifty flag-leaf samples at flowering stage, fifteen ear-leaf samples at silking stage and fifty leaflets for peanut, soybean and mungbean were collected from each plot as plant index tissue (leaflets) samples for nutrient uptake analysis. The collected tissue samples were oven dried and ground for laboratory analysis.

At harvest, biomass sub-samples (approximately 1 kg per sub-sample for both rice and legumes in each plot and three whole plant samples for corn) were collected for yield data processing. The biomass sub-samples were oven-dried then weighed. The grains or seeds were separated from the straw or stalk and placed in bags with proper labels. The samples were brought to PhilRice for nutrient uptake analysis.

Climatological data: The rainfall pattern in the study area was highly seasonal, fluctuating from 36 to 360 mm per month with a total mean annual rainfall of 2,080 mm (Figure 6). The months of January, February, and March were the driest (<75 mm), sometimes with no measurable rainfall. However, the data showed occasional rainfall of up to 271 mm in these months. Reliable rainfall began in April, May, June, and July (>75 mm). October and November, were the wettest months, with 66 mm and up to 1,018 mm mean rainfall (recorded one year in October). Strong typhoons occur during these months. Rainfall began to taper off in December and in January. Pan evaporation is highest in April and May and the average was higher than mean rainfall for January through June (Figure 7). Any month of the year, however, may have less rainfall than pan evaporation, so drought is a problem year-round (Corton et al. 1998). The mean monthly pan evaporation ranges from 59 to 184 mm and the mean annual pan evaporation is 1559 mm. The mean monthly minimum temperature in the study area fluctuated from 20.5 ˚C in February to 24.8 ˚C in June. The mean monthly maximum temperature ranged from 26.5 in December to 34.6 ˚C in June (Figure 8). The cool months are January, February, and December with a mean of 24 ˚C. The hot months are April, May, and June with a mean temperature of 28 ˚C.

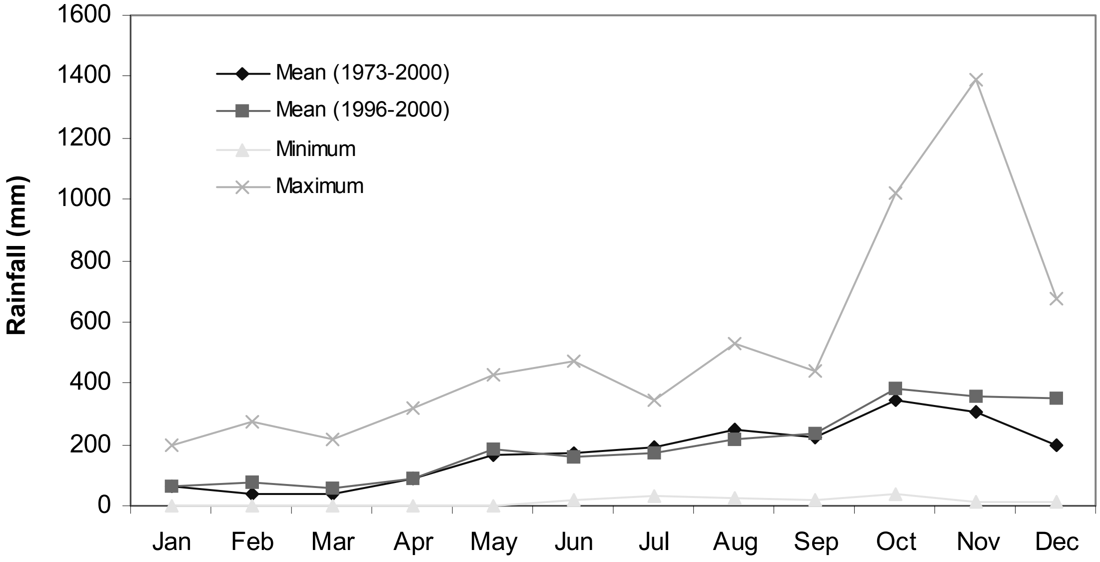

Figure 6. Average rainfall in Ilagan (1973-2000)

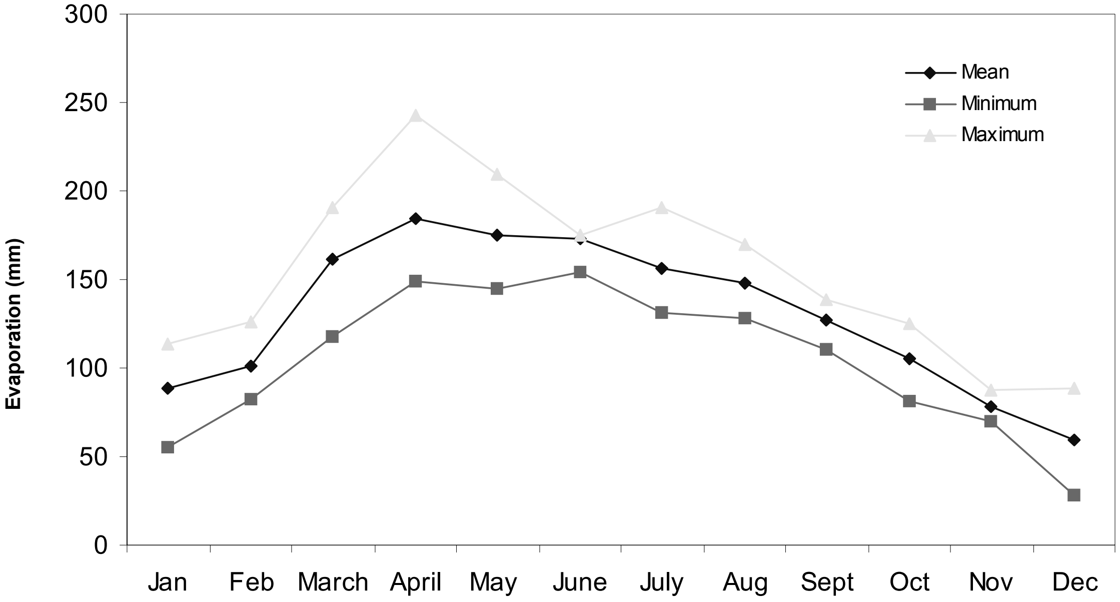

Figure 7. Average evaporation in Ilagan (1973-2000)

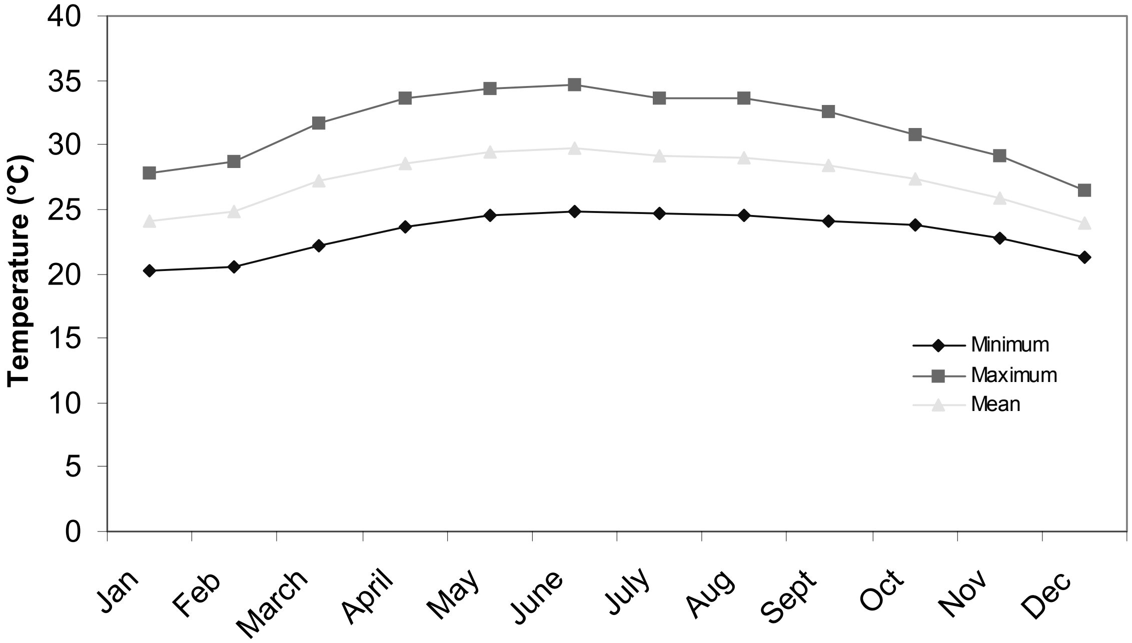

Figure 8. Average temperature in Ilagan (1995-2000).

Lime, fertilizer and green manure application: Lime, as calcium carbonate ($CaCO_3$), was applied at the start of the field experiment in August 1998 for the cereal and in November 1998 for the legume. The material was broadcast into each designated treatment plot and then manually incorporated into the soil (approximately 15-18 cm soil depth) four weeks before planting. The total amount of P and K and $^1/_3$ of the N was broadcast and incorporated into the soil manually one day before planting. The remaining amount of N was side-dressed at specific stage of crop growth: for rice, at maximum tiller count, panicle initiation, and flowering; and, for corn, at 15, 30, and 47 days after planting (DAP). For the N3 treated plots, the remaining N was side-dressed every week at 15 kg ha^{-1} one week after emergence up to 56 days after seeding (DAS), then 10 kg ha^{-1} from 63 up to near maturity (84 DAS for rice, 77 DAP for corn). For legumes, the total amount of P, K and ½ of N was applied before planting time similar to that of the cereals, and the other half of N was side-dressed at flowering stage (30-40 DAS). N3 plots for the legumes had a weekly N application like the N3 plots in the cereal. For green manure treatment, 5t ha^{-1} (oven dry weight basis) of freshly grown cowpea was applied in each treatment plot. The crops were harvested at flowering stage, chopped and incorporated in the soil one week before of corn, the predicted rate of N was 200 kg ha^{-1}, 45 kg ha^{-1} for P, and the residual of the previously applied lime. For upland rice, the NuMaSS-predicted rates of N and P tended to increase over a small amount with cropping seasons. The predicted N for corn was similar for the first two cropping seasons and slightly lower in the third and last cropping season. Meanwhile, the predicted P for corn increased from 45 kg P ha^{-1} in the first to 60 kg P ha^{-1} in the second cropping but decreased to 26 kg P ha^{-1} in the third and last cropping season. Apparently, there was a build up of P due to the consistent P application in each cropping season. This resulted in lower P application towards the last cropping season.

Results and Discussion

NuMaSS Predicted Rates for N, P, and Lime for Cereals and Legumes: The predicted rates for N, P, and lime by the NuMaSS decision-aids to attain target yields of 3.0 t ha^{-1} for upland rice, 6.0 t ha^{-1} for corn, and 2.0 t ha^{-1} for legumes from 1998 to 2001 cropping seasons are presented in Table 48. As mentioned earlier, soil samples from each plot were collected after harvest and analyzed and the results served as the basis for the prediction by the decision-aid on the rate of N, P, and lime to apply for the next cropping.

The NuMaSS-predicted rates for N, P, lime for 1998 upland rice were 80 kg N ha^{-1}, 30 kg P ha^{-1}, and 6.0 t lime ha^{-1}, respectively. For legumes, the NDSS-predicted N was 0 kg ha^{-1} for all cropping seasons, irrespective of the kind of crop. The predicted P varied slightly from 50 to 60 kg P ha^{-1} in the first two cropping seasons and 0 kg P ha^{-1} in the last two cropping seasons. Similar to the cereal area, P could have accumulated in the soil due to P application in the first two cropping seasons thereby increasing the soil P test value higher than the critical level. Like for cereals, predicted lime (4.2 ton ha^{-1}) was applied only in the first cropping season. For peanut planted in 1999, the succeeding crops used the residual lime applied in 1998.

Response of Cereals and Legumes to N, P, and Lime:

Upland rice - the upland rice planted in 1998 did not respond to N, P, and lime application. The reason for the negative response to inputs could be due to climatic constraints. Minimum and maximum temperatures fell below 20˚C and 25˚C respectively, during flowering until grain ripening stage. Rainfall data revealed the many rainy days and therefore, cloudy days during the months of November to January. Fageria et. al. (1991) stated that rice is most sensitive to low temperature 14 to 7 days before heading and at flowering resulting in high percentage of spikelet

Table 48. NuMaSS recommendation for N, P and Lime.

Crop	**NDSS (kg ha^{-1})**	**PDSS**	**ADSS (t ha^{-1})**
Cereals			
1998 Rice	80	30	6
1999 Corn	200	45	6r*
Rice	100	45	6r*
2000 Corn	200	60	6r*
Rice	140	45	6r*
2001 Corn	120	26	6r*
Legumes			
1999 Peanut	0	60	4.2
2000 Soybean	0	50	4.2r*
Mungbean	0	60	4.2r*+ 0.5
2001 Peanut	0	0	4.2r*+0.5r^{1}
Soybean	0	0	4.2r*+0.5r^{1}

r*=residual from first crop, r1=residual from 2000 Mungbean

sterility, and significantly reduced yield if sufficient solar radiation is not received during the reproductive and ripening growth stages of the crop. Grain yield across treatments was no more than 2.0 tons ha^{-1}, significantly lower than the expected yield of 3.0 tons ha^{-1}.

In 1999, upland rice positively responded to N, and P but not to lime application. However, similar to 1998 upland rice, the actual yield (1.7 tons ha^{-1}) obtained in 1999 was significantly lower than the target yield (3.0 t ha^{-1}). The NuMaSS-predicted N (100 kg ha^{-1}) and P (45 kg ha^{-1}) produced significant response for N and P. However, the response to 100% NDSS was the same as 50% NDSS rate. Grain yield, N and P uptake significantly increased with P application.

In 2000, upland rice showed significant response to predicted N (140 kg^{-1}), P (45 kg ha^{-1}), and lime (6.0 tons ha^{-1}, residual) rates. Due to the large response of the crop to predicted rates of N, P, and lime the actual yield obtained was similar to the expected yield of 3.0 tons ha^{-1}. The significant crop response to added inputs could be attributed to the favorable weather condition that prevailed during the season. There was also a positive response to 150% of the predicted N rate. No further crop response to 200% of the recommended P rate was observed. Lime treatment lower than that predicted by NuMaSS caused yield to decline by 0.4 t ha^{-1}.

Corn - there was no yield response to N in corn planted in 1999 while a significant response was obtained in 2000 and 2001. In 2000, the corn response to predicted N (200 kg ha^{-1}) was the same as 50% of the predicted rate. A significant response was observed at 150% of the predicted N rate. The response of corn to predicted N was more marked in 2001. Significant increase in seed yield was obtained at the predicted N rate while the 50% of N rate cause yield reduction and there was no further increase in seed yield at 150% of the predicted N rate.

Corn responded to P for the three cropping seasons (1999-2001) but only at 200% of the predicted N rate, which also received the high N rate (extra rate of 300 kg ha^{-1}). Analysis of covariance indicated no interaction between P treatment rates and N uptake and, therefore, the difference between N and P rates did not influence the yield response at the 200% of the predicted P rate. The relationship between Mehlich 1-P at harvest and corn yield indicate a critical P level of 17.5 mg kg^{-1}soil in 1999, 9.3 mg kg^{-1}soil in 2000 and 17.3 mg kg^{-1}soil in 2001. In 2001, the grain yield response to 100% of the predicted lime rate was higher but not statistically significant to the low rate.

Comparing the actual yields of corn with the expected yield in 1999 results showed that corn produced a yield of 4.60 t ha^{-1} significantly lower than the expected yield of 6.0 tons ha^{-1}. This could be due to the drought that occurred for almost two weeks during the reproductive stage. Generally corn is most sensitive to drought stress during pollination resulting in reduced fertilization and subsequently low grain yield (Fageria et. al. 1991). In contrast, however, the corn yields obtained in 2000 (5.8 t ha^{-1}) and 2001 (6.3 t ha^{-1}) were comparable to the expected yield of 6.0 t ha^{-1}.

Legumes - in 1999, peanut did not respond to rates higher that the predicted values for N and lime (4.0 t ha^{-1}), indicating that NuMaSS accurately predicted the N and lime requirement of peanut. A contrasting observation was seen in 2001 where peanut responded to both N and lime at higher rates than the predicted rate. The response to the predicted P rate (60 kg ha^{-1}) was significant in 1999 where yield obtained in both rates (50% and 200% of the predicted rate), were similar. This result implies that NuMaSS could have overestimated the P requirement of peanut.

Similar to the response of peanut in 1999, soybean did not respond to N and lime rates higher than the residual applications for peanut in 1999 (0 kg N ha^{-1} and 4 t lime ha^{-1}). NuMaSS predicted the crop requirement for N and lime in 2000. The response of soybean to P was significant at 50% predicted rate. However, the crop also showed response at 200% of the predicted rate indicating an overestimation of the P requirement of the crop. Grain yield, N and P uptake increased significantly with P application up to 50 kg ha^{-1}. On the other hand, N and P uptake were strongly related in both upland rice and corn.

Mungbean also gave a significant response at low N rate (30 kg ha^{-1}) suggesting that NuMaSS could have underestimated the N (0 kg ha^{-1}) requirement of the crop. In contrast, the response of mungbean to predicted P (60 kg ha^{-1}) was more marked. At 50% predicted P rate, seed yield declined and the crop did not respond at 200% of the predicted rate - indicating a good prediction by NuMaSS for P requirement of mungbean. There was no response in mungbean to lime rates higher than the predicted rate (4.0 + additional 0.5 t ha^{-1}) indicative of a good lime prediction by NuMaSS.

The critical P level identified was low for the three crops, i.e. peanut in 1999 (5.8 mg kg^{-1}soil), soybean in 2000 (4.8 mg kg^{-1}soil) and mungbean in 2000 (5.8 mg kg^{-1}soil). Comparison between the actual and predicted yield of legumes indicated that soybean and mungbean produced significantly lower seed yields than the expected yields in 2000. However, the peanut seed yield of 1.8 t ha^{-1} (1999) and 2.2 t ha^{-1} (2001), respectively, were comparable to the expected yield of 2.0 t ha^{-1}. In 2001, soybean produced 2.3 t ha^{-1} which was significantly higher than the expected yield of 2.0 t ha^{-1}.

Agreement Index Between Expected and Actual Yield - In contrast to simulation models such as DSSAT, NuMaSS does not actually predict yields from weather, solar radiation, rainfall, soil, and genetic properties of the plant. Rather it uses regional estimates of expected crop yield, or revised estimates based on local experience entered by the user. The expected and actual yield of cereals and legumes for four crop years using the NuMaSS are presented in Tables 49 and 50. An agreement index was used to evaluate the closeness between expected and actual yield. A value of 1.0, means that expected yield is equal to the actual yield. If the agreement index is less than 1.0 the expected yield is higher than the actual yield. If greater than 1.0, the expected yield is lower than the actual yield.

The agreement index for three cropping seasons in upland rice ranged from 0.2 to 1.0 while for corn, 0.7 to 1.0. Except for cropping seasons where there were climatic constraints as in 1998 and 1999, upland rice and corn obtained high agreement index between expected and actual yield indicating excellent prediction. The agreement index obtained for upland rice was 1.0 in 2001 while for corn, 1.0 (2000) and 1.0 (2001).

In legumes, the agreement index was also high except in mungbean which was affected by adverse climatic conditions in 2000. For peanut, the agreement index were 0.9 (1999) and 1.1 (2001); for soybean, 0.8 (2000) and 1.1 (2001). Like in cereals, these results indicate excellent prediction by NuMaSS.

Table 49. Expected yield and actual yield of cereals across years

Cereals	**Expected Yield**	**Actual Yield**	**Agreement Index**
	(t ha^{-1})		
Upland Rice			
1998 crop	3.0	2.0	0.5
1999 crop	3.0	1.7	0.2
2000 crop	3.0	3.0	1.0
Maize			
1999 crop	6.0	4.6	0.7
2000 crop	6.0	5.8	1.0
2001 crop	6.0	6.2	1.0

Table 50. Expected yield and actual yield of legumes across years

Legumes	**Expected Yield** (t ha^{-1})	**Actual Yield**	**Agreement Index**
1999 Peanut	2.0	1.8	0.9
2000 Soybean	2.0	1.7	0.8
2000 Mungbean	1.5	1.0	0.6
2001 Peanut	2.0	2.2	1.1
2001 Soybean	2.0	2.2	1.1

Soil Chemical Properties After Harvest - Only the soil chemical properties at 0-15 cm depth after harvest, and those from plots which received applications based on NuMaSS are reported. The results of chemical analysis done on other soils collected at 0-15 cm from other plots and soil samples collected at 15-30 cm in selected plots for both cereals and legumes will be reported in other papers to be published.

Soil analysis after harvesting upland rice (1998) and peanut (1999) showed significant increase in soil pH, available P, exchangeable Ca and a significant decrease in exchangeable Al and Al saturation due to the application of P and lime. Total exchangeable Mg and CEC did not change with the imposition of soil treatments.

The imposition of NuMaSS treatments for N, P, and lime in the cereal area for 4 years (1998-2001) involving six crops, increased soil pH from 4.1 to 5.9, available P from 3.1 to 17.3 mg kg^{-1} (Mehlich 1-P), exchangeable Ca from 1.1 to 5.2 cmol$_c$ kg^{-1} soil, and decreased exchangeable Al from 4.6 to 0.01 cmol$_c$ kg^{-1} soil and Al saturation from 58.6 % to 0.2 % (Table 51). In the legume area, the soil pH increased to 6.3, available P to 12.0 mg kg^{-1}, exchangeable Ca to 8.0 cmol$_c$ kg^{-1} soil, and decreased exchangeable Al and Al saturation to nil due to the imposition of NuMaSS treatments for a period of three years (1999-2001) involving five cropping seasons (Table 52).

Table 51. Soil chemical properties after harvest - cereal experiment.

	Values After Harvest of Crops					
Chemical	**1998**	**1999**		**2000**		**2001**
Properties	**Rice**	**Corn**	**Rice**	**Corn**	**Rice**	**Corn**
Soil pH (1:1 soil-water)	6.5	6.0	6.6	6.1	5.8	5.9
Organic Matter (%)	1.6		1.4	1.4	1.0	1.0
Available P (mg kg^{-1})	5.8	8.4	9.2	13.2	11.8	17.3
Exch. Cations (cmol$_c$ kg^{-1})						
K	0.2	0.2	0.2	0.2	0.2	0.3
Ca	10.7	6.5	6.6	7.2	7.2	5.2
Mg	0.3	0.1	0.3	0.3	0.3	0.4
Al	0.01	0.02	0	0	0	0.01
ECEC (cmol$_c$ kg^{-1})	11.1	6.8	7.1	7.7	7.6	5.9
Al Saturation (%)	0.1	0.4	0	0	0	0.2

Summary and Conclusions - The N, P, and acidity modules of the Nutrient Management Support System (NuMaSS) were validated for four years (1998-2001) using two important cereals (upland rice and corn) and three important legumes (peanut, soybean and mungbean) as test crops in an Ultisol soil in Barangay San Antonio, Ilagan, Isabela from 1998 to 2001. The objective of the decision-aids is to determine whether the prediction are within 50% of the field-determined optimum nutrient levels needed by the crop to achieve near maximum yield for the region under farmer's conditions.

Table 52. Soil chemical properties after harvest - legume experiment.

	Values After Harvest of Crops				
Chemical	**1999**	**2000**		**2001**	
Properties	**Peanut**	**Soybean**	**Mungbean**	**Peanut**	**Soybean**
Soil pH (1:1 soil-water)	6.0	6.1	6.6	7.5	6.3
Organic Matter (%)	0.8		0.9	0.8	0.8
Available P (mg kg^{-1})	12.9	8.3	15.2	28.6	12.0
Exch. Cations ($cmol_c$ kg^{-1})					
K	0.2	0.1	0.2	0.2	0.2
Ca	13.7	6.0	7.6	11.3	8.0
Mg	0.5	0.02	0.2	0.2	0.4
Al	0.02	0	0	0	0
ECEC ($cmol_c$ kg^{-1})	14.4	6.11	7.9	11.7	8.7
Al Saturation (%)	0.1	0	0	0	0

In general, the capability of the N, P and acidity components of NuMaSS to predict the N, P, and lime requirements of cereals and legumes differed among each other across seasons. Except for cropping seasons where there were climatic constraints, such as too much and too little amount of rainfall and abnormal low temperature during the reproductive stages of the crops, the prediction of NuMaSS was relatively good. The predicted the N, P, and lime requirements of cereals were correct in $^1/_5$, $^3/_5$, and $^3/_5$ cropping seasons and in legumes, $^3/_5$, $^3/_5$ and $^4/_5$ cropping seasons respectively. In cereals, the N requirement was overestimated for two cropping seasons while P requirement was underestimated for two cropping seasons.

The agreement index between expected and actual yield using the NuMaSS was very close, except in cropping seasons where there were climatic constraints. Results of soil analysis after cropping in both cereals and legumes areas showed significant increase in soil pH, available P, and exchangeable Ca and decrease in exchangeable Al in treatment where the NuMaSS decision-aid recommendations were followed. After four years of amending the soil and applying the right amount of fertilizers, upland rice, corn, soybean and mungbean grew normally and produced good yields in an Ultisol soil that was previously acidic and had low level of soil fertility.

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3. b. Managing excess manganese in acid soils (Jocelyn Bajita with collaboration from Josefina Lasquite, Miguel Aragon, Madonna Casimero and Russell Yost) The objectives of the study were to:

- evaluate the potential Mn toxicity of soils in the Ilagan region of Northern Luzon, and
- propose methods of diagnosing and predicting solutions to the Mn toxicity in crops in the Ilagan region.

Field Experiment in San Antonio, Philippines - The representative soil profile at the site of the SM-CRSP testing of the Nutrient Management Decision Support Systems (NuMass) in the Philippines is characterized not only by a very low soil pH but also of low exchangeable cations (Ca, Mg, K) and high exchangeable Al and soil solution Mn (Table 53). The potential for excess manganese in the soil during the crop growing period is indicated by the presence of black, pebble-sized Mn nodules within the first 40 cm of the soil profile. Symptoms of manganese phytotoxicity characterized by dark brown to black specks in older leaves and crinkling of younger leaves were particularly observed in the peanut crop in 1999. Similar symptoms and high foliar Mn levels were observed in the soybean crop grown in 2000, which confirmed the earlier suspicion of a potential Mn toxicity.

Table 53. Some chemical characteristics of the soil at the experimental site in San Antonio, Isabela, Philippines.

Hori-zon	**pH**	**SP[a] Mn**	**Tot. Acidity**	**Exchangeable**				**Sum Bases**	**Eff. CEC**	**Al Sat.**
				Al	**K**	**Ca**	**Mg**			
		mg l^{-1}	---------------------------------- $cmol_c\ kg^{-1}$ ----------------------------------							%
A1	4.47	1.37	2.73	2.53	0.11	2.00	0.53	2.63	5.36	47
A2	4.57	1.23	2.78	2.58	0.08	2.15	0.41	2.64	5.42	48
B	4.59	--	2.78	2.78	0.10	1.69	0.58	2.37	5.14	54

[a] Saturation paste extract.

We conducted a field experiment in 2001 to assess the effect of several management alternatives on alleviating the phytotoxicity of manganese in soybeans grown in the San Antonio Ultisol. Two local Philippine soybean cultivars PSB SY2 and PSB SY6 were used in this experiment. The effects of liming, mulching, rates of phosphorus and green manure additions on soil pH, exchangeable Al, soil solution Mn and seed yield of two soybean varieties were determined. Statistical analysis showed that these measured parameters were significantly influenced by treatments ($Pr<0.0001$) but not by varieties so that the data in Table 54 shows means including the 2 varieties. Although PSB SY2 tended to have higher yields compared to PSB SY6 in most treatments, the trend of response to each treatment was similar for both varieties. The comparison among treatments Co1, Co2 and Co3 indicates response to rates of lime application. Lime application of up to 5 tons ha^{-1} increased soil pH from 4.45 to 5.17, a 0.72 unit increase in pH. A 0.3 unit increase was obtained with 2 tons ha^{-1} of lime applied. Interestingly, 2 tons ha^{-1} of lime significantly lowered exchangeable Al but not saturated paste Mn. In fact, the reason for selecting this lower rate of lime application was to minimize exchangeable Al without affecting soil solution Mn and therefore to maintain potentially excessive levels in solution. The higher rate of lime only slightly lowered both exchangeable Al and saturated paste Mn. All of the P, mulching and manure treatments received 2 tons ha^{-1} lime so that comparison with Co2 indicates the effect of each particular treatment. None of the P, mulching and green manure treatments affected the level of soil pH and exchangeable Al when compared with Co2. On the other hand, green manure and chicken manure application caused about 2-fold increase in saturated paste-Mn.

Table 54. Effect of lime, manure, P and mulch on soil pH, exchangeable Al, soil solution Mn and seed yield of soybean in an Ultisol in San Antonio, Philippines.

Treat-ment[a]	**Applied**						**pH in H_2O (1:1)**	**Exch. Al**	**Sat. Paste Mn**	**Seed Yield**
	Lime	**Manure**	**Mulch**	**P**	**N**	**K**				
	t ha^{-1}				kg ha^{-1}			cmol$_c$ kg^{-1}	mg l^{-1}	kg ha^{-1}
Co1	0	no	no	30	40	60	4.45 c	1.61 a	1.38 bc	372 g
Co2	2	no	no	30	40	60	4.76 b	0.90 bc	1.10 bc	992 f
Co3	5	no	no	30	40	60	5.17 a	0.42 c	0.10 c	1445 def
+Mul	2	no	yes	30	40	60	4.62 bc	0.99 b	0.86 c	1234 ef
P60	2	no	no	60	40	60	4.71 b	0.76 bc	0.84 c	1451 def
P60+Mul	2	no	yes	60	40	60	4.74 b	0.76 bc	0.75 c	1568 cde
P100	2	no	no	100	40	60	4.69 b	0.78 bc	0.58 c	1688 cde
P100+Mul	2	no	yes	100	40	60	4.86 b	0.64 bc	0.57 c	1901 bcd
+GM	2	GM	no	30	25	60	4.77 b	0.69 bc	3.19 a	1821 cd
+GM+Mul	2	GM	yes	30	25	60	4.80 b	0.64 bc	2.28 ab	1992 bc
+CM	2	CM	no	30	25	60	4.60 bc	0.60 bc	2.81 a	2787 a
+CM+Mul	2	CM	yes	30	25	60	4.80 b	0.82 bc	2.06 ab	2286 b

[a] Co=control, GM=7 t ha^{-1} green manure as *Leucaena leucocephala*, CM=7 t ha^{-1} chicken manure, P= phosphorus as triple superphosphate, Mul= rice straw mulch approximately 2 inch thick over soil surface.

The yield increase from 372 to 1445 kg ha^{-1} due to increasing amounts of lime applied can be attributed to a decrease in soil exchangeable Al and therefore an alleviation of Al phytotoxicity. Soil solution Mn was not affected by changes in soil pH due to liming as much as exchangeable Al so that potential Mn phytotoxicity remained even after alleviation of Al phytotoxicity. However, the amounts of Ca also changed with liming which could also have alleviated Mn phytotoxicity. Further increases in yield due to higher rates of P and manure application did not directly result from lower exchangeable Al or soil solution Mn. On the contrary, there was a significant increase in soil solution Mn due to manure application and yet the highest yields were observed in these treatments. Increased yields and a coincident increased soil solution Mn indicates that there is more to managing Mn phytotoxicity than managing soil solution Mn. It is likely that the nutrients (i.e., cations Ca, Mg, K) contained in the manure helped the soybeans grow better and yield more despite the increase in soil solution Mn. This could mean that we need to manage the plant more than we need to manage the soil in certain situations where Mn is potentially toxic.

Greenhouse Experiment at the University of Hawaii - Reports of enhanced tolerance to toxicity of Mn due to manipulation of interacting nutrients as well as the environmental conditions are common in the literature. This is an interesting observation which has great implications on the management of excess Mn in acid soils. We proposed that this enhanced tolerance due to other nutrients and the environment can be explained by a higher growth potential set by the given growth condition; and that the phytotoxic response is a net effect of the continuous interaction between the plant's growth rate and uptake rate of manganese.

To understand this dynamics of Mn phytotoxicity response, we conducted a greenhouse experiment at the University of Hawaii using soybean as a test crop grown in Wahiawa series, a manganiferous Oxisol with extremely high total Mn content. We used two soybean varieties Forrest (Mn-susceptible) and Lee (Mn-tolerant). Three levels of excess soil Mn were established by liming Wahiawa from an unamended pH of 4.78 to pH 5.5 and 6.0. Various growth rate potentials were set by the growth condition treatments (Table 55).

Table 55. List of cultivars, soil pH levels and growth conditions imposed.

Cultivar	**Lime Addition to soil pH**[a]	**Growth Condition**	**Description**
Forrest (Mn susceptible)	4.78 (none)	Control	Field capacity (300 ml kg^{-1}), no green manure, 75 mg P kg^{-1}, full sunlight
Lee (Mn tolerant)	5.5 (1.2 g kg^{-1})	Dry	80-90% field capacity
	6.0 (2 g kg^{-1})	+GM	10 g green manure kg^{-1} of *L. leucocephala*
		+P	150 mg P kg^{-1}
		Shade	80% shade

[a] Numbers in parenthesis are amounts of $CaCO_3$ added.

The soil solution Mn measured from the saturated paste extract was about 25 ug ml^{-1} in the unamended soil. Liming significantly reduced saturated paste- Mn to about 1.5 mg ml^{-1}. While shading and P application did not affect soil solution Mn, the addition of green manure maintained soil solution Mn at >30 mg ml^{-1} regardless of soil pH (Table 56).

Forrest generally gave lower growth rates, manganese uptake rates and final biomass compared to Lee under all treatments, indicating its susceptibility to excess Mn (Figure 9). An interesting observation was that current relative growth rates (RGRs; leaf or whole plant) and relative uptake rates of Mn (RAR_{Mn}) were significantly correlated for both Forrest and Lee (data not shown). Because Mn uptake is poorly regulated, this tight correlation can be attributed to the linkage of both RGR and RAR_{Mn} to water use by the plant. As shown in Figure 9, both RGR_{Leaf} and RAR_{Mn} were correlated with water use. Soybean Lee that produced more biomass tended to use more water than Forrest, resulting to Lee having higher leaf Mn concentration than Forrest (data not shown).

Table 56. Changes in soil solution Mn (saturated paste) with lime application under five growth conditions.

Growth Condition	Soil pH in Water 4.78 (unlimed)	5.50 (limed)	6.00 (limed)
	---------------------------------- Mn, mg l^{-1}	----------------------------------	
Control	24.66 b	1.56 b	1.47 b
80-90 F. Capacity	24.94 b	1.35 b	0.66 b
+GM	35.48 a	30.54 a	32.31 a
+P	24.91 b	1.37 b	0.92 b
40% Shade	30.49 b	2.70 b	0.70 b

Despite a positive correlation between current relative growth rate and relative uptake rate, we observed a negative effect of current RGR_{Leaf} on future RAR_{Mn} and likewise a negative effect of current RAR_{Mn} on future RGR_{Leaf}. Continuous and negative effects were significant for variety Lee (Figure 10) but not Forrest. This can be due to the susceptibility of Forrest to the toxicity. This response mechanism may have occurred very early in the growth period, which was not captured within the 2-week growth interval when growth measurements were made.

The lack of correlation between total biomass accumulation and leaf Mn concentrations (data not shown) is likely due to the lack of direct control between biomass growth and Mn uptake. We explain this via a dynamic model of Mn phytotoxicity based on the dual feedback effect of RGR_{Leaf} on RAR_{Mn} observed to be significant for Mn-tolerant Lee. While current RGR_{Leaf} and RAR_{Mn} are positively correlated, the current RGR_{Leaf} exerts a continuous and negative effect on future RAR_{Mn}. At the same time, the current RAR_{Mn} exerts a continuous negative effect on future RGR_{Leaf}. This dual feedback interaction between RGR_{Leaf} and RAR_{Mn} results in a final biomass which is not necessarily related to a current or past leaf Mn concentration.

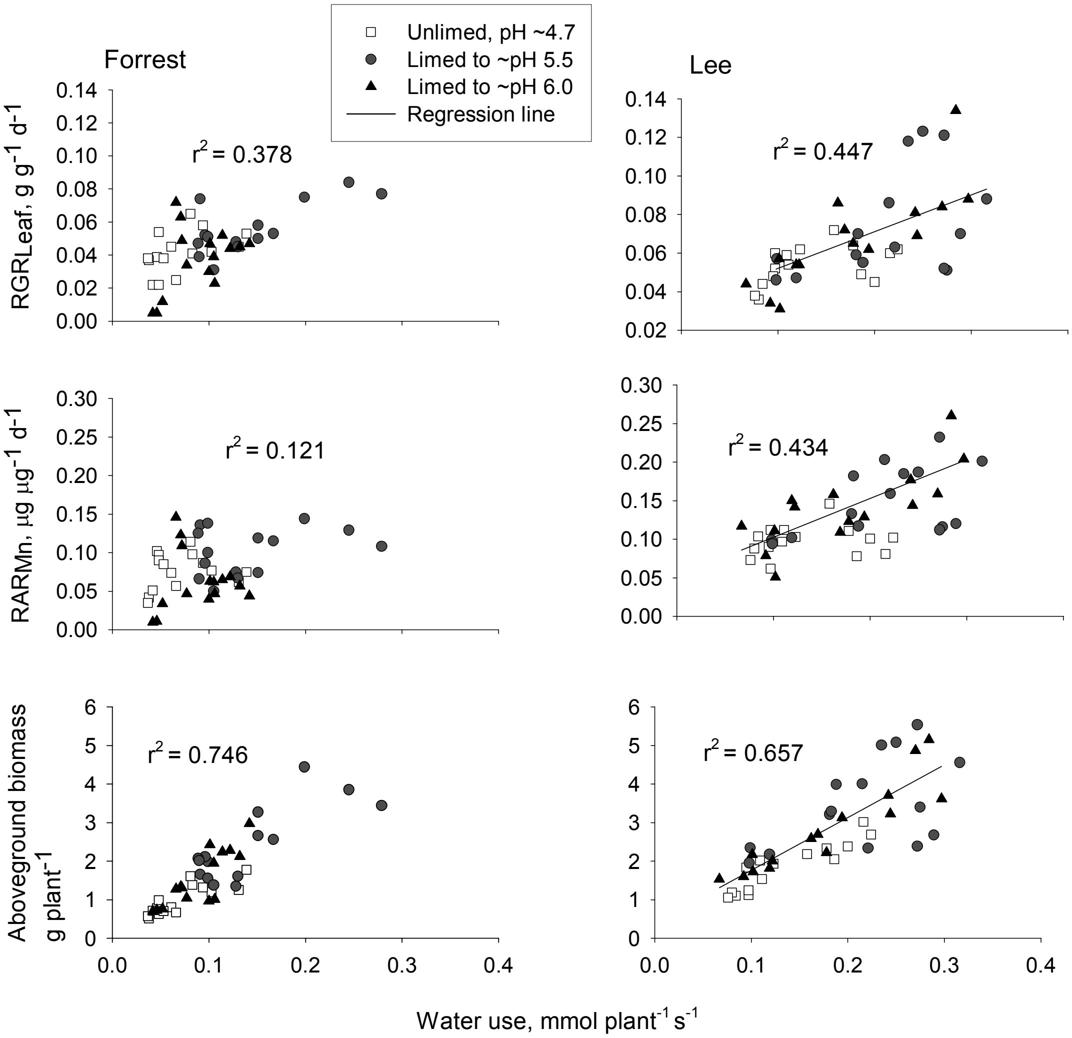

Figure 9. Correlation of water use to RGR_{Leaf}, RAR_{Mn} and Mn uptake of two soybean cultivars grown under three pH levels and varying growth conditions.

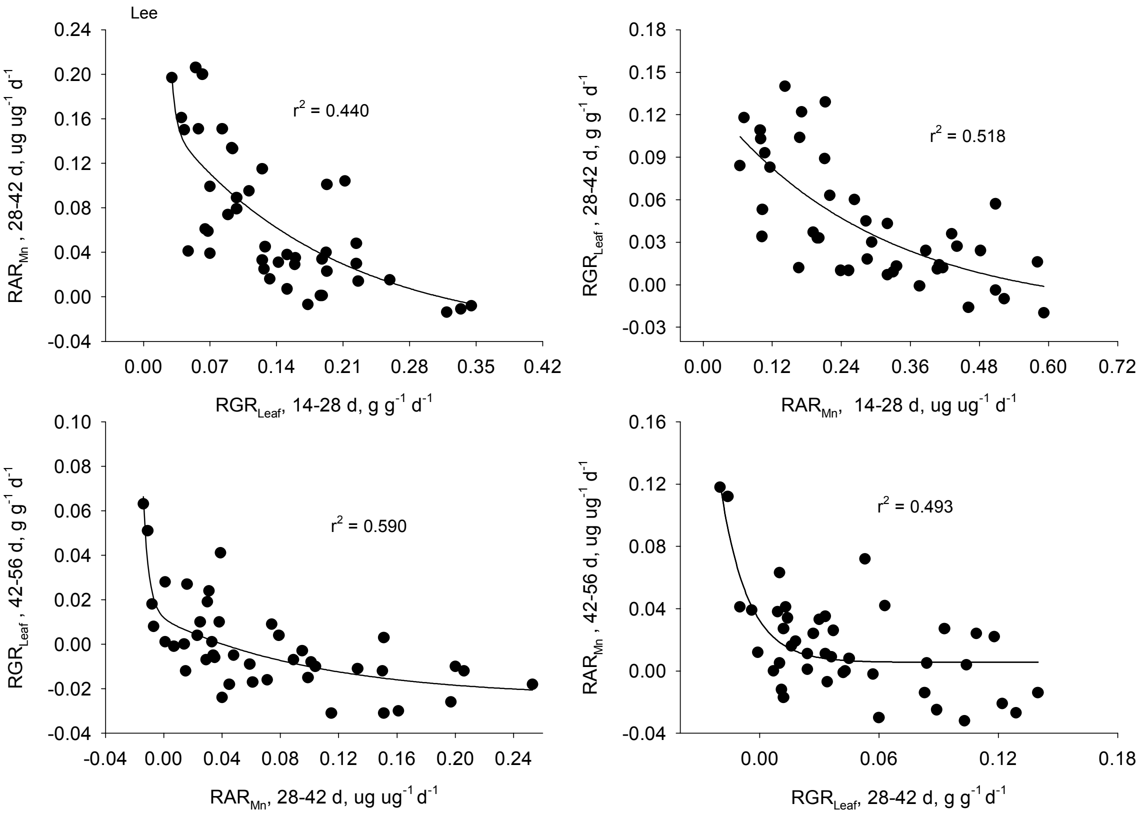

Figure 10. Feedback effect of current RGR_{Leaf} on future RAR_{Mn} and feedback effect of current RAR_{Mn} on future RGR_{Leaf} for Mn-tolerant Lee.

3. c. On-farm testing of NuMaSS in the Philippines (T. Corton, T. George, R. Escabarte, J. Lasquite, J, Quiton and M. Casimero of PhilRice with assistance from A. Mataia, Q. Asuncion B. Macarubbo) NuMaSS on-farm evaluation was undertaken in the Philippines with the objectives of:

- testing the nutrient decision-aids to determine whether they optimally diagnose and detect nutrient-responsive conditions on farms;
- documenting the farmer's diagnostic practices and crop management to improve diagnosis and prediction by and interface of NuMaSS; and
- using on-farm evaluation data to improve diagnosis and prediction by NuMaSS.

Since 1987, the International Rice Research Institute (IRRI) and the Philippine Rice Research Institute (PhilRice) as partners in SM-CRSP were involved with NuMaSS development in the testing, evaluation, and refinement of fertilizer and lime predictions in the Asian uplands. As part of this, IRRI and PhilRice have collaborated with US Universities on on-farm testing of NuMaSS in Ilagan, Isabella and Arakan Valley, North Cotabato in the Philippines. In the Philippines, the acid uplands, primarily Ultisols, comprise close to 9 million ha of underused, deforested land. Potentially, by the deployment of NuMaSS technology by the research and extension systems, a large proportion of this land could be brought to diversified and higher value crop production. The NuMaSS technology is similarly expected to be adopted and deployed by other Asian national agricultural research and extension systems.

Methodology - The on-farm evaluation involved superimposition of various fertilizer practices on farmers' crop of upland rice or maize. These treatments were:

1. Check (no fertilizer),
2. Farmer practice,
3. Regional blanket recommendation,
4. NuMaSS recommendation (K same as Regional), and
5. NuMaSS recommendation + high K (optional - only if regional K was deemed inadequate).

Farms and farmers were selected to provide a diversity of production situations while about equally distributed among farmers with and without off-farm income and among farms of gentle (0-8%) to moderate slopes (8-16%), low to high pH and small to large farms. Farmers were identified based on their intention to grow upland rice or maize. All operations other than NuMaSS recommendations were as per farmer practice. After conducting a diagnostic discussion with the farmer about his/her farming, soil samples to 15 cm depth were collected and analyzed for pH, Al, bases, clay and Mehlich 1 P. Based on soil analyses and intended yield levels, NuMaSS diagnoses and recommendations were made and implemented. Nitrogen, P and lime were incorporated into 15 cm depth before seeding. Grain yield and stover or straw was sampled at harvest. After recording fresh weight of bulk and sub-samples, the samples were oven dried for 48 h at 70 ˚C and analyzed for N, P and K.

On-farm plots were established in 13 upland rice farms and 15 corn farms in Ilagan in 1999, in 8 corn farms in Ilagan in 2000 and in 17 upland rice farms in Arakan Valley in 2000 (Table 57). The NuMaSS + K treatment was included to test whether K, which is part of the regional recommendation but not included in NuMaSS and applied in various amounts by farmers, was limiting yield.

Table 57. Number of on-farm trials established.

	1998		**1999**		**2000**	
Location	**Rice**	**Corn**	**Rice**	**Corn**	**Rice**	**Corn**
San Antonio	7		13	15	4	13
Arakan					17	
Total	7		13	15	26	18

NuMaSS diagnosis and assessment of its accuracy - Site and soil properties of upland rice and corn farms in Ilagan and Arakan Valley in 1999 and 2000 are presented in Tables 58 through 62. While most Ilagan soils were severely acid (pH_{KCl} less than 4.5 in 56% farms across upland rice and corn) and extremely low in exchangeable bases, soils in all farms in Arakan recorded pH_{KCl} exceeding 4.5 and contained high amounts of Ca and Mg, resulting in moderately high effective cation exchange capacity. While Ilagan and Arakan soils varied substantially in soil acidity and Ca and Mg contents, a majority of both soils were extremely deficient in Mehlich 1 extractable P. Across all farms, soils in 89% of farms were below 5 mg kg^{-1} soil in Mehlich 1 P. Percent of farms reporting P deficiency for both upland rice and corn increased to 94% when only Ilagan farms were considered and increased to 100% when only rice soils in Ilagan were included.

Thus, upland rice tends to be grown always in soil extremely deficient in P. Soils in Ilagan which were less acid and higher in bases compared to the remaining soils were on farms on the river plains that benefited from flood-derived alluvial deposits and frequently used to produce corn. Thus, for all crops and at both sites, NuMaSS diagnosed P deficiency in a majority of the farms and acidity as a constraint in only some farms.

Table 58. Site and soil characteristics of farms, upland rice, Ilagan, Isabela, Philippines, 1999.

Site	**Area**	**Slope**	**0 pH**	**Clay**	**0Mehlich1 P**	**Exchangeable**					**Eff.**
						Acidity	**Al**	**K**	**Ca**	**Mg**	**CEC**
	ha	%		%	mg kg^{-1}			(cmol$_c$ kg^{-1})			
1	0.50	8-16	4.1	35	0.6	1.9	1.7	-	1.9	2.1	5.9
3	0.75	8-16	3.9	45	1.0	2.7	2.6	-	1.3	1.3	5.2
9a	0.70	0-8	4.5	35	1.6	1.7	1.8	0.01	0.2	0.8	4.2
9b	0.70	0-8	4.5	35	1.4	1.7	1.8	0.04	0.2	0.8	2.8
12	0.25	0-8	3.8	40	1.5	1.5	1.4	-	1.5	1.1	3.1
13a	0.75	0-8	5.1	35	3.2*	1.5	0.8	0.02	1.5	1.4	4.4
13b	0.50	8-16	4.6	35	3.2*	1.2	1.1	0.02	1.5	1.4	4.1
22c	0.75	8-16	4.6	35	1.6	1.6	1.7	0.01	2.9	1.4	5.9
31	0.50	8-16	3.8	40	1.5	1.5	1.4	-	1.6	1.0	4.0
32	0.50	0-8	3.7	42	2.3	2.2	2.1	-	1.1	1.1	4.3
53	0.40	0-8	4.1	37	1.4	1.8	1.7	0.02	0.4	0.8	3.0
57	0.50	0-8	3.9	41	1.4	1.6	1.6	0.02	0.4	0.6	2.6
58	0.30	0-8	4.4	35	4.2*	1.4	1.4	0.02	1.5	1.4	4.2

* Olsen-extractable P.

Table 59. Site and soil characteristics of farms, corn, Ilagan, Isabela, Philippines, 1999.

					Mehlich 1	**Exchangeable**					**Eff.**
Site	**Area**	**Slope**	**pH**	**Clay**	**P**	**Acidity**	**Al**	**K**	**Ca**	**Mg**	**CEC**
	ha	%		%	mg kg^{-1}			cmol$_c$ kg^{-1}			
5	0.50	8-16	3.7	39	1.6	2.7	2.4	-	0.7	0.5	3.8
9	0.75	0-8	3.7	39	1.6	2.7	2.4	-	0.7	0.5	3.8
16	0.50	0-8	4.1	41	1.6	1.8	1.8	1.1	0.2	0.1	3.1
17A	0.70	8-16	4.1	41	1.6	1.8	1.8	1.1	0.2	0.7	3.1
19	0.25	0-8	4.2	40	2.2	2.2	2.0	1.0	0.3	0.04	3.5
20A	0.50	0-8	4.8	35	15.4*	0.4	0.4	1.0	1.5	1.0	4.0
22D	0.25	8-16	5.0	35	35.0*	1.2	1.0	0.02	0.4	0.7	2.3
24B	0.25	8-16	5.0	35	35.0*	1.2	1.1	0.2	0.2	0.04	1.7
27	0.50	8-16	4.9	35	8.2*	0.7	0.4	0.2	0.3	0.02	1.2
28	0.50	8-16	4.2	42	2.2	2.1	2.0	1.0	0.3	0.04	3.5
29	0.50	8-16	4.1	41	1.6	1.8	1.8	1.1	0.2	0.1	3.1
30	1.0	8-16	4.9	35	*8.2**	*0.8*	*0.5*	0.9	0.2	0.04	1.9
41	0.35	0-8	4.1	41	1.6	1.8	1.8	1.1	0.2	0.1	3.5
47	0.25	0-8	4.2	42	2.2	2.2	2.0	1.0	0.3	0.04	3.5
51D	1.0	0-8	4.9	35	8.2*	0.7	0.5	0.2	1.6	1.1	4.2

* Olsen-extractable P.

Table 60. Site and soil characteristics of farms, corn, Ilagan, Isabela, Philippines, 2000.

					Mehlich 1	**Exchangeable**					**Eff.**
Site	**Area**	**Slope**	**pH**	**Clay**	**P**	**Acidity**	**Al**	**K**	**Ca**	**Mg**	**CEC**
	ha	%		%	mg kg^{-1}			cmol$_c$ kg^{-1}			
3	0.50	8-16	5.3	35	1.1	0.3	0.1	0.2	4.0	3.1	17.6
4	0.20	0-8	5.2	35	1.1	0.2	0.8	0.5	5.5	17.9	24.2
6	0.50	8-16	4.6	35	1.3	0.5	0.4	0.1	4.8	13.3	18.8
8b	0.50	8-16	4.4	35	5.1	1.9	1.8	0.4	3.7	9.5	15.4
9	1.0	8-16	4.5	35	3.9	1.1	0.9	0.5	6.5	17.0	25.0
16	1.0	0-8	4.4	35	3.4	0.7	0.5	0.3	2.9	8.4	12.2
21b	0.75	8-16	4.3	35	2.1	5.1	4.9	0.3	7.5	23.8	36.7
17	0.50	0-8	4.5	35	2.6	1.6	1.5	0.1	1.0	4.8	7.6

Table 61. Site and soil characteristics of farms, upland rice, Arakan Valley, Philippines, 2000.

				Mehlich 1	**Exchangeable**					**Eff.**
Site	**Slope**	**pH**	**Texture**	**P**	**Acidity**	**Al**	**K**	**Ca**	**Mg**	**CEC**
	%			mg kg^{-1}			cmol$_c$ kg^{-1}			
GI1	0-8	4.5	Loamy	1.3	0.4	0.1	0.4	5.8	18.0	24.6
GI2	8-16	5.0	Loamy	2.2	0.6	0.2	0.7	22.4	21.7	45.4
GI3	0-8	4.9	Loamy	1.5	0.04	0.1	0.6	22.3	24.6	47.8
GI7	0-8	5.2	Loamy	4.6	0.2	0.1	0.5	14.6	27.5	42.8
GI8	8-16	5.2	Loamy	4.6	0.2	0.1	0.5	14.6	27.5	42.8
DN9	8-16	5.7	Loamy	54.4$^{\#}$	0.1	0.0	1.1	19.7	26.6	47.5
DN11	0-8	4.6	Loamy	1.6	0.7	0.2	0.5	10.4	26.8	38.3
DN12	8-16	5.1	Loamy	3.8	0.7	0.2	0.5	22.6	21.7	45.5
TC14	8-16	5.4	Loamy	3.5	0.2	0.1	0.7	18.8	24.7	44.4
SS15	8-16	4.6	Loamy	8.8	0.4	0.1	0.1	27.8	7.4	35.4
GB16	8-16	4.7	Loamy	8.3	0.7	0.1	0.2	28.7	7.6	36.6
ES18	0-8	5.7	Loamy	20.2$^{\#}$	0.1	0.02	0.1	21.3	8.3	29.8
SD19	0-8	5.2	Loamy	12.8$^{\#}$	0.1	0.04	0.1	20.0	6.6	36.7
JD20	0-8	5.0	Loamy	5.4	0.1	0.03	0.1	18.9	4.9	24.0
RB21	0-8	4.9	Loamy	14.5$^{\#}$	0.1	0.04	0.1	20.8	7.0	27.6
JM22	0-8	4.6	Loamy	4.0	0.2	0.1	0.1	17.4	4.4	22.0

$^{\#}$ Olsen-extractable P.

Table 62. Summary of soil acidity, extractable P and bases across rice and corn testing sites.

		Rice		**Corn**	
		Ilagan	**Arakan**	**Ilagan**	**Arakan**
		1999	**2000**	**1999**	**2000**
			% of farms		
pH (KCl)	< 4.5	62	0	60	38
	> 4.5	38	100	40	62
Mehlich 1 P, mg kg^{-1}	< 5	100	76	93	88
	> 5	0	24	7	12

		Rice		Corn	
		Ilagan	**Arakan**	**Ilagan**	**Arakan**
		1999	**2000**	**1999**	**2000**
		% of farms			
Ca, $\text{cmol}_c\ \text{kg}^{-1}$	< 2	99	0	100	13
	2 - 10	1	1	0	87
	> 10	0	99	0	0
Mg, $\text{cmol}_c\ \text{kg}^{-1}$	< 2	99	0	100	50
	2 - 10	1	49	0	50
	> 10	0	51	0	0

Diagnosing N deficiency was not as straight forward as acidity and P diagnoses which were based on soil tests calibrated against soil critical levels. According to the NuMaSS algorithm, we estimated N uptake by an N-unfertilized crop as the native N uptake. A deficiency was diagnosed when estimated native N uptake was lower than the N uptake required to achieve the target yield. The native N uptake estimated both in Ilagan and Arakan ranged only from 20 to 30 kg N ha^{-1}, hardly sufficient for 1 t ha^{-1} of upland rice yield and 1.5 t ha^{-1} of corn yield. Given this low yield level, the NuMaSS estimation of N fertilizer requirement would be heavily influenced by the selected target yields unlike estimates of P and lime, which are independent of target yields. Given the low native N levels, we used an average native N estimate across all farms to calculate the N requirement. Further, since there is no provision in NuMaSS to vary target yields between farms within the same general location, target yields were assumed to be same across farms. Based on these assumptions, N deficiency was diagnosed in all farms across Arakan and Ilagan for upland rice or corn.

NuMaSS diagnoses and observed responses for the various crops and sites are summarized in Tables 63 through 66. Given that there were no replications for observed responses in each farm, a minimum 500 kg ha^{-1} increase in grain yield of upland rice and 1 t ha^{-1} increase in grain yield of corn in the NuMaSS treatment compared to the check treatment of zero input was recorded as a positive response. Note that while diagnoses were done for individual nutrient constraints, responses were measured for the combined application of the deficient nutrients. Kappa statistics were calculated to determine the agreement between the diagnoses and field observed responses. A Kappa value of 1 indicates that diagnoses and field observed responses always matched. A Kappa value of 0 indicates that there were an equal number of correct and incorrect diagnoses. The Kappa values for the various crops and sites varied from 0.85 to 1 indicating high accuracy in NuMaSS diagnoses, i.e., there was almost always an agreement between responses to combined application of N, P and lime when any one or all of them were diagnosed to be deficient.

Table 63. Assessing the accuracy of diagnosis, upland rice, Ilagan, Isabela, Philippines, 1999.

Diagnosis		**Input**	**Farm**												
			1	**3**	**9a**	**9b**	**12**	**13a**	**13b**	**22c**	**31**	**32**	**53**	**57**	**58**
Res-ponse		N	+	+	+	+	+	+	+	+	+	+	+	+	+
	Pred.	P	+	+	+	+	+	+	+	+	+	+	+	+	+
		Lime	+	+	-	-	+	-	-	-	+	+	+	+	+
	Obs.*	NPLime	+#	+	+	+	+	-#	-	+	+	+	+	+	+
			Kappa coefficient=0.85, n=13												

* Observed response is to any or all of the deficiencies diagnosed.

\# An increase in grain yield of at least 500 kg ha-1 in the NuMaSS treatment compared to the zero input control is arbitrarily set as a positive response.

Table 64. Assessing the accuracy of diagnosis, corn, Ilagan, Isabela, Philippines, 1999.

Diagnosis		**Input**	**Farm**														
			5	**9**	**16**	**17a**	**19**	**20a**	**22d**	**24b**	**27**	**28**	**29**	**30**	**41**	**47**	**51d**
Res-ponse		N	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Pred.	P	+	+	+	+	+	-	-	-	+	+	+	+	+	+	+
		Lime	+	+	+	+	+	-	-	-	-	+	+	-	+	+	-
	Obs.*	NPLime	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Kappa coefficient=1, n=15																	

* Observed response is to any or all of the deficiencies diagnosed.

\# An increase in grain yield of at least 500 kg ha-1 in the NuMaSS treatment compared to the zero input control is arbitrarily set as a positive response.

Table 65. Assessing the accuracy of diagnosis, corn, Ilagan, Isabela, Philippines, 2000.

Diagnosis		**Input**	**Farm**							
			3	**4**	**6**	**8b**	**9**	**16**	**21a**	**17**
Response		N	+	+	+	+	+	+	+	+
	Pred.	P	+	+	+	+	+	+	+	+
		Lime	-	-	-	-	-	-	-	-
	Obs. *	N+P+Lime	+	+	+	+	+	+	+	+
Kappa coefficient=1, n=8										

* Observed response is to any or all of the deficiencies diagnosed.

NuMaSS prediction and on-farm testing of prediction

Evaluation of upland rice response in acid upland soil, Ilagan, Isabela, 1999 wet season - The farmer practice in the Ilagan 1999 upland rice trail varied widely in NPK use ranging from 0 to 134 kg ha^{-1} N, 0-18 kg/ha P, and 0 to 35 kg ha^{-1} K and thus some farmers exceeding NPK rates in both regional and NuMaSS recommendations. Because of the observed wide variation in NPK rates across treatments, the NPK applications were grouped in increasing bands of amounts and were assigned new NPK treatment designations (Table 67).

The new data set with the new NPK level designations were then subjected to cluster analysis. The data clustered only with respect to N and indicated that K was not a significant factor influencing yield. N clusters were N1 = 9 to 40 kg ha^{-1} and N2 = 60 to 138 kg ha^{-1}. Analysis of variance using these two levels of N as treatments showed that yield was significantly different

Table 66. Assessing the accuracy of diagnosis, upland rice, Arakan Vallley, Philippines, 2000.

Farm	**Diagnosis**			**Observed response***
	N	**P**	**Lime**	
GI1	+	+	-	+[#]
GI2	+	+	-	+
GI3	+	+	-	+
GI5	+	+	-	+
GI7	+	+	-	+
GI 8	+	+	-	+
DN9	+	-	-	+
DN11	+	+	-	+
DN12	+	+	-	+
TC14	+	+	-	+
SS15	+	+	-	+
GB16	+	+	-	+
ES 18	+	+	-	+
SD19	+	+	-	+
JD20	+	+	-	+
RB21	+	+	-	+
JM22	+	+	-	+
Kappa coefficient=1, n=17				

Observed response is to any or all of the deficiencies diagnosed.

[#] An increase in grain yield of at least 500 kg ha-1 in the NuMaSS treatment compared to the zero input control is arbitrarily set as a positive response.

Table 67. Range of NPK applied to upland rice in on farm trials at Ilagan, Isabela, 1999.

Nutrient	**Range of amounts applied (kg ha^{-1})**			
	None	**Low**	**Medium**	**High**
N	0	9-40	60-90	120-138
P	0	4-12	17-29	36
K	0	8-23	35	60-100

between these two clusters (p-value=0.0001) and about 78% of the variation in yield was accounted for by these grouping of N levels (Table 68). Uptake of N, P and K were also significantly different between these N clusters.

Given that K was not identified as a significant factor in the 1999 Ilagan upland rice trial, an analysis of variance was performed with NuMass and NuMaSS+K data combined. NuMass and regional recommendation produced similar yield of 1.2 t ha^{-1}, which was significantly superior to farmer practice and control treatments (Table 69). Similar differences were observed for NPK uptake as well. Evaluation of corn response across acid upland and less acid river plain soils, Ilagan, Isabela, 1999&2000 - In 1999, analyses of variance indicated no significant yield differences between regional and NuMaSS recommendations but only NuMaSS was superior to farmer practice (Table 70). In 2000, there were no significant differences in yield among all treatments except the control receiving no inputs (Table 71).

Table 68. Grain yield and nutrient uptake by upland rice, 1999, Ilagan, Isabela, Philippines. Data analyzed after separating into two N clusters.

N cluster	**Grain Yield**	**N uptake**	**P uptake**	**K uptake**
		kg ha^{-1}		
9 – 40	633b*	40b	4.8b	40.4b
60 – 138	1160a	86a	9.3a	66.8a

* Values in columns with the same letters are not significantly different at 5% level by LSD.

Table 69. Grain yield and nutrient uptake by upland rice subjected to various nutrient inputs, 1999, Ilagan, Isabela, Philippines.

Treatments	**N**	**P**	**0 K**	**Lime**	**Grain yield**	**Nutrient Uptake**		
						N	**P**	**K**
	Inputs, kg ha^{-1}				**(t ha^{-1})**		**(kg ha^{-1})**	
Control	0	0	0	0	0.59c*	37.6c	4.2d	38.2c
Farmer practice	0-134	0-18	0-35	0	0.93b	58.3b	6.8c	53.8b
Regional recommendation	90	9	18	0	1.21a	84.4a	8.8b	61.1ab
NuMaSS and NuMass + K	132	0-36	60-100	0-2	1.21a	94.7a	10.5a	73.1a

* Values in columns with the same letters are not significantly different at 5% level by LSD.

Table 70. Grain yield of corn in response to nutrient inputs, 1999 wet season Ilagan, Isabela, Philippines.

Treatments	**N**	**P**	**K**	**Lime**	**Grain yield**
		kg ha $^{-1}$			**t ha^{-1}**
Control	0	0	0	0	1.25c
Farmer Practice	0-274	0-20	0-50	0	3.86b
Regional	134	18	35	0	4.82ab
NuMass	210	0-60	60	0-2	4.95a

* Values in columns with the same letters are not significantly different at 5% level by LSD.

Table 71. Grain yield of corn in response to nutrient inputs, 2000 wet season Ilagan, Isabella, Philippines.

Treatments	**Nutrients applied (kg ha^{-1})**			**Grain yield**
	N	**P**	**K**	**(t ha^{-1})**
Control	0	0	0	1.36b
Farmer practice	90-120	12-25	12-23	2.52a
Regional	134	18	35	2.90a
NuMaSS + regional K	225	30-51	35	3.13a
NuMaSS + high K	225	30-51	80	3.10a

* Values in columns with the same letters are not significantly different at 5% level by LSD.

Evaluation of upland rice response in less acid upland soils, Arakan Valley, 2000 - Analysis of variance of grain yield data showed very large CV and low R^2 with no model significance. This was attributed to the fact that N applied under farmer practice varied widely, overlapping with N levels in the regional and NuMaSS treatments. The CV was significantly reduced (20%) and R^2 improved to 91% when the farmer practice N levels were grouped into 16 to 45, 90 and 113 to 180 kg ha^{-1} and re-analyzed. The results indicated that grain yield under NuMaSS (with regional or high K), regional recommendation and farmer practice with 90 kg N ha^{-1} were similar but significantly higher than the control and farmer practice of low and high N (Table 72). It should be noted that farmer practice did not include any K application and except under low N, no P application as well.

Table 72. Grain yield of upland in response to nutrient inputs, 2000 wet season Arakan Valley, Philippines.

Treatment	**Nutrients applied (kg ha^{-1})**			**Grain yield (kg ha^{-1})**
	N	**P**	**K**	
Control	0	0	0	0.99c
Farmer practice				
High N	113-180	0	0	1.34c
Medium N	90	0	0	1.77b
Low N	16-45	0-22	0	1.20c
Regional	90	26	25	2.07ab
NuMaSS + regional K	132	0-12	25	2.20a
NuMaSS + high K	132	0-12	67	2.05ab

[*] Values in columns with the same letters are not significantly different at 5% level by LSD.

Discussion - The on-farm trials collectively indicated that there is a high degree of accuracy in diagnosing constraints of N, P and acidity by NuMaSS. However, the yields achieved for both upland rice and corn were substantially lower than the target yields for which NuMaSS diagnoses and recommendations were made. In general, NuMaSS recommendations resulted in similar yields as the regional recommendation both at the more acid upland site in Ilagan, Isabela and at the less acid site in Arakan Valley and for both upland rice and corn crops. Thus, NuMaSS performed as well as the regional recommendation. But it should be noted that K, which is routinely included in the regional recommendation, is not currently addressed in NuMaSS. It should be also noted that there were instances where farmer practice yielded the same as the regional and NuMaSS recommendations and often with no P and K and never any lime applied. A cluster analyses on 1999 upland rice yield in Ilagan indicated that there was a yield response to N but not to P, K or lime. The overall results confirm N but not P, K or acidity as a limitation to yield of upland rice and corn. It cannot be concluded, however, that P, K or acidity was not limiting yields since the response to NuMaSS recommendation was observed collectively for N, P and lime. For example, George et al. (2001) demonstrated upland rice response to P application as increased P uptake in traditional varieties (increase in straw biomass) and as increased grain yield in improved varieties when constraints other than P were generally absent. In the present trials, it is likely that the soil P and K supplies were sufficient to support the relatively low yields achieved.

We could conclude from our results that NuMaSS performs as well as the regional recommendation in the initial years but it cannot be ascertained whether there would be savings in the long-term NuMaSS was followed given the expected reductions in future applications of lime and P because of residual effects. Economic assessment and long term performance of NuMaSS could be evaluated only by accounting for residual effects of P and lime inputs. Although cooperators were approached for repeat trials on the same plots, very few farmers repeated their crops in the succeeding year for various reasons, including lack of timely rainfall and fallowing the land.

Another important observation is that although NuMaSS target yields were reasonable for the regions, none of the trials produced such yields. This is particularly true for N diagnosis and recommendation for corn. The target yield of 6 t ha^{-1} used in the on-farm testing is indeed possible with hybrid corn as was demonstrated in the core experiments. But none of the farmer fields produced 6 t ha^{-1} while a N application regimen targeting 6 t ha^{-1} was employed. There are several reasons for this. The target yield was based on the assumption in NuMaSS that all factors other than N, P and acidity are not limiting yield, which in fact is not true. Unlike alleviation of acidity and P deficiency, N uptake is demand-driven and only by matching the actual demand that N fertilization can be optimized. In the current implementation of NuMaSS, soil N uptake is determined by N uptake of the unfertilized check. There could be two estimates based on this assumption alone, i.e., an N uptake when no other fertilizers are applied and N uptake when only N fertilizer was not applied but others were applied. These two estimates would vary substantially, given that in the absence of other nutrient limitations all of the initial and in-season mineralized N would be taken up by the crop. There is currently no provision in NuMaSS to account for initial as well as in-season mineralization of soil N. Further, since N uptake is demand driven, crop response to rainfall and other growth factors would strongly impact the utilization of the applied N. Thus, the fertilizer N amount estimated at the beginning for a potential target yield may no longer be applicable to the crop. Recommendations to vary or split N application or withhold N depending on in-season crop status are currently not options in NuMaSS.

Our results suggest the need to improve NuMaSS to better able to define realistic target yields and then matching input recommendations for those yield goals rather than solely basing them on soil nutrient levels. Achieving target yields may require considerations of other limiting factors such as yield potential of genotype and time of planting in relation to drought events. Although many farmers still use low yielding traditional varieties, NuMaSS would still make lime and P recommendations regardless of the expected low yields of those varieties. Although the economic analysis carried out in the economic module would indicate that such applications would be uneconomical, it is probably better that such recommendations are not made in the first place.

As discussed elsewhere, NuMaSS does not predict yields; rather it only attempts to quantify yield increases when nutrient constraints are removed for the purpose of economic analysis. Therefore, it would be only logical that NuMaSS is not used when there is no expectation of a yield increase from N, P or lime application. Further, potassium should be included in NuMaSS because this nutrient is sometimes deficient and is usually present in commercially available mixed fertilizers. Land slope should perhaps be included in the diagnosis step to identify lands prone to serious erosion should they be cultivated. The goal should be that NuMaSS is not unnecessarily relied upon in situations where it can be already determined that applications of N, P and lime would not change the yield outcome.

It is also necessary to improve upon the methodology used for on-farm evaluation of NuMaSS. The treatment combinations we used did not permit testing whether there were responses to individual nutrient constraints such as N, P, or acidity. In order to test the success of diagnoses of such individual constraints, additional NuMaSS minus-one treatments may be considered in on-farm evaluation of NuMaSS. Thus, NuMaSS - N, NuMaSS - P and NuMaSS - lime treatments are recommended. A significant response to NuMaSS treatment compared to NuMaSS – N treatment would confirm a diagnosis of N deficiency. We also suggest that two or more replications of treatments be installed on each farm. This would allow testing of responses on a per farm basis in addition to across all farms.

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Travel and Meetings Attended

- Adrian Ares, Lloyd Hossner, Deanna Osmond, Frank Smith and Jot Smyth - travel to Costa Rica, January 6-12, 2002 for the Latin American Regional Workshop on NuMaSS; during this trip technical backstopping support was provided to ongoing field and greenhouse trials.
- Frank Smith - travel to Costa Rica, June 1-9, 2001 for the fifth year project impact assessment survey.
- Frank Hons and Frank Smith - travel to Mali, April 17-22, 2001 to initiate farmer surveys and assist collaborators in interpretation of results.
- Fred Cox - travel to Costa Rica, April 17-22, 2001 to assist collaborators in the completion of the greenhouse P study.
- J. Lasquite traveled to Mindanao in support of the on-farm studies taking place there in two sites.

- ML Aragon, traveled to Honolulu, Hawaii, USA on February 5, 2002 to attend the annual reporting and planning meeting of the SM-CRSP project.
- MC Casimero, traveled to Atlanta , Georgia, USA on 17-22 April 2002 to attend the first meeting of project scientists for the SM-CRSP Phase 2.
- MC Casimero, traveled to Washington DC, USA to attend the impact assessment workshop for CRSP projects of the USAID.

Relevant Publications, Reports and Presentations at Meetings

Alvarado, A., Boniche, J., Alpizar, D., Smyth, J., Yost, R., Osmond, D., Ares, A. (2003) Field testing the diagnosis of nitrogen and phosphorus constraints by NuMaSS for peach palm in Andisols and Ultisols of Costa Rica. Manuscript for the Guide on Decision Support Systems for Integrated Nutrient Management, IFDC-Togo (in review).

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