SOIL MANAGEMENT COLLABORATIVE RESEARCH SUPPORT PROGRAM

PROJECT YEAR 8
ANNUAL PROGRESS REPORT

Cornell University
Montana State University
North Carolina State University
University of Florida
University of Hawaii

2004-2005

Soil Management C◆R◆S◆P

USAID
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EXECUTIVE SUMMARY

It is worth recalling the three purposes of research and upon which of the three the Soil Management CRSP focuses its efforts. The three purposes of research are, first to understand natural processes, second to use this understanding of how nature functions to make predictions, and third to enable others to apply science-based predictions to control outcomes of managed systems. In short, the three purposes of research are to understand, predict and control. The Soil Management CRSP focuses on the third purpose of research, which is to enable our customers to use science-based predictions to control outcomes in managed systems.

Working together with US and host-country institutions, SM CRSP enables developing country decision makers ranging from farmers to policy makers to apply science-based predictions to control and manage soils resources in an economically and environmentally sustainable manner. Centuries of carbon and nutrient mining of soils by subsistence farming now prevent profitable and sustainable agriculture in many regions of the world. Nutrients can be replaced with chemical fertilizers, but expensive chemicals are easily leached from the soil with the first rains, leaving farmers with unpaid debt instead of a bountiful supply of grain. Soil organic carbon is the sponge that absorbs and retains water and nutrients in the soils for plants to use. Agriculture cannot be the engine for economic growth if the engine is broken. The Soil Management CRSP is using science-based diagnosis and prescriptions to repair the broken engine. This report is about the Soil Management CRSP's global efforts on carbon sequestration and nutrient management related to reversing centuries of carbon and nutrient mining of soil so that profitable and sustainable farming can begin where it has not been physically possible before.

Nations vary in their institutional capability to adopt and apply new, knowledge-based tools in the competitive global marketplace. They vary in institutional readiness from countries like Thailand that are able to refine knowledge-based tool to suit local preferences and scale up their use from villages to provinces and regional scales, to countries like Angola and East Timor that are still recovering from recently ended civil strife. But in every case, the advantage of adopting science-based predictions over traditional trial-and-error adaptive research is so great that the desire to change is evident.

For change to occur, the knowledge-based tools must be written in language users can understand. The Soil Management CRSP researchers' proficiency in Spanish, French and Portuguese has made it possible to conduct workshops in these languages and to develop knowledge-based software in these important languages including Tagalog and Tetun (East Timorese).

A small but key part of the Soil Management CRSP is centered on biotechnology. The impact of genetically modified crops on food safety and the environment is being hotly debated. The Soil Management CRSP is looking into the effect of genes added to crops to combat pests on beneficial soil organisms that live symbiotically with crops in the rhizosphere. The results so far indicate that no detrimental effects on soil organisms occurred and the work initiated by the CRSP is now being expanded by industry.

Lastly, the Soil Management CRSP provides field support to USAID Missions. Two former Portuguese colonies, Angola and East Timor, still recovering from the devastating aftermath of warfare, have been served in this way. In East Timor, for example, the SM CRSP was able to involve a small U.S. business firm to establish a candlenut oil extracting plant to add value to a common forest product to create new jobs and income in rural communities (districts of Baucau and Los Palos). The U.S. firm derives benefits by selling the candlenut oil to the cosmetic industry in the international marketplace. In the end, the goal is to enable all CRSP activities to benefit the U.S. as much as they benefit our host-country collaborators.

PROGRAM AREA PROGRESS REPORTS

Global Plan, Objectives and Program Areas

The global plan of the Soil Management CRSP is directed toward achieving food security in regions of the world where hunger and poverty are highest and enabling its clients to do so without compromising the sustainability of agro-environments. The plan gives priority to the food insecure regions of Africa, Asia, and Latin America where most of the 700 million food-insecure people live.

The three objectives of the Soil Management CRSP contribute to the on-going international effort to reduce food insecurity by focusing on the following:

1. Enable developing country institutions to apply information technology and knowledge-based tools to increase agricultural productivity.

2. Enable developing country institutions to scale-up technology adoption from local to regional scales by farmers.

3. Strengthen human and institutional capacity to combat poverty, land degradation and food insecurity.

To achieve these objectives, the Soil Management CRSP will focus on five program areas plus a sixth to respond to requests from USAID missions globally. Each of the program areas, projects and countries involved, principal investigators and host country institutions are listed in the following Table 1.

Table 1. List of participating U.S. universities with project title, principal investigators, collaborating countries and participating institutions.

Project Title	Countries	Principal Investigators	Participating Institutions
Program Area 1. Nutrient Management Support System			
Testing, Comparing and Adapting NuMaSS: The Nutrient Management Support System	Mali, Senegal, Ghana, Mozambique, Thailand, Philippines, Angola	Russell Yost, Tasnee Attanaadana, Madonna Cusimero	University of Hawaii Kasetsart University Philippine Rice Research Institute
Adoption of the Nutrient Management Support (NuMaSS) Software Throughout Latin America	Honduras, Ecuador, Brazil, Panama	T. Jot Smyth and Deanna L. Osmond	North Carolina State University
Program Area 2. Trade-Off Analysis			
Trade-Off Analysis Project Phase 2: Scaling Up and Technology Transfer to Address Poverty, Food Security and Sustainability of the Agro-Environment	Kenya, Senegal, Peru, Equador	John M. Antle	Montana State University
Program Area 3. Rice–Wheat Systems			
Enhancing Technology University Adoption for the Rice-Wheat Cropping System of the Indo-Gangetic Plains	Nepal, Bangladesh	John Duxbury and Julie Lauren	Cornell University
Program Area 4. Carbon Sequestration			
Measuring and Assessing Soil Carbon Sequestration by Agricultural Systems in Developing Countries	Ghana, Mali, Senegal, The Gambia, Cabo Verde, Nepal, Bangladesh	Russell Yost, James Jones, John Duxbury, and Julie G. Lauren	University of Hawaii University of Florida Cornell University Cornell University
Program Area 5. Biotechnology			
Assessing the Effects of Bt Crops And Insecticides on Arbuscular Mycorrhizal Fungi and Plant Residue Carbon Turnover and Fate in Soil	United States, China, Colombia	Medha Devare, Janice Thies, John Duxbury	Cornell University Cornell University Cornell University
Genetic Characterization of Adaptive Root Traits in the Common Bean, *Phaseolus vulagris*	United States	C. Eduardo Vallejos and James W. Jones	University of Florida University of Florida
Program Area 6. Field Support to Missions			
Timor-Leste Agricultural Rehabilitation, Economic Growth and Natural Resource Management	Timor-Leste	Goro Uehara and Harold McArthur	University of Hawaii University of Hawaii
Improving Maize Productivity in the Planalto Area of Angola	Angola	Russell Yost	University of Hawaii

NUTRIENT MANAGEMENT SUPPORT SYSTEM (NuMASS)

Project: Testing, Comparing and Adapting NuMaSS: The Nutrient Management Support System

Principal Investigator: Russell Yost, University of Hawai`i at Manoa

Introduction to Southeast Asia and Africa Activities

In the *Philippines,* in PY7, implementation was devoted to further testing and adapting the recommendations prescribed by NuMaSS (Nutrient Management Support System) in farmers' fields. Results of post-harvest soil analysis indicate an improvement in the soil chemical properties in the farms after two cropping seasons on plots receiving fertilizer at rates generated with NuMaSS Soil pH increased at all sites. The soil organic carbon, phosphorus and ECEC likewise increased. In many sites, the soil P increased to the optimum level required for favorable corn growth. The aluminum saturation and exchangeable aluminum decreased and is now within the critical limit. With the continuous application of NuMaSS generated fertilizer management, more improvements can be seen in the soil chemical properties in the initial sites used for on-farm testing.

The response of upland rice to NuMaSS was positive in South Cotabato. Inclement climatic conditions in North Cotabato prevented implementation of field testing. Drought at rice heading stage in North Cotabato resulted in crop failure. The target yield of 2 t/ha was attained in South Cotabato. Grain yield of upland rice in the plots using NuMaSS recommended rates increased by more than 1.3 t/ha and 0.6 t/ha compared to yields of the control and the regional recommendation, respectively (Table 2).

Table 2. Grain yield of upland rice as affected by the various application rates of fertilizer, South Cotabato, WS 2004.

Treatment	Fertilizer Applied (kg/ha)				Grain Yield (t/ha)
	N	P	K	Lime (t/ha)	
Control	0	0	0	0	2.0 b
FP	60	14	14	0	3.2 ab
RR	60	30	30	0	2.9 ab
NuMaSS	81	0	29	0	3.2 a

At Isabela and South Cotabato, recommendations with NuMaSS increased corn grain yield by the more than 5 t/ha. Yields obtained from the plots using NuMaSS recommended treatments were significantly higher than the farmers' practice and the regional recommendation. In Isabela province, the yield increase of the NuMaSS fertilized plots was 2 t/ha and 3 t/ha over the regional recommendation and the farmers' practice, respectively. A similar trend was observed in South Cotabato. In North Cotabato, the target yield of 5 t/ha was also attained in the plots using NuMaSS recommended treatments. Though the corn grain yield obtained in Leyte province did not reach the same level as those in Luzon (Isabela) and Mindanao (South and North Cotabato), NuMaSS treatments produced significantly higher yields than the regional recommendation and farmers' practice. During the second year, yields obtained in all farms used in the trial in Leyte were better compared to the first year which may indicate that with NuMaSS recommendations the soil properties in the site have improved.

The economic dominance analysis showed that:
- NuMaSS provided the best fertilizer management option for farmers growing corn in Isabela and South Cotabato.
- Yield increments for rice in North Cotabato and Leyte were not as high as those in Isabela and South Cotabato. Though higher yields were obtained with NuMaSS recommendations, the high cost of fertilizer and lime in this treatment reduced the net return. Hence, in North Cotabato, the better option was the regional recommendation.
- In South Cotabato, the control treatment was more profitable for rice farmers than the regional recommendation, farmer's practice and NuMaSS recommendations.
- In Leyte, NuMaSS provided the most profitable fertilizer management for peanut.

With the increasing cost of fertilizer in the Philippines, alternative sources of fertilizer such as those from farm wastes and by-products need to be explored to reduce dependence of farmers on chemical or inorganic fertilizer, the primary source of fertilizer in the NuMaSS.

A regional workshop was conducted in January 2005 to review the progress in implementing the PY7 workplans and plan for the linking of NuMaSS to other available nutrient management tools like the leaf color chart, soil test kit (STK) and the Minus One Element Technique (MOET). During the workshop, plans were also made to simplify the identification of the Philippine upland soil series to help farmers diagnose soil nutrient deficiencies and to see if this can be linked with the STK. This would then become a simple tool for farmers to diagnose as well as generate fertilizer recommendation for their crops planted in the uplands.

In *Thailand,* a graduate research program was initiated at Kasetsart University in Bangkok, to have a researcher from the Lao National Agriculture and Forestry Research Institute complete a Ph.D. dissertation under the supervision of Prof. Tasnee Attanandana of Kasetsart University and R. Yost of the University of Hawaii. The objective of the research study is to determine the causes for the consistent over prediction of N requirements reported by NuMaSS and DSSAT Nitrogen modules in the previous two years. Initial results of the thesis study indicate more soil N is mineralized than expected. However this factor alone does not explain the discrepancy. A new method of estimating N requirements will be tested in the thesis program—one that doesn't depend so heavily on precise soil measurements of N content and eventual mineralization. Also in progress are two other dissertation projects. One is the completion of a Thailand Research Fund (TRF) supported investigation into predicting rock phosphate requirements in acid sulfate soils. The other, just beginning, is predicting fertilizer potassium requirements using algorithms of the type already found in PDSS. A TRF-funded doctoral student at Kasetsart University is completing the field-testing of a potassium algorithm developed in Thailand last year. That algorithm has been incorporated into the PDSS software and is being field-tested in both Thailand and Mali.

In *Laos*, the initial results of NuMaSS and PDSS (Phosphorus Decision Support System) application at three sites enabled us to evaluate the effect of predicted fertilizer rates for N, P and K. In fine sandy soils at Phon-ngam, there was no response to either inorganic or commercial organic fertilizer. Experimental treatments didn't seem to respond to added COF, but did respond to potassium and did increase soil organic matter content. Soil data analysis after crop harvest showed no increase of nutrients. Nutrients applied in the undulating area of fine sandy soil may have been lost by leaching and run off under the high rainfall.

Testing of various fertilizer recommendation methods in farmers' fields indicated that maize yields associated with NuMaSS treatments increased over those using the farmers' or the state's recommendations. These increased yields could serve as an indicator of the potential of crop production of the upland soil with appropriate fertilizer inputs and crop management.

In *Senegal*, the introduction of the NuMaSS software and approach followed the discussions and directions set in the 2003 Bambey workshop in which consultant Mandy Haggith, Scotland, and Dr. Abou Berthe, Mali, provided some very cogent advice regarding the introduction of decision-aids. Contrary to all other locations, we decided to first conduct a diagnosis of location specific nutrient management needs and conditions. This was carried out with a survey conducted by Dr. Mamadou Ndiaye, ISRA, Bambey. The results of this survey indicated that reported yields of crops planted were a fraction of the generally accepted national averages (millet 450 kg/ha, maize 700 kg/ha, sorghum 225 kg/ha, peanut 450 kg/ha) and the virtual absence of fertilizer applications. Such incredibly low yields are indicators of the severe limitations to productivity in the region. A soil test kit workshop was carried out at the CERAAS (Centre 'Etude Régional pour amélioration de l'adaptation à la secheresse) station in Thies, Sénégal. Among the participating organizations was the ANCAR (Agence Nationale de Conseil Agricole et Rurale). This organization provides an extension function and is comprised of young agents. These agents were extremely enthusiastic about the possibility of having diagnostic tools such as a soil test kit that they could use to accomplish their mission to provide technical assistance to the growers and producers. They also were very enthusiastic about the NuMaSS software, and although it was in English, they could understand the purpose and potential of it. The NuMaSS and PDSS software has been reviewed by Dr. Mamadou Ndiaye who has made a number of suggestions for improvement, most of which are needed in order to adapt the software to West African conditions, especially crops and varieties. Dr. Ndiaye is currently reviewing the initial translation of PDSS into French.

Field studies have been carried out that confirm the greenhouse identification of severe potassium and sulfur deficiencies in the peanut cropping systems in Southern Senegal. Nitrogen and phosphorus deficiencies have been well known in the region for years. ISRA and CERAAS scientists, through SM CRSP assistance, have identified and confirmed these deficiencies.

In *Mali*, the majority of the activities under NuMaSS take place in the form of support for a graduate assistantship for Ms. Aminata Sidibe-Diarra. Ms Sidibe-Diarra has developed a prediction model to estimate the amounts of locally mined rock phosphate necessary to apply in soils of Mali to remove the pervasive deficiency in nutrient phosphorus. This model is one of the first to make quantitative predictions based on many factors involved in the complex decision. The model was field-tested for the first time in the 2004-2005 cropping season in Mali. Test results of model outputs are very promising; however, further research and analysis are required to address a substantial over-prediction of the amounts of rock phosphate to apply. It is interesting to note that the field testing of the algorithm on acid sulfate soils in Thailand also suggest an over prediction. Current testing will repeat the experiment from last year, add another, and begin testing in Senegal using three rock phosphates ranging from very low to high solubility. The results will permit testing whether the algorithm predicts adequately in both varying soils and rock phosphates. Doctoral students from Mali and Thailand collaborated on the development of the model. Both ladies have published their research and are now field-testing the models.

Preliminary testing of the K algorithm developed in Thailand is being tested by IER scientists in Mali and will continue in the 2005-06 season. Beta testing of the K algorithm will likely take place later on in South America. A Malian scientist will be working in the US to analyze his data and intensively learn English for a graduate program at UH. Two Malians scientists have contributed substantially to the French translation of the PDSS software.

In *Angola*, a one year field support activity included a workshop in February 2005 to provide further training and experience with the NuMaSS and PDSS decision-aids. That workshop comprised training in farmer-to-farmer visits, presented by Ms. Isaurinda Baptista, Cabo Verde, and statistical analysis of ProPlanalto experiments, presented by Ms. Zelia Menete, Cornell University and Eduardo Mondlane University, Mozambique. Over 200 farmers participated in the visits to the ProPlanalto project locations and World Vision experiments and outreach programs. While the farmer-to-farmer visits and the data analysis workshops helped meet ProPlanalto project objectives of extending the experimental results of the ProPlanalto project to producers of the region, the data analysis workshop was part of the ProPlanalto project objectives to improve capacity building of the Faculty of Agricultural Science at the Universidade de Agostinho Neto, Huambo. Additionally, a laboratory consultant was identified, with World Vision support, to jumpstart the soil, plant and water analysis laboratory at the Chiangas Experimental station. Laboratory apparatus such as Kjeldahl distillation apparatus, hotplate, visible range spectrophotometer and Mg atomic absorption lamps were provided to encourage and enable the laboratory to move forward. Some $15,000 of additional chemicals was purchased by World Vision to further assist the operation of the laboratory.

The statistical and economic analyses of two years' results were the objective of a concluding visit in May 2005. The results indicated that potato production was highly profitable with current prices, but not maize production. We anticipate that prices of fertilizers will likely decrease as the transportation options from the coastal port improve and prices of produce may increase also as transportation options improve.

A collaborative proposal, which included the Centro des Estudos Pedologicas de Lisboa and the University of Hawaii, in collaboration with IIA (Instituto de Investigações Agronómica) and the Faculdaded de Ciencias Agrárias (FCA)–Universidaded de Agostinho Neto, was written and submitted to the Luso-Americana Foundation to support post-graduate study of two faculty members of the Universidade in Huambo, which would be under the joint supervision of faculty from CEP, Lisboa, and the University of Hawaii.

In *Mozambique*, SM CRSP project activities were initiated last year with a soil test kit workshop. This workshop comprised some 35 participants and included some 10 NGOs with extensive programs in the country. The SM CRSP also partnered with the INTSORMIL CRSP to enable Ricardo Maria, IIAM (Instituto de Investigação Agrária de Mozambique) to complete an MS level graduate program at the

University of Hawaii. Mr. Maria's thesis was almost entirely supported by INTSORMIL and USAID/Maputo. This thesis program was completed in Dec. 2004 and Mr. Maria returned to Mozambique in December. His thesis results indicated that there are some regions with relatively acid soil conditions likely requiring either alternative crops or the application of liming materials—especially for cotton, an important crop in many regions. The soils were only moderately weathered with few cases of extreme P sorption and deficient levels of Ca and Mg. Fortunately, it seems that K is not a generally limiting nutrient—probably due to the presence of micaceous minerals that were identified in the soils for perhaps the first time. The likelihood of zinc deficiencies appears substantial in specific sites. These results pointed out the need for soil analysis capability for both the cations and micronutrients. Discussions with INTSORMIL raised the possibility of purchasing an atomic absorption unit for IIAM and this is in progress. IIAM scientists are assisting in the testing of the Portuguese version of the PDSS software. Mr. Antonio Querido from Cabo Verde did the initial translation of this software.

Objective 1: Test and Compare NuMaSS Predictions on Nutrient Diagnosis and Recommendations with Existing Soil Nutrient Management

Southeast Asia

Philippines

The on-farm trial was set up in upland areas where rice and corn were commonly grown on the three large islands of Luzon, Visayas and Mindanao during the 2003-2004 dry season and 2004 wet season. In Luzon, 11 farms were located in three villages in San Antonio, Morado and Sta. Victoria, Ilagan, Isabela. In the Visayas, the on-farm trial was set up in the same farms in Matalom, Leyte. The on-farm trial was established in seven farms in two provinces, South Cotabato and North Cotabato in Mindanao. Upland rice was planted in North Cotabato and South Cotabato during the WS and corn was planted in the dry season (DS). In Luzon, corn was planted during the 2004 wet season (WS) while no planting was done in the dry season (DS) because of drought conditions. In the Visayas, corn was planted in both seasons.

Prior to the establishment of the on-farm trial, a meeting with the collaborators in various government agencies and farmer cooperators was held to discuss the results of the previous cropping season and plans for the next season. Farmers' feedback about the trial were likewise gathered and considered as inputs in formulating plans for the following season.

Whenever possible, field days were conducted before harvesting the crops. The field days served as a venue for more farmers to be informed and learn about the project. Farmer cooperators served as resource persons and explained to other farmers what was done in the trial and how the different treatments performed based on their personal assessments. An open forum followed where other farmers in the village and the nearby villages ask questions and expressed their impressions about the project.

Soil Sample Collection and Analysis

Soil samples were collected separately from each plot one month before the cropping season for new sites. In old farms where the on-farm had been established in 2003, the soil analysis after the wet season of 2003 served as the basis for generating the new NuMaSS recommendation for the succeeding cropping season. Samples were analyzed for N (Walkley-Black), P (using Bray #2 and also Olsen P methods), pH (1:1 H_2O), exchangeable acid and aluminum, and exchangeable bases (K, Ca and Mg).

Treatments

The treatments used in the on-farm trial in Luzon and Visayas were the following: T1—control; T2—farmer's practice; T3—regional recommendation; T4—NuMaSS recommendation; T5—NuMaSS-N; T6—NuMaSS–P and T7—NuMaSS-lime. In Mindanao, only five treatments were used; T5 and T7 were not included because in the soil analysis, farms had high organic carbon and normal pH especially, in South Cotabato. For T4, the specific amount of chemical fertilizer and lime applied varied across farmers depending on the soil analysis and recommendations generated by NuMaSS. The farmers' practice used in the trial is the prevailing fertilizer application rate agreed upon by the farmers during the consultation meeting. The regional recommendation was that obtained from the local agriculture office.

Soil Properties

After two cropping seasons in Ilagan, there was an improvement in the soil chemical properties with the application of NuMaSS generated fertilizer management. Similar results were observed in both Visayas and Mindanao.

Rice

Rice was planted in two sites in Mindanao during 2004 WS. The on-farm experiment had five treatments as follows: T1—control; T2—farmer's practice (FP); T3—regional recommendation (RR); T4—NuMaSS recommendation; and T5 —NuMaSS-P. Higher yields were obtained in the NuMaSS treatment across farms. The grain yield in NuMaSS plots was higher by more than 1.3 t/ha and 0.6 t/ha compared to the control and RR, respectively. Drought prevailed at the heading stage of rice in North Cotabato, thus no yield was obtained in the on-farm trial.

Corn

Wet season. Corn was planted in each site during the wet season in Isabela and Leyte provinces 2004. In Isabela province, N and P rates with NuMaSS resulted in significantly higher yield than the rest of the treatments in both old and new farms. From the old farms, the yield advantage in the NuMaSS plots was 2 t/ha and 3 t/ha in the RR and FP, respectively. On the new farms, the same trend was observed though the yield advantage in the NuMaSS was 1.5 t/ha from RR and 2 t/ha from FP. The target yield of 5 t/ha was attained in the NuMaSS plots indicating an excellent predicting capability of NuMaSS for this site. Apparently, the N, P and lime modules accurately predicted the N, P and lime requirements as indicated by the significant reduction in grain yield when N, P and lime were removed from the NuMaSS recommendation.

Analysis of the yield parameters showed that the biomass yield in the NuMaSS plots was significantly higher than RR and FP in both old and new farms. Bigger and heavier corn ears were likewise harvested from the NuMaSS applied plots. The positive response of these parameters resulted in significantly higher yield obtained in NuMaSS plots. Ear length and 1000 grain weight obtained in NuMaSS plots were comparable with those of the RR. Phosphorus is a very limiting element for corn in Isabela as indicated by the significant reduction in biomass, ear length, fresh weight of ears and 1000 grain weight which subsequently resulted in lower grain yield. Highly variable yields were obtained across farms in Leyte province during the 2004 WS. The target corn yield of 5 t/ha was attained in only one of the four farms. The average yield obtained in NuMaSS plots was 4.2 t/ha, not significantly different from those obtained in plots applied with NuMaSS-N and regional recommendations. Removal of N from the NuMaSS recommendation did not result in drastic reduction of corn yield. However, the removal of P resulted in a low yield (0.95 t/ha) that was comparable to those obtained in control plots. In South Cotabato province, plots applied with the NuMaSS predicted fertilizer recommendation had higher yield (7.2 t ha) than the regional recommendation (6.51 t/ha), farmers' practice (5.70 t/ha) and control (2.31 t/ha).

Corn yield in the NuMaSS plots matched the target yield of 5 t/ha in North Cotabato. The highest yield was obtained in NuMaSS fertilized plots (5.6 t/ha), similar to that of the RR. Both the FP and control had very low yields. As observed in South Cotabato province, the yield in NuMaSS-P was slightly lower than the NuMaSS recommendation but still within the target yield of 5 t/ha. These results suggest that NuMaSS can be a helpful tool for farmers to determine the proper amounts of fertilizer to apply for improved yields.

Dry season. Hybrid corn was also planted in DS 2004 in Leyte province. The target yield was not attained. It was noted, however, that NuMaSS recommended treatments resulted in the highest yield followed by NuMaSS-N, RR, FP, NuMaSS-P and control in decreasing order. The grain yield advantage of NuMaSS compared to RR is more than 1 t/ha. These results indicate that NuMaSS can substantially improve the yield of corn in the extremely adverse soil condition of Matalom, Leyte. Removing the P from the NuMaSS recommendation significantly affected growth and yield of corn.

Peanut

Peanut was planted in two farms in Leyte province during the 2004 WS. Results showed that the yield of peanut was highest in NuMaSS fertilized plots but comparable with those obtained in the RR, FP, NuMaSS-N, and NuMaSS-P. Yield in the control plot was significantly lower than all other treatments.

Economic Analysis

Rice. In South Cotabato fertilizer recommendations for rice from NuMaSS, FP and RR resulted in yield levels comparable to the control. Hence, when production costs are factored into the NuMaSS fertilizer recommendation, it is clearly not the preferred practice to increase household income.

Corn. Results obtained in the dominance analysis of different fertilizer treatments varied across sites. In Isabela and South Cotabato, the dominance analysis showed that NuMaSS was the best fertilizer treatment in terms of economic profitability compared to the RR, FP, NuMaSS-N, NuMaSS-P, NuMaSS-lime and control. Control was better than the rest of the fertilizer treatments in Leyte because of the zero fertilizer input cost. However, in the 2004 WS, NuMaSS minus lime emerged to be the dominant fertilizer treatment followed by the NuMaSS treatment, suggesting that lime constitutes a big bulk in the cost of fertilizer management in NuMaSS.

In favorable corn growing areas like Isabela and South Cotabato, adopting the NuMaSS generated fertilizer recommendation resulted in higher yields and profits. In Leyte and North Cotabato where grain yields are relatively lower compared to Isabela and South Cotabato provinces, the NuMaSS fertilizer recommendation may not be a profitable option as the increase in yield was not high enough to give a better profit than the regional recommendation for North Cotabato and the control for Leyte. Though high yields were obtained in the NuMaSS, the cost of fertilizer was very high, resulting in the poor comparative performance of NuMaSS in the dominance analysis. This result suggests that there is a need to look at the profitability of the NuMaSS recommendation and alternative options may have to be developed for farmers to generate higher profit from NuMaSS. To lower fertilizer costs, farmers should learn to use farm wastes like rice straw as organic fertilizer.

Peanut. Two farmers planted peanut during the wet season, results seem to be promising. NuMaSS treatment was most dominant among all fertilizer. No nitrogen was applied which reduced the cost of fertilizer in the NuMaSS treatments.

Laos

A major focus of the Thai program is the support of the Lao program wherein site-specific nutrient management with the use of test kits, decision-aids, and improved soil identification is taking place with the Lao National Agriculture and Forestry Institute participation and support.

At present maize and legume cultivation occurs only in the Xayabuli and Vientiane provinces, where the farmers lack of experience in upland soil improvement and nutrient management results in poor yields, food insecurity, economic hardship and increased soil degradation. These problems need to be specifically addressed and the appropriate technology transferred or developed to help farmers. This may involve changing from subsistence to production agriculture for sale and export. At present, fertilizer applications depend on the farmers' estimates, which has resulted in nutrient imbalance and unsustainable yield. NuMaSS and PDSS can be useful tools to diagnose soil constraints and to select the appropriate practices. Predictions from both were tested in the Dongdok (Vientiane), Vang-veun-phy (Kham-mouane) and Phon-ngam (Champasack) research stations and in on-farm trial involving Ban Hai farmers (Vientiane).

On-farm and Research Station Experiments

In order to test NuMaSS and PDSS knowledge base predictions under Lao environment condition, and to adapt NuMaSS and PDSS to address nutrient management issue of critical importance to Lao farmers, a study area was categorized into two main areas: research station and on-farm experiments. Experiments on the research station were carried out by researchers, and on-farm trials were cooperatively conducted by both farmers and researchers.

The experiments were conducted in four different upland fields and in three provinces. There were two experimental sites (on-station and on-farm trial) conducted in the Vientiane municipality. The third site was located in Khammouane province as being representative of the central region of Laos, and the fourth site was located in the southern part of the country in Champsack Province. The climate of the sites has been characterized as tropical monsoon wet and dry climate (FAO/UNESCO, 1979) and ustic soil moisture regime (A. Van Wambeke, 1985), which is distinguished by two distinctive seasons. The rainy season runs from May to October and the dry season from November to April. Total rainfall in the three study areas was not much different (about 1700 to 1900 mm per year). The maximum temperature in April was 41.50 C°, the minimum in January was 3.10 C° and the mean value was about 26 C°. The mean relative humidity was about 75 percent in with March havings the lowest humidity (67 percent) and August, the highest (85 percent).

Since soil data is the basis for fertilizer prediction for each treatment in every one of the experimental sites. Twenty to 24 samples were collected at each site, at a depth of 0-20 cm, before land preparation and after harvest. The distance between sampling points was 8 m; each point was a composite collection of three points. Except for soil samples in farmers' field, all were composite samples. All soil samples were sent to SSLCC laboratory for physical and chemical properties analysis. Soil samples collected from many points were used for soil data for nitrogen, phosphorus and potassium prediction using both NuMaSS and PDSS. Both software tools were used for observation of stored chemical properties of soil at each site. The Surfer 8 program, in conjunction with both NuMaSS and PDSS, was used to demonstrate variability of soil properties across the sites.

On-station Experiments

In the Vientiane municipality, the on-station experiment was located in Ban Nong-Viengkham, Xaythani district, approximately 12 kms north of central Vientiane municipality. On-farm trial sites were located in Ban Hai, Xaythani district, about 28 km north of Vientiane City, near Nam-ngum River. In previous years, farmers cultivated maize and some vegetables in these areas.

In Khammouane province, the experiment was conducted in the agricultural research station, 55 km south of the centre of province. The landform was gentle sloping (2-5 percent) and the elevation was about 140 meter above sea level. Ground water was less than 2 m deep in the wet season and runoff was very slow. The soil group was *Ultisols (USDA)/ Acrisols (FAO)* with a soil depth of more then 100 cm. For the last five years this area was covered by forest and in previous years, the land was cash crop cultivated. During the soil sampling the areas were covered by legumes and grasses.

The experiment in Champasack province was conducted at the field of Phon-ngam rice research station. The land area was planted to sugar cane during the last 10 years. The soil group is *Ultisols/ Aerisols*, with a soil depth of more than 100 cm.

Soils at the Khammouane and Phon-ngam sites are both sandy textured with very low nutrient contents. The Phon-ngam site is strongly acidic, while the Khammouane site has low to medium levels of phosphorus and potassium.

The experiments were set up as a Randomized Complete Block Design (RCBD) for all sites, with four replications. All of the experimental sites were blocked along major trends in the field slope. The application rates of fertilizer for each site were different, except control treatments.

Soil data, and previous field information were used as a basis for fertilizer recommendations, using the NuMaSS decision aid for nitrogen (N) prediction, and P and K by PDSS software with a target yield of 5 t/ha for maize at all sites. Fertilizers (P, K and half of N rate) were applied at the same time at planting; the remaining N fertilizer was applied as a top dressing. Fertilizer application method was band (0.1) for NuMaSS P recommendation. Maize plant heights were measured at 30 and 60 days after planting. Maize was harvested at 115 to 120 days. In each plot, an area about 15 m was harvested for maize and yield analysis was conducted using the IRRISTAT program with grain moisture content of 15 percent.

On-farm Trial

Most of the soils in the on-farm trials were clay loams, with low levels of phosphorus and medium levels of potassium at each site, and high in organic matter content. The experiments were undertaken in Ban Hai, in the 2004 wet season (WS) at four sites. Four "representative farmers" were selected, by which is meant farmers who had suitable land (aerobic conditions), capability in maize cultivation and the ability to transfer technology to other farmers.

Each of the four experiments was set up as one big replication with five treatments for each field. Fertilizer treatments were as follows: 1) control, 2) farmers practice, 3) state recommendation, 4) NuMaSS and PDSS recommendations and 5) without K treatments, and with target yields of 5 t/ha for maize. A local maize variety (DK4) was chosen by the farmers, who did the land preparation and crop planting. We assisted with treatment design, soil sampling and fertilizer calculation. The time and method of fertilizer application differed. Farmers' practice and state recommendation treatments were broadcast at the same time as maize planting. NuMaSS and PDSS predicted treatments were calculated assuming a band application (0.1) method. P, K and half of N were basal; the remaining N was for top dressing only. Farmers did some activities, like weeding and fertilizer application and data collection and harvest area were conducted at three randomized points within plot sizes of 28 m^2.

The NuMaSS predictions of N fertilizer rates and lime and PDSS predictions of P & K fertilizers resulted in yields somewhat less than the target yield of 5 t/ha for maize.

Research Station Results

The initial results of testing NuMaSS and PDSS knowledge at the three sites enabled us to evaluate the effect of improved fertilizer prediction. The N, P and K recommendations produced by NuMaSS and PDSS resulted in a reduction in the amount of fertilizer recommended, while maintaining sustainable crop yields. The most remarkable result, however, was the significant difference in fertilizer recommendation. The result indicated that in fine sandy soil, there would be no response to inorganic and commercial organic fertilizer (COF); exactly what happened in the Phon-ngam site. The application of more than 9 t/ha of COF did not increase maize yield. Soil data analysis after crop harvest did not show an increase in nutrient contents in the soil. Cultivating cereal crops on the undulating soils with fine sandy texture may result in loss of nutrients by leaching and run off under high rainfall. Yield results from the experiment indicates little response to added COF, but response to potassium. The application of single COF doesn't appear to improve soil fertility but does increase soil organic matter.

On-Farm Results

The first year of testing different fertilizer recommendation in the farmers' fields indicated that maize yields associated with NuMaSS treatments were greater than those of the control, farmers' practice and also better than yields based on the state recommendations. These yields are an excellent indication of the potential of these upland soils or agriculture with appropriate fertilizer inputs and crop management. The impact of NuMaSS and PDSS is that farmers can benefit from this technology (fertilizer application and maize cultivation techniques), with increased maize yield. Results from these experiments will be the basis for a farmers' field school in this region. Economic analysis of on-farm trials showed that only one on-farm trial did not show a profit. This may be due to lodging of the plants during the flowering stage.

Training and Field Visits

Training and field visits were the second activity of the project leading to improved knowledge of maize production by the research staff and upland maize farmers. Thai colleagues with the NuMaSS Project organized two training courses and field visits for researchers and farmers in 2004. The first training course on soil nutrient management and soil test kit use was organized at Soil Survey and Land Classification center (SSLCC), Vientiane, Laos in August. Fifteen researchers from research centers surrounding the National Agriculture and Forestry Research Institute and six upland farmers attended. Participants learned concepts of soil nutrient management, used the Thai soil test kit and visited maize experiments at research station and at on-farm trials at Ban Hai.

In September 2004, seven researchers and five farmers attended a training course on sustainable maize production system in Nakhon Ratchasima Province, Thailand. This was a country-to-country farmer visit, whereby farmers from Laos visited maize farmers in Thailand on their farms. Participants learned about the farmers' empowerment concepts, soil series identification and the use of Thai soil test kits. They also visited the Suwan farm in Thailand, which is a successful maize farm, and the surrounding smallholder maize farms mainly to share and exchange experiences on maize production systems in the two countries. In January 2005, another training course was organized by NAFRI with SM CRSP support. Prof. Tasnee Attanandana presented lectures (in Thai) on farmer empowerment and soil. She also discussed issues related to nutrient management with farmers and extension personnel.

Before the courses, researchers and farmers offered their assessment of problems and problem solutions. They indicated a lack of knowledge on soil series identification and soil testing, lack of funds to buy fertilizer and improve their land, and little awareness of the nutrient deficiencies in their lands. To solve such problems, they suggested extension workers or researchers offer training on fertilizer application methods, soil series identification and soil testing techniques and support and help farmers with fertilizer management, and in improving knowledge of nutrient management.

The course evaluation indicated that most farmers and researchers benefited from the workshop. Information on soil management and sustainable maize production, new techniques of soil testing using the Thai soil test kit and soil series identification were listed as helpful in enabling farmers to apply their knowledge on their own and to transfer it to other farmers in their regions.

Africa

Senegal

The NuMaSS model was field tested for fertilizer application validation in Senegal this project year. It was found that soil degradation had advanced and compromised the efficacy of actual fertilizer recommendations. Consequently, nutrient deficiencies of crops became persistent, and it was necessary to apply nutrients on the fields in light of the farmers' goals, the nutrient uptake by crops and the physical and chemical characteristics of the soils. The NuMaSS model, based on information from a specific site, was used to provide farmers with a diagnosis of deficiencies and offer them management recommendations for multiple scenarios on soils, crops and fertilizer sources.

Three villages were selected in each of two ecological zones of the Peanut Basin: a northern center with a millet/peanut system and a southern center with a maize/peanut system. The aim was to assess the effects of fertilization by comparing four treatments: T1=control (without any fertilizer); T2=rate of fertilizer based on research recommendations; T3=fertilization based on NuMaSS predictions; and T4=Twice T3. In the southern center, the treatment T2 consisted of 200 kg/ha NPK (15-10-10) and 200 kg/ha urea (46-0-0) for maize and 150 kg/ha NPK (15-10-10) for peanut. For the treatment T3, 20 to 26 P kg/ha and 117 to 220 N kg/ha were applied on maize while only 5 P kg / ha were provided to peanut. In the northern center, the treatment T2 consisted of applying 150 kg/ha NPK (15-10-10) and 100 kg/ha urea (46-0-0) for pearl millet and 150 kg/ha NPK (15-10-10) for peanut. For the treatment T3, 0 to 3 P kg/ha and 193 to 254 N kg/ha were applied on pearl millet while only 2 to 14 P kg/ha were provided to peanut.

In the northern center, grasshopper attacks that occurred during the maturation phase of pearl millet compromised grain yields and no grain remained for harvest. As a result, only stover was analyzed for treatment comparison. On pearl millet, actual fertilizer recommendations and NuMaSS fertilizer recommendations improved yields of stover of farmers' fields.

In the southern center, a delay in providing fertilizers, seeds and data of soil analysis led to late planting dates, particularly for the 110 day maturing variety of peanut, which showed bad pod filling and produced very low yields.

- Grain yield of maize was significantly increased by fertilizer application based on actual recommendations or NuMaSS prediction. The use of the recommended dose of mineral fertilizer outperformed the fertilizer application based on NuMaSS predictions. However, fertilizer application based on NuMaSS prediction improved maize grain yields five-fold compared with the control.
- On peanut, there was no significant increase of pod yields with the actual fertilizer recommendation or fertilizers applied from NuMaSS prediction.

Angola

An extension of the work on the NuMaSS and soil test kits has been extended to field support activities in Angola. These activities are reported later in this Annual Report (see Field Support to Missions, *Improving Maize Productivity in the Planalto Area of Angola*).

Mozambique

SM CRSP project activities in Mozambique were initiated last year with a soil test kit workshop. This workshop was composed of 35 participants and included ten NGOs with extensive programs in the country. Dr. Tom Walker of Michigan State and a member of the SM CRSP Technical Committee gave a lecture on important economic considerations when seeking to increase productivity and fertilizer use efficiency. The SM CRSP also partnered with INTSORMIL CRSP to enable Ricardo Maria, IIAM (Instituto de Investigação Agrária de Mozambique) to complete of the MS graduate program. Mr. Maria's thesis was supported almost entirely by the USAID mission through the INTSORMIL CRSP. His thesis program was completed in December 2004 when Mr. Maria returned to Mozambique. The thesis results indicated that there are some regions in Mozambique with relatively acid soil conditions that will most likely require either alternative crops or the application of liming materials, especially for cotton, an important crop in many regions. The soils were only moderately weathered with a few cases of extreme P sorption and deficient levels of Ca and Mg. Fortunately, it appears that K is not a generally limiting nutrient, probably due to the presence of micaceous minerals that were identified in their soils for perhaps the first time. The likelihood of zinc deficiencies appears substantial in specific sites. These results pointed out the need for soil analysis capability for both the cations and micronutrients. Currently IIAM does not have an atomic absorption or an ICP with capability of such analyses. Discussions with INTSORMIL raised the possibility of purchasing an atomic absorption unit for IIAM and this is in progress. Acquisition of such an instrument will increase in IIAM capability in providing analytical support that was previously non-existent.

Objective 2: Identify and Refine the NuMaSS Components that Aid Its Adoption and Usefulness

Southeast Asia—Thailand

After rice, maize is the most the important cereal crop in Asia. It is increasingly used as animal feed and maize starch is used for industrial purposes such as a coating for paper and paper products and wallboards for buildings. Maize will continue to play a major role in food security in the future and the demand for maize grain for animal feed will greatly increase. The Tropical Asian Maize Network was designed to strengthen the collaboration between national institutions in maize research and development. Founding members are Bangladesh, Cambodia, People's Republic of China, India, Indonesia, Lao PDR, Malaysia, Philippines, Sri Lanka, Thailand and Vietnam (FAO, November 1, 2004).

Maize production in Thailand (and Laos) is limited by many factors, such as the low nutrient status in soil, soil degradation and soil acidity. The lack of information and knowledge of soil and nutrient management are part of the reason for low yield and soil degradation. Institutional capacity must be improved in order to tailor appropriate technology to increase maize production. Research is needed on site-specific nutrient management approaches.

Site-specific nutrient management (SSNM) is an approach to efficiently use fertilizer by dynamically adjusting the application and management of nutrients to crop needs at specific locations and seasons. The SSNM approach aims to increase farmers' profit through 1) increased yield of maize per unit of applied fertilizer; 2) higher maize yields; and 3) reduced nutrient loss and increased fertilizer use. The features of SSNM are:

1. Application of nitrogen (N) fertilizer by crop modeling; N predicted by NuMaSS and DSSAT; and
2. Phosphorus (P) and potassium (K) fertilizer predicted by PDSS software.

For this to occur, it will be necessary to evaluate the nutrient management strategy for maize under current Thai (and Laos) practices, with the aim of identifying appropriate and sustainable technologies that can be transferred to farmers. These technologies must be appropriate for their different agro-economic conditions, and be based on results from previous years. Testing of the N recommendation algorithm in NuMaSS is one aspect that requires further research to investigate the causes for the over prediction of NuMaSS and DSSAT N recommendations in Thailand and Laos (see NuMaSS in SM CRSP PY7 Annual Progress Report). A second aspect is the testing of the K algorithm developed by researcher at Kasetsart University with the support of the Thailand Research Fund. The K algorithm is now ready for field testing.

Development of the K Algorithm

Diagnosing and prescribing accurate applications of potassium (K) fertilizers continues to be an important activity in most production systems, especially those based on soils with low cation exchange capacity and abundant rainfall. The SSNM as described in Attanandana and Yost, (2003) and Attanandana *et al*., (2004a) is a technology oriented towards small farmers of the tropics and proposes training farmers to identify their soil series through a simplified, visual decision-tree; the use of soil test kits to assess N, P, K, and pH status; and a decision-aid to estimate fertilizer requirements (Attanandana and Yost, 2003). One attempt to improve soil K diagnosis and prediction arose from a study involving over 300 maize growers in 2002 and 2003 (Attanandana *et al*., 2004b). The results of that study, based on site-specific nutrient management, indicated that N and P were often applied in excess while K was often applied at a deficit. The project proposed a methodology or algorithm for estimating K requirements very similar to those in use in many countries where targeted soil levels are used and reactivity of the soil to fertilizer K is considered. The diagnosis of K sufficiency was based on multiple categories of information, including data observable by growers (Yost *et al*., 1992, 1999). The diagnostic step was designed to detect K responsive conditions. After identification of likely K responsive conditions, a prediction of K requirement was made and was based on a more detailed analysis of the soil and crop conditions. This prediction constitutes the site-specific K fertilizer requirement estimate and is further supported by an economic analysis. A summary recommendation for the grower is made after diagnosis, prediction and economic analysis results are completed.

The prediction described above was based on a K algorithm proposed by Attanandana *et al*. (2004b) that includes terms that represent the K status in the plant, the status of the soil K supply, the reactivity of the soil to added K and selected management factors, such as depth of fertilizer incorporation and whether or not stover was removed. This algorithm builds on previous work of Gill and Kamprath (1990) and Dierolf and Yost (2000). The estimate of the plant K status is expressed by the crop identification, the Kpercentage and plant biomass quantity. A critical level of soil K, Kcritical, was also proposed. The soil K status and reactivity are represented by measures of exchangeable K or extractable K for K status and by the buffer coefficient for reactivity of the soil with added K fertilizers. When assembled in equation form the above terms plus some terms for the effects of management give the following:

$$K_{req.}(\text{kg K/ha}) = [(K_{critical} - K_{soil})/BC_K * \text{B.D.}) * (\text{Application depth}/10 * \text{placement factor}) + (\text{Biomass removed (kg/ha)} * K_{percentage}/100)] \qquad \text{Eq.(1)}$$

where:

- $K_{critical}$ is the critical level of K in the soil using the same extractant as used for the measurement of soil K in the field (*Ksoil*) and that used for the calculation of the buffer coefficient (BC_k). The units are mg/kg.
- K_{soil} is the measured soil K level of the specific field using the same extractant as used for the calculation of K*critical* and buffer coefficient (BC_k). The units are mg/kg.
- BC_k is the buffer coefficient for K, for the specific soil based on the same extractant as used for the K*critical* and K*soil* measurements. This coefficient is the increase in extractable soil K per unit applied K. The coefficient is dimensionless, but requires similar units of extractable soil K and applied K, e.g. mg/kg.
- *B.D.* is the soil bulk density, kg/dm.
- *Application depth* represents the depth of incorporation of the fertilizer K, the units are in cm.
- *Placement factor* is an estimate of the effect of placement of fertilizer K based on an approximation proposed by de Wit (1953) and adapted for PDSS (Wang, X., 1998, personal communication).
- *Biomass* is the amount of above-ground crop biomass removed from the field. The units are kg/ha.
- $K_{percentage}$ is the percent K in the biomass that is removed from the field. The units are percent.

Conclusions

The proposed K model was field-tested during the 2004-2005 cropping season and predictions of K fertilizer requirement were compared with field-based estimates of K requirement developed from response curves. The results indicated that site-specific nutrient management, as implemented using the K algorithm, provide more accurate estimates of K fertilizer requirements than did the existing Mitscherlich-Bray equations that provided only a general recommendation for the crop, wherever planted.

The components of the proposed K model, the K critical level, and the K buffer coefficient compared favorably with field-based estimates of these coefficients. A comparison of K requirement on a survey of 16 sites on 12 soil series indicated that the field prediction of K requirements was more accurate with the proposed K model and the site-specific nutrient management approach. The algorithm has been incorporated into the PDSS software for use and further testing. Remaining work to be done includes the incorporation of a leaching loss estimate into the model, testing with other crops, and further testing in differing regions and locations in the tropics.

Training is an integral part of the program in Thailand. There are both informal and formal training programs. For the latter, three PhD students [one Lao, and two Thai (both women)] at Kasetsart University are involved. All three are supported by non-CRSP funds, but their programs were made possible by the NuMaSS project. A two-year FAO funded project to Kasetsart University for the amplification of the site-specific nutrient management and the conduct of an international workshop on the methodology ended in 2004. Informal training continues of growers and farmer leaders in new applications of the site-specific nutrient management technology. Local Thai programs have been developed and funded (Thai Research Fund) to extend the methodology to rice, soybean, and sunflower.

Africa—Mali

The adoption of NuMaSS to local conditions in Sub-Saharan Africa encompassed activities carried out in Mali, West Africa. Specifically, the activity was the field testing of the rock phosphate algorithm designed to predict the amounts of rock phosphate needed in soils of Mali.

The overall goal of this study is to insure food security by increasing agricultural productivity through the promotion of the use of local resources such as rock phosphate (RP), with the aim of developing a decision aid that will consider the option of the direct use of RP for soil fertility management in West Africa.

The specific objectives of this study are:

- To propose a decision-making sequence to assist potential RP users in deciding whether or not the option of using RP is a good alternative for supplying P to crops and how much rock phosphate to apply;
- To develop an algorithm (method) that would produce quantitative estimates of the amount of Tilemsi rock phosphate necessary to provide nutrient P for crops in West African soils;
- To generalize the model recommendations to a broad range of RP and agro-climatic conditions and provide a framework for economical analysis.

On-farm studies were conducted to test the recommendations from the developed RP module and to identify refinements needed in the equations to predict the amounts of RP needed to meet crop P requirements. These tests were implemented for millet at Konobougou and Cinzana (Mali) with an annual rainfall of 850 and 650 mm respectively. Samples were collected from experimental units for laboratory characterization and prediction of P application rates by PDSS and the incorporated RP module. The P sources, TSP and Tilemsi RP, were applied at 0, 1/2, 1 and 2 times the recommended rates. Linear Regression Plateau (Shuai *et al.*, 2003) was used to determine the amount of Tilemsi RP needed to be applied for maximal yield and the critical P level of P.

Millet response curves for different sources of P are presented in Figures 1 and 2. The critical P level for TSP and Tilemsi RP (Figure 2) on the acid and P deficient soil of Konobougou are respectively 9.68 and 12.04 mg P/kg soil. The RP module overestimated the amount of Tilemsi RP needed to meet the millet P requirement. The maximum yield was obtained at about 824 kg RP/ha rather than the 1330 kg/ha recommended by the RP module.

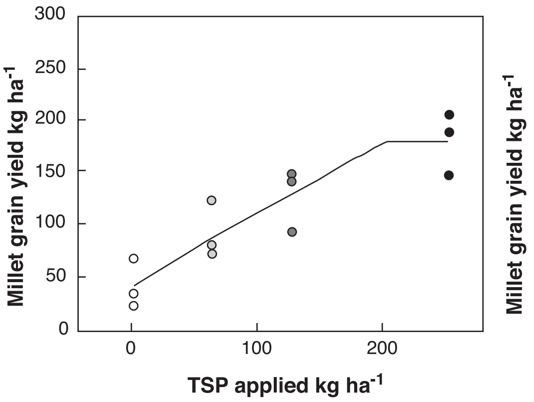

Figure 1. Millet response to triple superphosphate (soluble).

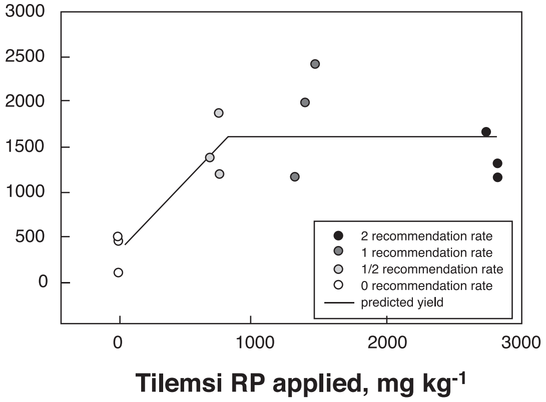

Figure 2. Millet response to rock phosphate—Tilemsi.

For TSP and Tilemsi RP, the experiments at Cinzana village did not show a distinct trend to different levels of P application.

In 2005-2006, a multi-location field evaluation of the RP model will be performed in Mali and Senegal, West Africa in order to assess the performance of RP in farming conditions. These experiments aim to integrate RP properties, climate conditions and farmer practices into the RP module. This will enable enhanced predictions and improved decision-making by inclusion of the experimental results in the database, validation, modification or refinement of the equations to predict the amounts of RP needed to meet crop P requirements.

Objective 3: Adapt NuMaSS Database and Structure to Users and Regions

Southeast Asia—Philippines

On 20-21 April 2004, the 2nd Annual Workshop on Decision Aids—NuMaSS On-Farm Testing in SE Asia—was held at the Philippine Rice Research Institute, Maligaya, Munoz, Nueva Ecija, Philippines. Approximately 30 participants composed of researchers and extension workers from the Philippines, Laos and the USA participated in the workshop. Progress for PY6 on-farm testing in the Philippines was reported and the baseline survey results were also presented. During the workshop, the extension workers were trained on the NuMaSS version 2.0. The software was found to be user friendly and easily learned by extension workers. Part of the retraining activity was for extension workers and researchers so they could identify parts of the modules that need improvement as it becomes more useful and adapted to local conditions. Some of the suggestions were as follows:

1. Include the K module for nutrient constraint;
2. Include diseases in the agronomic constraint;
3. Include pictures and description of indicator plants, preferably at various stages found locally;
4. In the Philippines, farmers plant crops in two distinct seasons. This variable is not taken into consideration in the NuMaSS software. Fertilizer rates normally vary in the wet and dry season (i.e., lower rates are applied in the wet season than in the dry season because of lower solar radiation and cloudiness).

On 21 January 2005, a data analysis workshop was held at PhilRice, Maligaya. The following week, a workshop was held on the results of the NuMaSS research in the Philippines. The workshop's objective was to present the results of the 2004-2005 cropping year and also address some ways to better adapt NuMaSS to local conditions. Several specific presentations were made:

1. Simplify the soil series identification so that identification can be made by farmers and growers—analogous to the approach used in Thailand with the soil test kits and decision-aids;
2. Use the leaf color chart for better detecting and managing nutrient N in upland crops. This methodology has been successful in paddy rice; can it be used in upland crops?;
3. Use of the STK (soil test kit) as developed by the Philippines Soil Bureau;
4. Use of the MOET (minus one element test), an adaptation of the missing element experiments long known in soil science.

Project: Adoption of the Nutrient Management Support System (NuMaSS) Software Throughout Latin America

Principal Investigators: T. Jot Smyth and Deanna L. Osmond, North Carolina State University

The goal of the NuMaSS Software Adoption project is to support the adoption of NuMaSS-based knowledge via a network of on-going programs throughout Latin America with potential to benefit from the improved access to information on soil N, P and/or acidity management. The primary target groups within the policy-to-farmer decision-making continuum are the national research/extension services. These groups provide, interpret and have immediate access to the location-specific soil and crop data required to develop nutrient recommendations and economic evaluations from the NuMaSS knowledge base.

An additional project component focused on integration of nutrient management-related activities with other SM CRSP projects. Intra-project collaboration would develop service capabilities through (a) overseas collaborator participation in annual SM CRSP workshops, (b) development of training modules for improved soil management technologies and (c) travel and technical backstopping support in response to service requests.

Introduction to Latin America Activities

In *Mexico*, sorghum yield response to N fertilization was significant at all nine sites with N x P factorial experiments in the alkaline, relatively unweathered soils of Northern Tamaulipas. Yield response and N deficiency, however, were minimal because of significant quantities of residual soil NO_3-N (100 to 176 kg N/ha, 0-60cm depth). In most instances, fertilizer N for optimum economic yield was achieved with 40-80 kg/ha. Phosphorus fertilization did not influence sorghum yield at any of the sites. The lowest Olsen-extractable P level in preplant samples of 11 mg/kg indicates that the critical limit for sorghum in these soils is below this soil test P value.

In *Honduras and Nicaragua*, among the harvested six corn experiments to evaluate N fertilization and legume cover crops , a significant yield response to fertilizer N was obtained in four experiments. Optimum fertilizer N requirements among three of the responsive experiment sites ranged from 69-113 kg/ha with yield increments of 1.25-2.15 t/ha relative to zero-N treatments. Grain:stover ratios for two local corn varieties were 0.47 (HS-15) and 1.22 (NB-6), and differ considerably from the default value of 0.84 used by the NuMaSS software in the absence of local user data. When combined with pending tissue N analyses and estimated fertilizer N use efficiencies, grain:stover ratios for local varieties should improve fertilizer N recommendations by NuMaSS for site-specific conditions in the region.

A significant corn yield response to P fertilization was obtained at one of two sites on Inceptisols in Honduras with initial Olsen-extractable soil P levels of 4.3 and 5.3 mg/kg. Near-maximum yield was obtained with 66 kg of broadcast P/ha. Foliar tissue analyses at both sites indicated that yield at the non-responsive site was constrained by deficiency in S and, possibly, Mg.

In *Bolivia*, maximum yield of an andigena subspecies of potato (variety Waych'a) was achieved in an Inceptisol at Toralapa with 120 kg/ha of urea-N. Upon incorporating tuber:foliage fresh weight ratios, % N in plant components, native soil N uptake and fertilizer N use efficiency values determined in the experiment, NuMaSS recommended 128 kg N/ha for the optimum yield of 14.88 t/ha. NuMaSS recommendation for the same target yield with the software's existing default values for potato, however, was 86 kg N/ha. In Costa Rica and Ecuador, potato yields for on-farm P fertilization experiments increased significantly in four of five sites on Andisols. The crop was lost at the fifth site due to hail and frost damage. Estimates of fertilizer P requirements for optimum yield at three of the P-responsive sites ranged from 75-83 kg/ha.

In *Panama*, nitrogen requirements for upland rice varieties IDIAP-2503 and CHI-330 were investigated at two sites on Ultisols in Veraguas. Maximum yields, ranging from 3-5 t/ha, were obtained with N fertilizer rates ranging from 54-119 kg/ha. When rice was planted after harvesting *Cajanus cajan* in the previous rainy season, there was no response to fertilizer N. Values for grain:stover ratios, tissue % N, fertilizer N use efficiency and crop uptake from soil N determined in these experiments will enable IDIAP to refine their fertilizer N recommendations for upland rice in the region's Ultisols. Corn grain yield increased with broadcast P fertilization in an Alfisol of Azuero, Panama.

In *Brazil*, a survey of soil test data for 82 samples in the cowpea production area of Northeast Pará indicates that a majority of the soils are deficient in K, Mg, P and S. Clay content of these soils averages nine percent and does not exceed 15 percent. More than half of the samples have less than 5 mg/kg of Mehlich-1 P. In two sandy Oxisols within this region, S deficiency has been identified as the primary factor limiting corn and upland rice response to fertilizer N. The Mehlich-1 critical soil P value for a local cassava variety in these sandy soils is about 6 mg/kg, and requirements for cowpea, corn and upland rice may be greater. Corn yield response to lime as Al saturation values are greater than 20 percent. About 50 kg of fertilizer K/ha are required for optimum corn and upland rice yields.

Mehlich-1 critical soil P values for optimum forage dry matter production by *Brachiaria brizantha* were estimated to be 8.5 mg/kg in a Quartzipsamment (10 percent clay) and 1.9 mg/kg in an Ultisols with 36 percent clay. However, P buffer coefficient values for both soils were considerably higher than those predicted by NuMaSS. Collectively, observed crop yield responses to N, P and/or lime in these field experiments throughout Latin America matched the predictions of NuMaSS Diagnosis for presence/absence of each nutrient constraint. The one exception was for prediction of P constraints to sorghum with Olsen-extractable data in the alkaline soils of Tamaulipas, Mexico. A good match between field-observed and NuMaSS-predicted P constraints with Mehlich-3 soil data, however, suggests that the software's Olsen P critical value in NuMaSS for sorghum needs to be revised downward for these high-base status soils.

Interim version 2.1 of NuMaSS was released in March 2005, and corrects several flaws in algorithms for nutrient recommendations in version 2.0. Collaborators are currently testing a prototype of NuMaSS with a data table editor. Feedback has already identified several additional soil and crop coefficients users wanted to see included in the data table editing features. Collaborators continue to identify the absence of soil K constraints as a major weakness.

Dissemination of NuMaSS-related results to farmers, extensionists and the agri-business sector continues through a combination of field day tours and their direct participation in ongoing activities. Several collaborators in the network have involved local university faculty and their students; others have either sponsored training workshops on NuMaSS or have begun field testing NuMaSS recommendations with local NGOs and seed production companies.

Objective 1: Test and Compare NuMaSS Predictions on Nutrient Diagnosis and Recommendations with Existing Soil Nutrient Management

NuMaSS uses various soil and crop coefficients in diagnosing nutrient constraints and recommending their corrections. Coefficients in the current version of the software come from extensive reviews of published and gray literature from throughout the tropics. Testing of existing coefficients with field trials is necessary to ensure the local crop its validity for cultivars and soil conditions. These tests initially focused on available data sets from previous trials in each region. A milestone event for this objective in PY6 was to visit each potential group of collaborators, verify their interests and potential contributions, review existing data, and identify knowledge gaps relative to data necessary to derive soil and crop coefficients.

Visits to all potential collaborators were completed in PY6 with travels to Bolivia and Argentina after the SM CRSP's annual meeting in July 2003. Other milestone events for this objective were completion of the assessment of field trial results related to NuMaSS Diagnosis in PY7 and those related to NuMaSS Recommendations in PY8. Results and ongoing activities, since the last progress report, are described in the following for each site.

INIFAP, Mexico

Research in the Tamaulipas province of Mexico focuses tests to determine soil and crop coefficients to enhance adoption of NuMaSS-based knowledge for N and P management in dryland and limited irrigation systems on alkaline, relatively unweathered soils (Aridisols, Mollisols and Vertisols). Grain sorghum trials started in PY6 to evaluate N and P requirements and to compare different nutrient recommendation were completed this year. Some of the experiments comparing nutrient recommendations and N and P requirements were continued this year and new ones were added for corn and cotton which are re-emerging crops among producers in the region.

N x P Fertilization Trials from 2004

Sorghum grain yields last year were higher than normal due to above normal precipitation. Interaction of N x P fertilization and P fertilization (0-60 kg P_2O_5/ha) alone did not influence yield at any of the 10 test sites. The lowest concentration of Olsen-extractable P in preplant soil samples was 11 mg/kg. The critical limit for sorghum by this extractant, therefore, appears to be below 11 mg/kg.

A significant influence of N fertilization (0-120 kg N/ha) on yield, however, was observed at all evaluated sites.

Quantities of residual soil NO_3-N were significant in 2004 and likely reduced yield response to fertilizer N. Yield responses to added N in the 2005 trials and results for tests of N recommendations by TAES which adjust for quantities of residual NO_3-N present should give additional guidance as to the importance of accounting for residual soil NO_3 in NuMaSS.

Grain and stover subsamples collected at harvest were analyzed for N to calculate total crop N uptake. Results indicate crop N uptake increased with increasing fertilizer N.

Quadratic response functions of sorghum yield vs. total available P (fertilizer plus extractable soil P) were reported for each trial. Total available P explained less than 16 percent of the variation in yield across sites. This is consistent with the absence of a statistical affect by P fertilization at any evaluated site.

Sorghum Yields from On-Farm Strip Tests in 2004

Grain yields were also determined at four of five on-farm strip tests to compare NuMaSS recommendations to others. One test was lost because the producer harvested plots before yields could be estimated. Fertilizer recommendations significantly increased yields compared to the controls in only one on-farm test (Figure 3). Quantities of N recommended by NuMaSS were 20-26 kg/ha greater than recommendations by INIFAP and TAES. NuMaSS also recommended 32-40 kg P/ha, whereas INIFAP recommended 30 kg/ha and TAES recommended no P. Algorithms for P recommendations on alkaline, calcareous soils likely need to be revised in NuMaSS. Coefficients for N need to also be revised to account for residual soil NO_3.

Field Experiments Planted in 2005

A series of four dryland sorghum, four irrigated sorghum, one irrigated corn and one irrigated cotton trials (4 replications) with complete factorial N x P fertilization treatments, were planted this year.

To compare recommendations by NuMaSS and others, on-farm strip tests with the same crops and water management were also established at each site. Treatments were NuMaSS recommendations, that of the Texas Agricultural Experiment Station at Weslaco (TAES), INIFAP recommendations, a control without added N or P and TAES recommendations for fertilizer N minus residual NO_3-N to 30- and 60-cm soil depths. Composite preplant soil samples were taken at each site for residual NO_3 and sectioned into depths of 0-30 and 30-60 cm. Dryland sites averaged 173 kg NO_3-N/ha, while irrigated sites averaged 161 kg NO_3-N/ha. These quantities may be sufficient to reduce or preclude a crop yield response to added N, especially if moisture is available to a 60 cm depth.

Since evaluating crop response to N and P fertilization are important objectives, we hypothesized that in-season chlorophyll meter readings might reflect or predict this response. Meter readings were significantly affected by added N at all sites, but explained only 22-50 percent of the variation in leaf chlorophyll readings.

CIAT-MIS Consortium, Honduras and Nicaragua

Yield Response to Fertilizer N and Legume Cover Crops

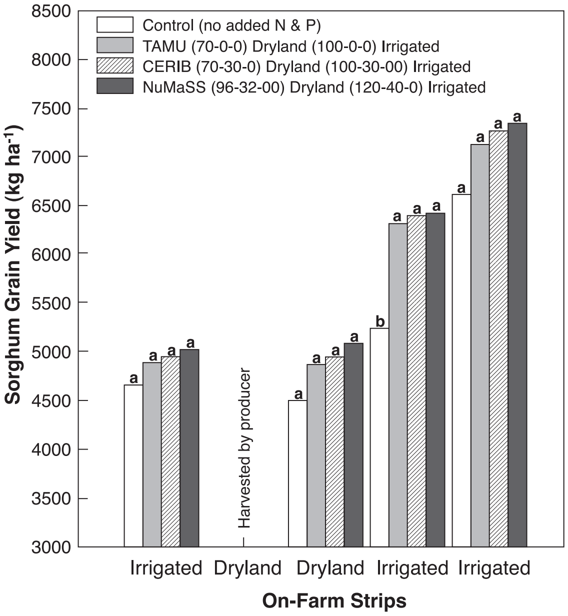

Figure 3. Sorghum grain yield for each on-farm test as affected by NuMaSS, TAES and INIFAP (CERIB) fertilizer recommendations.

Members of the CIAT-MIS consortium initiated two-year trials at various locations throughout Honduras and Nicaragua to evaluate corn yield response to fertilizer N and legume cover crops. Lead investigators for each site and their institutional affiliations are listed in Table 3.

At several of these sites, undergraduate students at local universities participated in the experiments and used the data for their senior term papers.

The experiments consisted of three replications with seven rates of urea-N (0-200 kg/ha) split applied in two equal amounts at 25 and 40 days after planting. In locations with sufficient rainfall prior to the corn planting season, N supply to corn from three legume cover crops was also compared with the urea-N treatments. Soil P constraints were avoided by applying 100 kg P/ha to all urea-N and legume cover crop treatments. Each site used corn varieties or hybrids that are commonly grown in their respective regions. Measurements at harvest of grain, stover and N uptake were designed to provide various variety (grain:stover ratio, % tissue N, optimum grain yield) and soil (native soil N supply, yield without fertilizer N, % fertilizer N use efficiency) coefficients that will be used in NuMaSS to improve regional diagnosis and recommendations for N.

Analyses of soils and plant tissue samples are still ongoing for several of the trials. Chemical characteristics for soils at five of the sites, prior

Table 3. Lead investigators and institutional affiliations for each of the fertilizer N and legume cover crop trials conducted in Honduras and Nicaragua.

Honduras			Nicaragua		
Location	Investigator	Institution	Location	Investigator	Institution
La Ceiba[a]	Manual López	CURLA	San Rafael	Elbenes Vega	INTA
Yorito	Gilman Palma	CIAT	San Dionisio	Pedero Pablo	CIAT
Comayagua	Oscar Cruz	DICTA			
Catacamas	José Reyes	UNA			
Talgua	José Reyes	UNA			
Candelaria[b]	Juan López	ITC			

[a] Trial failure due to unseasonably dry weather.

[b] Trial failure due to poor plant stand.

Table 4. Routine soil test data prior to fertilization and planting at some of the fertilizer N and legume cover crop trials in Honduras and Nicaragua.

		Exchangeable				Al	Olsen-Extractable			
Location	pH	Ca	Mg	K	ECEC	Sat.	P	Cu	Mn	Zn
		----------$\text{cmol}_c\text{kg}^{-1}$----------				%	----------mgkg^{-1}----------			
Comayagua	7.1	17.73	2.43	0.32	20.58	0	32.5	4	1	2.1
Catacamas	6.8	17.20	2.67	0.87	20.82	0	23.2	4	49	4.9
Candelaria	4.8	9.70	2.22	0.25	13.32	9	17.1	3	21	0.8
San Rafael	6.0	14.20	2.54	0.19	16.98	1	21.4	4	14	2.0
San Dionisio	5.8	13.80	2.90	0.17	16.99	1	12.2	4	4	1.4

to fertilization and planting, are shown in Table 4. Most of the soils have adequate supplies of K, and P constraints, based on NuMaSS diagnosis, would only be present at Candelaria and San Dionisio. None of the soils presented an acidity constraint for corn.

Among the six trials that were harvested, there was a significant response to fertilizer N at four sites (Comayagua, Talgua, San Rafael and San Dionisio). Due to considerable variation among N rates, a linear function characterized the yield response at Comayagua. At the three other sites linear-plateau functions estimated optimum fertilizer N requirements ranging from 69 to 113 kg N/ha with yield increments of 1.25 to 2.15 t/ha relative to the zero-N treatments.

As reported last year, a pilot fertilizer and legume N trial were conducted with corn at San Dionisio during the short rainy season, which is more conducive to crops like beans. Although optimum yields were lower last year (1.8 vs. 4.8 t/ha), estimated optimum fertilizer N values differed by only 2 kg N/ha.

Among the two sites without a response to fertilizer N, a mean yield of 5.6 t/ha at Catacamas is indicative of good native soil N supply. There was also no significant response to three cowpea legume cover crop treatments grown for 40 days before planting corn. Determinations of percent dry matter for corn residues in trials with varieties HS-15 at Catacamas and NB-6 at San Dionisio allowed development of grain:stover ratios, which is an important crop variety coefficient that is used in N recommendations by NuMaSS. In the absence of a grain:stover ratio value for a given variety, NuMaSS recommends a default value of 0.84, which is based on an average of existing coefficients in the software database.

A meeting with NuMaSS collaborators in the CIAT-MIS Consortia was held on June 1-2 at Granada, Nicaragua. Existing results from the trials in Honduras and Nicaragua were discussed and impacts of varietal grain:stover ratios and estimates of native soil N contribution from zero-N treatment yields on site-specific N recommendations by NuMaSS were evaluated. Plans were also developed for continuation of the N trials during the upcoming planting season, which begins in July 2005. The site at Comayagua, Honduras will be replaced with an additional trial site in the San Dionisio watershed. All other sites will be continued for a second year and will encompass seven corn varieties that are commonly grown in the region. Technical support strategies were also developed to correct problems encountered during the last season to expedite plant tissue analysis for N and determinations of stover dry matter by some collaborators.

Yield Response to Fertilizer P and Interactions with Fertilizer N

Field data sets characterizing soil test P critical levels and soil P buffer coefficients in soils with montmorillonitic clay mineralogy are limited in Central American. The Olsen P extractant is widely used in the region, but the NuMaSS database has insufficient information to predict soil P critical level and P buffer coefficient variation with clay content. In previous single-rate NPK trials conducted in Honduras and Nicaragua, N-by-P interactions were suspected when significant corn yield responses in many sites were only detected upon the application of both nutrients.

During the last cropping season, replicated experiments with variable P and N rates were initiated in Candelaria and Yorito, Honduras to calibrate crop response and soil tests to applied P and to further investigate potential NxP interactions.

There was a significant corn yield response in Candelaria. Similarities in yields at 99 kg P/ha between treatments with 90 and 180 kg N/ha are indicative that the lower N rate was sufficient to achieve the maximum yield of 3 t/ha. In the absence of fertilizer N there was no difference in grain yields between 0 and 99 kg P/ha. In these soils, the 2 t/ha yield response can only be achieved upon simultaneous correction of both the P and N constraints.

Corn yields at Yorito were not significantly different among treatments. Foliar analysis suggested that yield response to N and P might have been limited by a sulfur (S) deficiency. Sulfur deficiency symptoms were evident in both the P trial and the adjacent fertilizer and legume cover crop N trial. As previously noted, the lack of a yield response to N may be related to an S deficiency. We plan to remedy the S constraint with blanket applications of S to all N and P treatments prior to planting the next crop. Soil samples from both P trials are being analyzed for P with various soil test extractants. These data will be used to estimate P buffer coefficients, crop critical levels and correlations between extractants.

Bolivia, Costa Rica and Ecuador

Activities in these three countries are reported jointly because they are related to potato-based production systems and project efforts to adapt NuMaSS P Diagnosis and Recommendations to soils from volcanic materials. The existing database for P in NuMaSS is based on knowledge developed in soils dominated by clays with crystalline mineralogy. In such soils, clay content is a useful proxy variable for site-specific adjustments of soil P critical levels and buffer coefficients. During development of NuMaSS, laboratory P incubation studies with soils derived from volcanic materials throughout Central and Northern South America indicated that differences in P buffer coefficients correlated with differences in amorphous Al extracted with either oxalate or KOH (IntDSS Project Annual Report for 2000-2001). Field trials with potato in Costa Rica and Ecuador will test the use of soil amorphous Al as a proxy variable for P diagnosis and recommendations in Andisols. Field trials in Bolivia on Inceptisols provide a reference point for soils with crystalline clay mineralogy and test current NuMaSS diagnosis and recommendations of N and P for potato.

Bolivia Inceptisols

Completion of soil and plant analyses for the potato crop harvested in 2004 enable a more thorough interpretation of the yield data reported last year for the N and P fertilization trials at the Toralapa Experiment Station. Wheat was cropped in both experiments during the 2004-05 season and is currently being harvested. A second potato crop will be evaluated during the 2005-06 season. These data sets will be used for N and P coefficients and for potato cultivars used in the trials.

a. Nitrogen—Treatments for the N experiment included six rates of urea-N (0 - 200 kg/ha), applied in two equal splits at planting in the seed furrow and at hilling, and 7 t/ha (fresh weight) each of four organic N sources: cattle manure, sheep manure, chicken litter and a small grain manure compost (‘bocachi’). Yield response of the local potato variety Waych’a (andigena subspecies of *Tuberosum solanum*) was evaluated. All plots received 35 kg P/ha band-applied at planting in the seed furrow.

There was a significant and linear yield response to urea-N. Fertilizer N also increased the proportion of yield in larger size-class tubers. Mean yields for the organic N sources were similar to the yield plateau achieve with 120 or more kg/ha of urea-N.

Due to limited knowledge of dry matter tuber: foliage ratios, users recommended during NuMaSS development that data input for tuber crops should be on a fresh weight basis. Towards this end, NuMaSS has to assume a percent dry matter for each plant component and each tuber crop. The fresh weight tuber:foliage ratio for Waych'a is estimated as 0.68 as opposed to a NuMaSS default value for potato of 0.9.

b. Phosphorus—fertilizer P treatments consisted of five rates of broadcast P (0, 28, 56, 84 and 139 kg/ha) and two rates of banded P (23 and 46 kg/ha), in factorial combination with the varieties Waych'a and Robusta (tuberosum sub-species of *Solanum tuberosum*). All plots received 120 kg urea-N/ha with the same split-application as used in the N experiment. Average potato yield for both varieties increased with broadcast P fertilization up to 86 kg P/ha, but yield response to P (0.05 t/kg of P) was less than to urea-N (0.07 t/kg of N) and there was no difference between varieties in their yield response to P.

There was no significant difference in Olsen-extractable soil P among the broadcast P treatments for samples taken at both flowering stage and harvest. These findings raise questions about the ability of this extractant to measure P availability at such high soil levels. In contrast with the Olsen extractant, Mehlich-1 and Mehlich-3 soil P increased significantly with broadcast P in samples taken at both flowering stage and harvest.

Estimates of the P buffer coefficient with the Mehlich-1 extractant were 0.80 with samples at flowering stage and 0.61 at harvest. Both of these estimates are greater than the predicted value of 0.49 by NuMaSS. With the Mehlich-3 extractant the estimated P buffer coefficient was 0.44 and did not differ between soil sampling dates.

Costa Rica and Ecuador Andisols

The first potato crop was harvested on the five P experiments (one in Costa Rica and four in Ecuador) in P-deficient Andisols selected to represent a broad range of oxalate-extractable amorphous Al and Fe. Treatments in each experiment consisted of fertilizer P rates as main plots and frequency of P application and subplots. Each experiment contained three replications. Fertilizer rates were 0, 66, 132, 198 and 264 kg P/ha in Costa Rica and 0, 66, 132, 198 kg P/ha in Ecuador. Prior to planting the first crop, P was applied to each main plot. The same P rates will be reapplied to two of the three subplots prior to the second crop and to one of the three subplots before the third crop. This treatment design will allow comparisons between residual and repeated P applications as well as total applied P for each of the three crops.

Yield responses to fertilizer P for the first potato crop are shown in Figure 4. At the Santa Ana (Costa Rica) site there was no harvest due to severe frost and hail storms. A linear yield response across the entire range of fertilizer P at the Cochabamba (Ecuador) site was attributed to drought problems during flowering and tuber initiation. Yields for the three other sites fit a linear-plateau response with estimated near-optimum P levels between 75 and 83 kg/ha.

Despite the use of two different varieties ('Super Chola' and INIAP-Fripapa) among the three sites in Ecuador (Cochabamba, Quinua Corral, Chaupi), there was a linear relation between tuber yield and P uptake across all treatments and sites.

Thus far, soil P analyses have only been completed for the site at Turrialba, Costa Rica. Upon completion of the soil analyses for the sites in Ecuador, soil P buffer coefficients will be estimated and compared with oxalate-extractable Al and Fe for each site. All sites are currently planted to their second crop.

IDIAP, Panama

N Fertilization for Upland Rice

Trials were continued on Ultisols at the Calabacito Experiment Station and a new on-farm trial was initiated at Trinchera. There were four replicates of each urea-N treatment (0-200 kg/ha) and two varieties: IDIAP-2503 and CHI-330. Fertilizer N was split applied in three equal amounts, at planting, 30 and 60 days. A third trial, also at Calabacito, evaluated the residual N effects of a pigeon pea (*Cajanus cajan*) crop harvested in the previous rainy season.

There was no significant yield response to fertilizer N (0 -100 kg/ha) by IDIAP-2503 when cropped on land after harvesting pigeon pea in the previous rainy season.

In previous variety trials grain:stover ratios have been consistently lower at Trinchera than at Calabacito and illustrate the need to develop 'regional' values and coefficients within the country for use in NuMaSS. Nitrogen uptake without fertilizer N

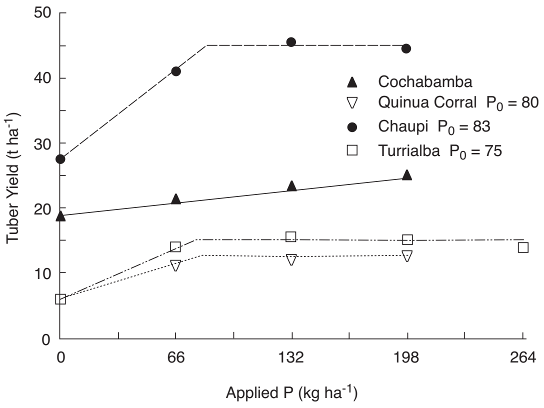

Figure 4. Potato tuber yield as a function of fertilizer P applied to Andisols in Costa Rica and Ecuador.

ranged from 45 to 68 kg/ha among the experiments and varieties. Data sets from these tests will be used for N coefficients.

P Fertilization for Corn in an Azuero Alfisol

A replicated split-plot experiment was started this year in an Alfisol to evaluate corn yield response to fertilizer P and to calibrate soil test P. Main plots consisted of broadcast P applications (0-100 kg/ha), applied once before the initial corn crop, and subplots contained banded P rates (0-30 kg/ha) that will be applied to each corn crop. The initial Mehlich-1 soil test P value for these soils was 1 mg/kg.

Grain yields for the first corn crop increased by 1.7 t/ha with broadcast P rates averaged across banded P treatments. Mehlich-1 soil P was determined in samples taken at planting, 30 and 60 days. Relations between soil test P for the broadcast P treatments and relative yield varied with sampling dates and suggest that maximum fertilizer P availability occurred between planting and 30 days. Estimates of the soil P buffer coefficient, by linear regression of the change in Mehlich-1 soil P on applied broadcast P, yielded similar values for samples taken at planting and 30 days with a mean value of 0.68. This value is considerably higher than the predicted P buffer coefficient of 0.16 by NuMaSS for a soil with 42 percent clay.

When combined with yield and soil test data from subsequent corn crops we hope to refine the critical soil P level and P buffer coefficients for corn, evaluate the residual effects of broadcast P and recommend banded P rates needed to sustain adequate supply of P in Azuero Alfisols. The IDIAP labs will use this information to identify and correct soil P constraints in the corn production region of Panama.

EMBRAPA, Brazil

A memorandum of agreement was implemented this year between EMBRAPA and North Carolina State University. The agreement is structured to allow collaborative technical cooperation projects on soil nutrient management with all EMBRAPA centers.

CPATU

Activities focused on application of NuMaSS in the State of Pará for cassava and grain crop production in both sandy Oxisols of the coastal region and clayey Oxisols in degraded pastures of the Paragominas region. Field trials in the coastal region are concentrated at the Terra Alta Experiment Station near Castanhal and Mr. Dutra's farm near Tracuateua.

a. Soil nutrient status of coastal region sandy Oxisols—with the help of county agricultural offices and banks we have assembled soil test data for 82 samples from farms throughout four counties in the coastal region. Many of these samples targeted cowpea production, estimated to encompass 20,000 ha in the region, but which is now diversifying into rotations with cassava, upland rice and corn. Soil test results indicate that most samples are acid, and low in exchangeable bases and cation exchange capacity. Fortunately, most soils are also low in exchangeable acidity. For clayey Oxisols near Manaus, Brazil, previous research indicated that lime response by cowpea was more closely associated with Ca saturation (>40%) and Mg saturation (>6%) of the ECEC, than with acidity per se. In this soil data set, 98 and 39 percent of the samples had Ca and Mg levels that were below the desirable levels for cowpea production. There is growing evidence that S may be limiting in this region.

Clay content of these soils averages nine percent and does not exceed 15 percent. More than half of the samples have Mehlich-1 soil P levels of 5 mg/kg or less. Estimated NuMaSS banded P recommendations for soils with nine percent clay and 5 mg Mehlich-1 P/kg are 4 kg/ha for cowpea, 10 kg/ha for maize and 3 kg/ha for upland rice.

b. Phosphorus—continuation of an experiment at Terra Alta evaluating residual effects of fertilizer

P and organic inputs for a fourth crop enabled establishment of the soil P critical level for cassava. During three previous crops of cowpea and corn, the experiment compared effects of four P rates and four rates of three organic sources - cow manure, chicken litter and agro-industrial waste from a cassava processing plant. Blanket applications of lime, N and K were corrected for other major nutrient variables among treatments. Cassava fresh root yields ranged from 11 to 38 t/ha among residual treatments of fertilizer P and organic inputs. The yield plateau was achieved in treatments with Mehlich-1 soil P as low as 6 mg/kg, whereas NuMaSS predicts a P critical level of 9 mg/kg for a soil with 17 percent clay. The default foliage:root ratio used by NuMaSS is 0.63.

The second (cowpea) and third (upland rice) crops were harvested during the second year of a P experiment at Tracuateua. No significant yield response to P in either crop was found although mean yields for cowpea varieties BR3 (1.9 t/ha) and BR2 (1.6 t/ha) were similar to those achieved in the first crop in 2003. Mean yield for upland rice variety 'Bonança' was 2.1 t/ha.

c. Nitrogen—during field visits last year to experiments at flowering stage of corn and upland rice it became apparent that N response at Terra Alta was compromised by a S deficiency, albeit too late to correct for those crops. Consequently, corn and rice yield response and fertilizer N were similar to those observed in 2003. During this year's field tour of experiments, it was visually apparent that S constraints were corrected with blanket applications to all plots, and we expect that similar yield maxima will be achieved at N rates below 160 kg N/ha.

Two N fertilization experiments were started in the clayey Oxisols at Paragominas this year, each with two varieties of corn and rice that are widely used within the region. These experiments are currently being harvested and data will be presented in the next report.

d. Liming—due to limited capacity in the CPATU labs, many farmers rely on analytical services and lime recommendations from labs in Southern Brazil. We have found that lime recommendations for a given soil sample can vary by as much as 5-fold, because labs use different analytical criteria for their recommendations. The second corn crop was harvested in an experiment at Terra Alta designed to compare the most common lime recommendation formulas with that used by NuMaSS. The soil had an initial pH of 4.9, 0.5 emol_c/kg of exchangeable acidity and 18 percent acid saturation. Corn yields in 2004 were superior to 2003, but were depressed by lime rates > 1 t/ha (100% $CaCO_3$ effectiveness) due to induced Mn deficiency.

Cowpea yield, following corn in 2004, was not affected by lime treatments. However, liming increased foliar Mg content and rates >1.0 t/ha reduced foliar Mn content significantly.

e. Potassium—experiments evaluating fertilizer K needs for either corn or rice, followed by cowpea on residual K, continued at Terra Alta. Yields for both corn and rice (cv. 'Bonança') increased significantly up to 50 kg K/ha. Cowpea yields improved with residual fertilizer K applied to the prior corn crop up to the rate of 75 kg/ha. Cowpea yield on residual K applied to the prior rice crop was low (575 kg/ha) due to seed germination problems, resulting in a lack of response to K treatments. In the K experiment at Tracuateua there was no yield response with either rice or cowpea. The absence of a K response at this level of soil K supports our estimates for critical soil K values in experiments at Terra Alta.

CNPGC

Activities focused on nutrient requirements for the establishment and maintenance of *Brachiaria* and *Panicum* pastures in Alfisols, Oxisols, Ultisols and Entisols in the 'Cerrados' region of Mato Grosso do Sul. Investigations are conducted jointly with faculty and students at the University for Development of the State and 'Pantanal' Region, also located in Campo Grande.

The third and final cut of Panicum (cv. 'Massai') was completed this year in an on-farm trial at Ribas do Rio Pardo in a Quartzipsamment (10 percent clay) that compares lime versus Ca and Mg requirements for forage production. For the initial cut of forage, reported last year, the only response in dry matter occurred between the control and all other treatments, and was attributed to the exclusion of N, P and K from this treatment. Combined analysis of all three cuts provides similar results and no yield difference between the Ca+Mg treatments and the equivalent lime treatments. These data suggest that lime responses in acid, sandy soils by these improved Panicums are due to the supply of Ca and Mg rather than the neutralization of soil acidity.
A P fertilization experiment with *Brachiaria*

brizantha was also conducted this year at the same on-farm site. Forage dry matter production for replicated treatments of 0, 17.5, 35, 70 and 140 kg P/ha was evaluated with three cuts during the rainy season. Forage dry matter yield increased with each successive cut, as did response to P fertilization. A linear plateau estimate of the P critical level for mean dry matter production across the three cuts was 8.5 mg/kg. Forage dry matter yield increased with each successive cut, as did response to P fertilization. A linear plateau estimate of the P critical level for mean dry matter production across the three cuts was 8.5 mg/kg. Similar relations were also developed with the other soil test methods and P critical level estimates were 12 mg P/kg with Mehlich-3 (R^2=0.96) and 4.1 mg P/kg with the anion resin (R^2=0.94). There was good correlation between all three soil P methods (r=0.99).

Since shallow incorporation of fertilizers is often practiced in pasture systems, there is some concern as to whether "plow-layer" sampling depths (0-20 cm) provide an adequate indication of soil nutrient status for pastures. Comparisons of soil P between depths of 0-10 and 0-20 cm with the Mehlich extractants indicates that P concentration in the shallow samples were 11 percent higher than in the deep samples. Predicted P buffer coefficients for this soil by NuMaSS are 0.66 for Mehlich 1 and 0.65 for Mehlich 3. Using a fixed P critical level of 8.5 mg/kg, the difference between observed and predicted P buffer coefficients for the Mehlich-1 extractant amounts to 28 kg/ha in NuMaSS recommendations for broadcast-applied P.

Data for two of the three cuts of forage dry matter have been compiled thus far in the lime-by-P factorial experiment to evaluate productivity and nutrient requirements for new cultivars and accessions of *Brachiaria brizantha* in an Ultisol with 36 percent clay at the Beef Cattle Research Center in Campo Grande.

Effects of liming or lime-by-genotype interactions on forage production were not significant, indicating that the grasses tolerated acidity levels of 35-40% base saturation. Forage dry matter production increased significantly with P levels and with successive cuttings.

Lower critical soil P levels for this clayey Ultisol than for the Quartzipsamment, described previously, are consistent with clay-based predictions by NuMaSS. Estimates of the P buffer coefficient for this Ultisol are 0.11 with Mehlich-1 and 0.20 with the Mehlich-3 extractant. Lower P buffer coefficients for the Ultisol relative to the Quartzipsamment are consistent with differences in their percent clay. Furthermore, these estimated P buffer coefficient values for this Ultisol are similar to those predicted by NuMaSS for the Mehlich-1 (0.16) and the Mehlich-3 (0.15) extractants.

Assessment of NuMaSS Diagnosis with Field Trial Results in Latin America

The Diagnosis module of the NuMaSS software seeks to answer questions of whether acidity, N and/or P constraints exist in a site-specific field for an intended crop. The module uses various types of information provided by the user: geographic location, climatic conditions, soil type, previous crop yield and nutrient management, nutrient deficiency symptoms and indicator plants. Soil and plant analytical data are considered, if available, but are not required. Minimum data requirements for a "yes/no" answer on soil nutrient constraints include location, climatic conditions and intended crop. Although information requirements are intentionally minimal and flexible, the quality and specific answers improves t of soil and crop coefficients in NuMaSS. The ongoing field experiments with a diversity of crops and soils in Latin America provide the opportunity to compare NuMaSS Diagnosis predictions with observed field results. Last year, we reported on such comparisons for 31 site-years of single rate NPK trials with corn in Honduras and Nicaragua. NuMaSS Diagnosis of N matched field results at 29 of 31 sites, whereas P Diagnosis matched field results at 23 sites. These results on P Diagnosis led us to initiate field experiments with the CIAT-MIS consortium to develop additional information on P requirements for soils in the region.

Objective 2: Identify and Refine the NuMaSS Components that Aid Its Adoption and Usefulness

Interim Version 2.1 of NuMaSS

Version 2.1 (Deanna Osmond and Jot Smyth of N.C. State Univ., Will Branch of Understanding Systems, Inc. and Russ Yost and Hu Li of the Univ. Hawaii) was officially released in late March 2005 upon replacement of the downloadable file for version 2.0

on the website *intdss.soil.ncsu.edu*. The new version corrects several crop-soil-ecosystem combinations where algorithms for nutrient recommendations did not perform as expected. During the three months since it was available on the website, there have been 17 downloads with unique identifiers from Africa, Asia, Latin America, Europe and North America. We have also distributed CD copies of the software to our collaborators in Latin America. As public domain software, each of these downloads or CDs can potentially be distributed to a number of additional local users. During the 27 months wherein the prior version (2.0) was available on the website, it was downloaded by 153 unique user identifications from Latin America (88), Africa (18), Asia (30), Europe (5) and North America (12).

NuMaSS Module to Customize the Software's Data Base

This new module (Deanna Osmond and Jot Smyth of N.C. State Univ. and Will Branch of Understanding Systems Inc.) seeks to help local users improve software performance at the regional level by adding their own values from crop and soil coefficients and fertilizer mixture formulations. A new software version (2.2) with the module is being tested among our collaborators. As crop coefficients for local varieties and soil test data are developed from the ongoing field experiments, instructions will be provided with the software on data entry, storage and editing via the module and compare NuMaSS fertilizer and lime recommendations for their site-specific conditions against those using the software's original default values. Preliminary tests with users have identified several additional variables which they would like to see added as "editable" entries to the software data tables, namely, nutrient analysis for composts, crop N uptake from native soil N reserves, fertilizer N use efficiency, critical soil P levels and soil P buffer coefficients. Enabling user entry of some of these values will require reviewing and, if deemed practical, revising programming code for algorithms driving the nutrient recommendations.

Identification of Software Weaknesses in Latin America

The existing language (English) is an obvious limitation identified by many users. Translations into Portuguese and Spanish are planned by PY10. We also "brainstormed" how future versions of the software would be managed among the different language users and believe that a feasible approach is to produce a future single version where users will have the option to select from available languages upon installation. This will require development of new tables wherein text will be retrieved in the user's language of choice for each software page.

This year, we have identified several locations in Latin America where responses to N are limited by an S deficiency. However, few of the regional labs have analytical capabilities for this nutrient. Warnings about potential S deficiencies, the consequences and potential remedial actions need to be included in future versions of the software.

Objective 3: Adapt NuMaSS Database and Structure to Users and Regions

Immediate collaborator goals of testing and refining NuMaSS predictions at the local level are, hopefully, evident from the report for Objectives 1 and 2 (see *Test and Compare NuMaSS Predictions on Nutrient Diagnosis and Recommendations with Existing Soil Nutrient Management and Identify and Refine the NuMaSS Components that Aid Its Adoption and Usefulness* sections). As collaborators gain confidence in the ability to adjust NuMaSS for local performance, through their ongoing field and laboratory tests, the types of auxiliary tools needed to enhance local use of the software knowledge will become more apparent.

Preceding sections of this report also indicate subgroups of collaborators with common interests—the CIAT-MIS consortia in Central America; potato production systems in Bolivia, Costa Rica and Ecuador; the use of chlorophyll meters (an auxiliary tool) with N recommendations for maize in Mexico and Panama; nutrient management for upland rice production systems in Brazil and Panama. Because network-wide workshops are cost prohibitive, we focus collective dialogue among these common interest subgroups. Network wide information exchange is accomplished through various conduits: (a) distribution of these annual reports, (b) summary presentations and discussions of annual report findings during site visits and (c) e-mail correspondence.

Dissemination of results at the local level occur through various formats:

- EMBRAPA-CPATU continues to provide annual field day tours to extension, agri-business and farmers of activities at the Terra Alta Experiment Station, on-farm trials at Tracuateua and, starting this year, experiments at the Paragominas Experiment Station. Results from ongoing trials, are eventually incorporated into soil-test based nutrient diagnosis and recommendations provided to farmers in this humid tropical region by the CPATU labs.
- Collaborators at EMBRAPA-CNPGC, INIAP-Quito and the CIAT-MIS consortia often involve faculty and their undergraduate and graduate students at local universities in ongoing project activities. Students gain on-site training and the NuMaSS knowledge base is incorporated into course curricula.
- PROINPA is assisting a local potato seed production company (SEPA) in Cochabamba, Bolivia with field tests to compare fertilizer recommendations for site-specific fields by NuMaSS with blanket formulations currently in use. The company contracts seed production with farmers and rotates a set number of production fields among 200 sites on an annual basis. Two replicated trials were recently harvested at sites near the Toralapa Experiment Station.
- IDIAP sponsored a three-day workshop on soil nutrient management in February at Divisa, Panama that was attended by 36 people distributed among the research, extension and agribusiness sectors. After two days of intensive review of basic concepts on soil fertility management, users were provided with hands-on training of NuMaSS.
- Collaborators at INIFAP, Mexico have been invited to participate in a new program of the Mexican government that emphasizes soil fertility/plant nutrition research throughout the country.
- The CIAT-MIS consortia are assisting FAO and seven NGOs in Honduras to compare soil-test based NuMaSS recommendations for N and P fertilizers with local nutrient input practices for corn in seven location. Replicated treatments include local fertilizer practices, with and without prior legume cover crops, and NuMaSS recommendations.

TRADEOFF ANALYSIS

Project: The Tradeoff Analysis Project Phase 2: Scaling Up and Technology Transfer to Address Poverty, Food Security and Sustainability of the Agro-Environment

Principal Investigator: John M. Antle, Montana State University

Objective 1: Further Develop and Refine the Existing TOA Method and TOA Model Software through Applications with Collaborating Institutions in the Andes, West Africa and East Africa

Project Years 6 and 7

A major goal of the Tradeoff Project for Phase 2 was to further develop and test the TOA approach and tools through new applications with collaborating institutions. The Tradeoffs Project strategy for developing collaborations in Phase 2 is that new applications should be based in and managed by the collaborating institutions. Under this strategy, the Tradeoffs Project would provide training and technical support for new applications but would not provide operational funding. However, it was also recognized that demonstration applications would be needed to convince potential collaborators that the approach and tools would be useful to them. Therefore, in West Africa an initial application using available data was prepared for the Senegal peanut basin and was used for the Dakar workshop held in November 2003. Likewise, a preliminary application in Machakos, Kenya was developed for the Nairobi workshop held in September 2004.

The latter application was based on the Nutrient Monitoring data collected by Wageningen University Research Center (Netherlands) (WUR) and Landbouw Economisch Institute (LEI). As part of this application development, procedures were developed to extract the Nutrient Monitoring data and put them into the format that could be used for implementation of TOA models. In addition, an interface has been developed that allows for calculations of soil nutrient balances (using the NutMon methodology) from within the TOA software. The economic model for the Machakos analysis incorporated a new design that represents a whole-farm, integrated crop-livestock system. Measures of poverty and food security were developed and incorporated into the Machakos model as well. Methods for efficient soil and climatic data collection were developed including digital soil mapping techniques and the interpolation methods for weather station data.

Project Year 8

A TOA training workshop was held in Nairobi in September 2004 for scientists and institutions working in the East Africa region. Based on this workshop, three collaborative agreements were established in the region with national and international institutions in Kenya and Uganda. A “minimum data” (MD) method for economic analysis in the TOA framework was developed and prepared for publication. In collaboration with CIP’s (International Potato Center, Lima, Peru) Ecoregional Fund project in Panama, a TOA training workshop was held in Panama for IDIAP scientists in February 2005, based on the MD approach, and presented to Panamanian officials in May 2005. In West Africa, agreement was reached with the Senegalese Agricultural Research Institute (ISRA) for ISRA’s Bureau of Macroeconomic Analysis (BAME) to utilize TOA tools for analysis of policies and sustainability in Senegal’s peanut basin region. The BAME team initiated data collection to support this collaboration. Also in West Africa, collaboration continued with the SM CRSP carbon project (Jim Jones) and scientists from the Sahel Agriculture Research Institute in Ghana. Economic data from two villages was collected to support an economic analysis of carbon sequestration potential.

Two training workshops (in Kenya and Panama) were conducted in PY8, with participants from ICRAF, ILRI, KARI and Egerton University, from Makerere University in Uganda, and from IDIAP in Panama. Collaboration with KARI to use TOA in a Global Environment Facility (GEF)-supported project in Western Kenya was initiated. Collaboration with Makerere University was established to use TOA software in an interdisciplinary MSc program in agricultural policy analysis. An agreement was reached with CIP to use TOA as the basis for further development of its NRM program in East Africa and for development of new funding proposals led by CIP. In West Africa, collaboration was initiated with the Bureau of Macroeconomic Analysis (ISRA, Senegal) and with the Sahel Agricultural Research Institute (Ghana) and plans to scale-up the peanut basin analysis were made and implementation started. A new "minimum data" method for economic analysis was developed and implemented in the U.S. and in Panama. Linkages between the Nutrient Monitoring system and TOA were further developed and documented in publications. Project results were published in refereed journals and presented at scientific conferences.

A major methodological innovation completed in PY8 was the development of a "minimum data" (MD) approach to characterizing the economic models used in TOA. A paper on this approach was prepared and submitted for publication. At the request of CIP's Ecoregional Research project (led by Roberto Quiroz) and IDIAP in Panama, a TOA training workshop for a group of IDIAP scientists was held in February 2005. This workshop was based on the MD modeling approach and was judged to be highly successful by the participants. IDIAP subsequently developed a TOA application for a potato-producing region of Panama to assess potential for integrated pest management adoption and associated environmental and human health benefits. A workshop organized by IDIAP was held in May 2005 in Panama to present the findings of the preliminary TOA application to Ministry of Agriculture officials and to develop plans for further collaboration and application of TOA in Panama.

A TOA training workshop was held in Nairobi in September 2004. Participants from this workshop included scientists from ILRI as well as from three teams who plan to use TOA:

- The KARI/ICRAF project on carbon sequestration and water quality protection in Western Kenya funded by the Global Environmental Facility (GEF).
- The Njoro watershed project based at Egerton University, funded by the Pond Dynamics-Global Livestock CRSPs.
- The Pallisa, Uganda Nutrient Monitoring study led by Makerere University in collaboration with LEI/WUR.

In addition, collaboration continued with the analysis of soil degradation in Machakos, and results were presented at the WUR Ecoregional Research workshop held in Nairobi in June 2005. A collection of papers reporting findings were prepared and published. Findings were also presented at an FAO-sponsored workshop on environmental services in Rome in May 2005.

In West Africa in PY8, agreement was reached with the Senegalese Agricultural Research Institute (ISRA) to incorporate ISRA's Bureau of Macroeconomic Analysis (BAME) into the TOA analysis of policies and sustainability in Senegal's peanut basin region. The BAME participation supported collection of data to incorporate off-farm income and a livestock component into the analysis. This activity will also add additional data from the Ecole National d'Economie Applique (National School of Applied Economics) so that the analysis can be scaled up to the entire peanut basin area of Senegal. A project meeting to present preliminary results will be held in Fall 2005 in Dakar, with a workshop planned for 2006 to present results of this collaboration to stakeholders in government and non-governmental organizations.

Also in West Africa, collaboration continued with the SM CRSP Carbon Sequestration project (Jim Jones) and scientists from the Sahel Agriculture Research Institute in Ghana. Economic data from two villages was collected to support an economic analysis of carbon sequestration potential.

Other Accomplishments

Analysis of System Dynamics

A journal article on system dynamics was accepted for publication. A paper on existence of multiple equilibria in production systems was completed and submitted for publication.

Analysis of Carbon Sequestration Potential

A paper was prepared for publication in a special issue of *Agricultural Systems* on analysis of carbon sequestration potential in Senegal. A presentation was made at the FAO-sponsored workshop on Environmental Services and Poverty (May 2005), based on analysis of carbon sequestration in Peru, Senegal and Kenya. The organizers invited a paper to be prepared for a special issue of *Environment and Development Economics* on this topic. Analysis of carbon sequestration in agro-forestry systems in Peru was completed, and a Master's thesis on this topic was completed at the National Agrarian University.

Collaboration with LEI and WUR on Nutrient Monitoring Analysis in East Africa

Collaboration continued with the analysis of soil degradation in Machakos, and results were presented at the WUR Ecoregional Research workshop held at ILRI in June 2005. A collection of papers reporting findings was prepared for publication.

Collaboration with ISRA in Senegal Peanut Basin Study

In West Africa, agreement was reached with the Senegalese Agricultural Research Institute (ISRA) to incorporate ISRA's Bureau of Macroeconomic Analysis (BAME) into the TOA analysis of policies and sustainability in Senegal's peanut basin region. The BAME participation supported collection of data to incorporate off-farm income and a livestock component into the analysis. A project meeting to present preliminary results will be held in September 2005 in Dakar, with a workshop planned for 2006 to present results of this collaboration to stakeholders in government and non-governmental organizations.

Collaboration with Makerere University in Uganda

Following up from the Nairobi workshop, the TOA team met with the Makerere team at Makerere University in February 2005, and at Wageningen University and Montana State University in May 2005, to implement the NUTMON/TOA application in Pallisa district of Uganda. In June 2005, J. Antle presented at a seminar on TOA to the Faculty of Agriculture at Makerere University and met with the Dean and with the Head of the Agricultural Economics program. Agreement was reached to develop a research and training program that would integrate TOA tools into the Collaborative MSc program in agricultural economics that involves universities from East and South Africa. A concept note was prepared for the Forum for Capacity Building in Agriculture based at Makerere University. The Forum was established by the Rockefeller Foundation.

Objective 2: Develop Methods to Scale-up the Analysis Possible with the TOA Method from Single Agro-ecozones to Larger Regional Scales

Project Years 6 and 7

Several strategies were developed for scaling up TOA analysis:

- Using available secondary, aggregated data (e.g., district-level census data) to construct economic land-use models. Data availability in Peru was assessed. An economic modeling methodology was developed and successfully implemented in a complementary project in the central U.S. region by the project PI.
- CIP collaborators (led by Quiroz) investigated the use of fractal methods to scale-up results.
- A proposal by CIP collaborators was developed to extrapolate analysis of human health impacts of pesticides from case studies to larger regions (this is a continuation of work carried out in the previous phase of SM CRSP research in Ecuador).
- The TOA project PI initiated work on development of a "minimum data" (MD) approach to economic modeling for TOA applications. This approach was designed to allow implementation of economic models using existing secondary data (e.g., average yields and costs of production, and measures of spatial variability in yields and costs) rather than requiring extensive farm survey data. MD methods for crop models and environmental process models are also being investigated.

Project Year 8

The minimum data approach was further developed using data from the United States, and a paper on this methodology was prepared and submitted for publication. A MD application in Panama was implemented.

Agreement was reached with the CIP Natural Resources Management program (led by Quiroz) to utilize the Nutrient Monitoring-TOA systems to develop a regional policy analysis tool for the East African region. Agreement was reached to jointly support two PhD thesis projects at WUR, and a post-doctoral researcher based at CIP's Nairobi office, all working on this theme. The plan is to utilize the set of Nutrient Monitoring case studies in Kenya, Ethiopia and Uganda to develop TOA applications and scale-up these studies to the regional level. In addition, as noted above, the Senegal peanut basin study aims to scale up the analysis from case study areas to the larger peanut basin region.

Minimum Data Methods

A significant limitation to widespread application of spatially-explicit simulation tools is the need for a large amount of data. A notable accomplishment of Year 8 was the development and testing of "minimum data" (MD) methods to parameterize the economic models used in TOA. A paper on this approach was prepared and submitted for publication. Concepts for minimum-data versions of bio-physical simulation models were investigated, and a publication is planned for PY9.

Scaling Up TOA Analysis to the Regional Level in East Africa

Agreement was reached with the CIP Natural Resources Management program (led by Quiroz) to utilize the Nutrient Monitoring-TOA systems to develop a regional policy analysis tool for the East African region. Agreement was reached to jointly support two PhD thesis projects at WUR, and a post-doctoral researcher based at CIP's Nairobi office, all working on this theme. The plan is to utilize the set of Nutrient Monitoring case studies in Kenya, Ethiopia and Uganda to develop TOA applications and scale-up these studies to the regional level.

Methods to Link TOA to Market Models

Methods to link TOA analysis with market-equilibrium models were developed and incorporated into Roberto Valdivia's PhD proposal for Wageningen University.

Analysis of Climate Change Impacts

Analysis of climate change impacts in Peru was completed, and preparation of publications was begun. Analysis of climate change impacts in Senegal and Kenya was started and will be completed and written up in PY9.

Objective 3: Development of Protocols and Materials to Transfer the TOA Method and TOA Model Software to Existing and Future User Groups

Project Years 6 and 7

Jetse Stoorvogel of WUR created a web site for the TOA Model (www.tradeoffs.nl) with on-line training materials in PY6. The TOA model, sample programs, and workshop materials can be downloaded from this web site. These materials formed the basis for the Senegal workshop and were revised and used for the workshops in Kenya and Panama.

Through our Phase 2 experiences developing new collaborations, we have established a process for transferring the TOA method and tools to clients. The process of institutionalization includes the following steps:

- Informing client staff about TOA products.
- Training in use of TOA products (seminars, workshops).
- Formalization of an agreement for the client to use TOA with support from the TOA team.
- Execution of TOA by client project staff with backstopping of TOA-team.
- Follow-up meetings to assess findings, get feedback from clients on strengths and weaknesses of methods and software.

Procedures for linking data collected with the Nutrient Monitoring system to TOA analysis were developed in Year 7. This linkage will be used to expand the general applicability of the TOA method and software and to develop further collaborations in the East Africa region and elsewhere in the world that the NUTMON methodology has been applied.

Project Year 8

The methods for linking the Nutrient Monitoring data to TOA were further developed and documented in a set of publications prepared for the WUR Ecoregional Research workshop held at ILRI in June 2005. The TOA on-line course, developed for the Dakar and Nairobi workshops, was updated and adapted to the minimum data methodology.

This new version was used for the Panama training workshop held in February 2005.

An agreement was reached with Makerere University in Uganda to incorporate the TOA method and tools into its Collaborative MSc program in agricultural economics (a program involving universities in East and Southern Africa). A concept note for funding this activity was prepared for the Regional Universities Forum for Capacity Building in Agriculture based at Makerere University.

A memorandum of understanding was developed with CIP regarding the use of TOA as the basis for CIP's natural resource management programs in East Africa.

TOA On-Line Course and Workshop Training Materials

The TOA on-line course, developed for the Dakar and Nairobi workshops, was updated and adapted to the minimum data methodology. This new version was used for the Panama training workshop held in February 2005. These materials are available at the TOA Model website *www.tradeoffs.nl*.

Using TOA Software for Graduate Training

An agreement was reached with Makerere University in Uganda to incorporate the TOA method and tools into its Collaborative MSc program in agricultural economics (a program involving universities in East and Southern Africa). J. Antle met with the Department Head of agricultural economics and the Dean of the Faculty of Agriculture to discuss this collaboration. J. Antle also presented a seminar to the Faculty of Agriculture about the TOA project. The outcome was a concept note for funding this activity prepared for the Regional Universities Forum for Capacity Building in Agriculture based at Makerere University.

Institutionalization of TOA in CIP

A memorandum of understanding was developed with CIP regarding the use of TOA as the basis for CIP's natural resource management programs in East Africa. Agreement was reached to jointly support a post-doc position at CIP in Nairobi to coordinate TOA activities in East Africa.

RICE–WHEAT SYSTEMS

Project: Enhancing Technology Adoption for the Rice-Wheat Cropping System of the Indo-Gangetic Plains

Principal Investigators: John M. Duxbury and Julie G. Lauren, Cornell University

Introduction

Our focus in PY8 has been to expand training and support of technology transfer to new partners, along with farmer appraisal, evaluation of productivity and biophysical impacts and assessment of adoption. Emphasis has remained on the Healthy Seedling technology.

We collaborate with technology transfer partners who have the capacity to reach large numbers of farmers, and use NARES scientists to provide training and technical backstopping. This strategy builds upon other program investments by AID. We primarily collaborate with international and large national NGOs and national extension systems. The international NGOs we collaborated with in PY8 were CARE and WINROCK International. Large national NGO partners in Bangladesh were the Bangladesh Rural Advancement Committee (BRAC) and Rangpur-Dinajpur Rural Service (RDRS). All of these institutions leverage local capacity by working through a network of local NGOs. In Nepal, we also partnered with two smaller NGOs FORWARD and Educate the Children (ETC). An exploratory extension of the Healthy Seedling and micronutrient enriched seed technologies for rice was initiated in NE Thailand through partnership with Mahasrakham University and Ministry of Agriculture Rice Research Centers at Khon Kaen and Ubon Ratchathani.

Our partnerships with CARE, RDRS and WINROCK (Nepal) target resource poor, small farms and especially women farmer groups. Partnerships with national extension systems and WINROCK (Bangladesh) tend to target average to large size farms. Our partnerships with BRAC and East-West Seeds in Bangladesh target the commercial seed production sector.

Technology adoption activities in PY8 utilized the following technologies:

- Healthy seedlings of rice and vegetables through use of solarized soil seedbeds;
- Micronutrient enriched seeds;
- Permanent raised beds for crop production in the rice-wheat system;
- Surface seeding of wheat; and
- Liming program for Bangladesh.

Objective 1: Develop Methods to Accelerate Technology Transfer of Soil Management Products and Practices and Scale Up Technology Adoption from Local to National and Regional Scales

In this year we have continued to train and support technology transfer with partners, together with evaluation of technology impact and farmer appraisal of the technologies. Our greatest effort is directed to our Healthy Seedling technology, the transfer of which has been expanded. Adoption studies have also been carried out with this technology. Progress with individual technologies is as follows.

Healthy Seedling Production for Rice and Vegetables

Partner Training and Technology Transfer

Collaborations continued in PY8 with CARE, Bangladesh and Nepal, BRAC and DAE, Bangladesh and programs with new transfer partners were also initiated (Table 5). A big push with solarization was made by CARE Bangladesh to coincide with their last year of funding for the Rural Livelihoods Program. New transfer partners in Bangladesh were the Rangpur-Dinajpur Rural Development Service (RDRS) and East-West Seeds, Inc. In Nepal we conducted training workshops and started extension of Healthy Seedlings technology with FORWARD (an NGO operating with DFID funding), WINROCK and IDE's International Smallholder Irrigation Market Initiative (SIMI) and Educate the Children (ETC), a small NGO, focusing particularly on women and children from ethnic minorities and dalit castes in the mid-hills region.

Table 5. Summary of Healthy Seedlings technology transfer activities in PY8.

Partner	Groups/Venue	Gender (Caste)	Farm HH's	Locations
Bangladesh				
CARE	234 FFS (rice)	100% male	5,850	Gaibandha, Joypurhat, Niphamari, Rangpur, Panchagarh, Thakurgaon
	323 FFS (rice)	90% female	8,075	Kurigram, Lalmonirhat, Gaibandha, Niphamari, Thakurgaon, Joypurhat
BRAC	Contract rice growers	100% male	20	Meherpur, Thakurgaon, Dinajpur
	Contract veg. growers		31	Meherpur, Chaudanga, Thakurgaon, Dinajpur
DAE	District ext. (rice)	100% male	30	Dinajpur
	District ext. (veg.)		20	
RDRS	7 FFS, 5 district training centers (rice and veg.)	63% female	140	Thakurgaon, Pirganj, Lalmonirhat, Panchagarh, Rangpur
East West Seeds, Inc.	Central farm (veg.)	-	-	Gazipur
BARI Horticulture Research Centre	Experiment station	-	-	Gazipur
Nepal				
CARE	10 FFS (rice)	55% female, 8% dalit	250	Mahottari, Sarlahi
FORWARD	Demo locations	23% female	22	Jhapa, Saptari, Kapilbastu
Winrock Intnl. SIMI	1 farmer group	23% female	26	Rupandehi
Educate the Children	2 women groups; 1 gov. school	100% female, 25% dalit	30	Kathmandu, Lalitpur VDCs

Information transfer materials (handouts and flip charts), developed last year were distributed to all groups for farmer training sessions. In addition CARE, Bangladesh included clips of the Healthy Seedlings technology in an informational video, entitled *Farmers Empowerment*.

Targeting Healthy Seedling Technology for Rice in Bangladesh and Nepal

In PY7, the impact of Healthy Seedlings of rice on crop productivity showed significant variation by site in Bangladesh. In addition a positive relationship between nematode gall counts on rice seedlings from unsolarized nurseries and yield responses to nursery solarization was found. These results suggested the Healthy Seedling technology would have the most impact on farms with high levels of nematode galls on unsolarized nursery seedlings. Surveys of galls on farmer rice seedlings could be used to target areas where the technology would have the greatest effect.

During PY8, nematode galls were counted from 10 rice seedlings at randomly selected farmer seedbeds in Nepal's Terai and Northwest Bangladesh. Locations of the selected sampling sites were noted with coordinates from GPS readings along with soil texture and seedbed condition (flooded/unflooded).

Figure 5 shows the distribution of gall counts at 286 sites in the Nepal Terai. Gall numbers on rice seedlings increase from West to East, along a texture gradient—clayey soils in the West to sandy soils in the East. This finding is consistent with what others have reported in the literature (Norton, 1979; Trudgill *et al.*, 2000). Median yield responses to Healthy Seedlings of 10-13 percent with maximum yields of 16-34 percent (Figure 5 inset) were found in Jhapa, Mahottari and Sarlahi districts where high gall counts were found. However the Kapilbastu district, with very low levels of nematode galls in seedbeds, showed the highest yield response to nursery soil solarization, which is not consistent with our targeting hypothesis.

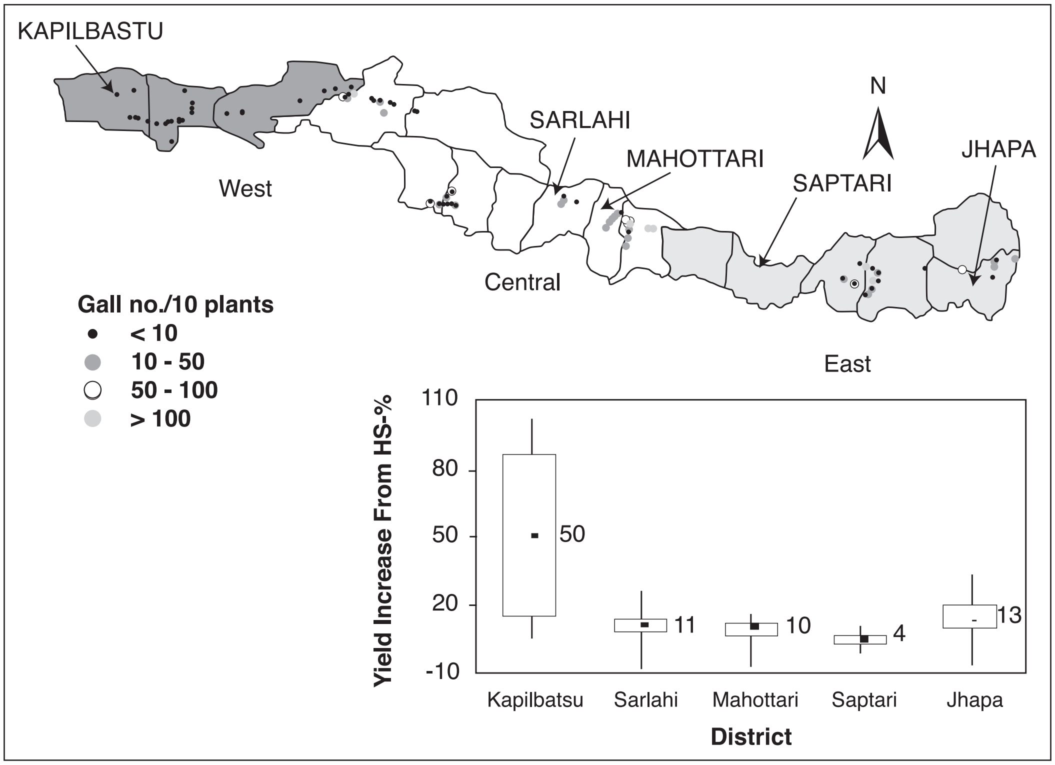

Figure 5. Nematode gall survey results from Nepal terai, summer rice nurseries 2004. (inset) Box and whisker plot of yield responses from Healthy Seedlings in five districts of the Nepal terai.

Gall survey results from 459 Northwest Bangladesh sites were similar to results from Nepal. Higher gall numbers per 10 seedlings were found in the lighter textured soils and less in the clayey soils. In 2004, median rice yield responses to Healthy Seedlings ranged from 7-11 percent with maximums of 11-52 percent in most of these districts.

Healthy Seedlings Impacts on Vegetable Performance

Results with Healthy Seedlings for vegetables continue to be encouraging, and farmers introduced to the technology are very enthusiastic about the benefits. To date farmers have used Healthy Seedlings for cole crops, brinjal, tomato, chili, Indian spinach, kangkong, onion, potato and bitter gourd. During PY8, data were collected to support farmer observations on the impacts of nursery solarization on vegetable seedling and main field plant parameters. Enhanced emergence, substantial decreases in nematode galls and infected seedlings point to better soil health conditions in the nursery with less pressure from soil borne pathogens. As a result of the improved growing medium, seedlings developed 19-26 percent longer root systems and 10-22 percent taller plants. In main fields, nematode gall numbers did not increase as much on solarized seedlings as on normal seedlings. Better growth overall translated into more fruit per plant for brinjal, kangkong and tomato and greater fruit weight for all vegetables.

PY8 yield increases using Healthy Seedlings for cole crops, brinjal and tomato averaged 22, 28 and 30 percent, respectively.

Impacts of Healthy Seedlings on Insects and Diseases

From the beginning of the extension work with Healthy Seedlings in Nepal and Bangladesh, farmers have observed that insect and disease pressures are less, and as a consequence the need for spraying is reduced. Insecticides and pesticides are often used in excess for rice and vegetables in South Asia. These inputs burden farmers and consumers with additional management costs and adverse health impacts. Opportunities to reduce use of non-essential insecticides and pesticides can only be positive. Insect and disease surveys were carried out during 2004-05 rice and winter vegetable seasons in order to quantify the impact of Healthy Seedlings on major insects and diseases in these crops. Data were collected from Healthy Seedling and normal seedling comparison plots at 31 sites for rice and 3-19 sites for vegetables at seedbed and main field stages. Insect and disease pressure was determined by counts/scoring (on 10 seedlings or plants) or by net sweeping. Rice plants from solarized seedbeds had consistently lower insect and disease incidence than plants from normal seedbeds, and in most cases the differences were statistically significant. Insects causing white head and gall midge were significantly less at all sites, along with sheath blight and sheath rot. Only beneficial insect numbers were not affected by the solarization treatment.

Consistently less insects and diseases were also found on vegetable plants from Healthy Seedlings; however, the differences were not always statistically different. Only leaf miner and wilt in tomato and prodenia caterpillar and head rot in cabbage were statistically less in plants from solarized seedbeds. The results confirm that root knot nematode infects tomato, brinjal and cole crops and that soil solarization of seedbeds can reduce this infection substantially.

Technology Adoption Studies

Adoption surveys were undertaken during the PY8 rice and vegetable seasons to document the impact of our technology transfer approaches for Healthy Seedlings. Farmers who had participated in initial transfer of the technology through either farmer field schools (FFS) or demonstrations were questioned about whether they were still using the technology, their understanding of the technology and what problems or benefits they may have encountered. In addition secondary adoption by farmer-to-farmer transfer was measured by surveying farmers who did not participate in the FFS.

Rice

A total of 140 responses were collected from Bangladesh and Nepal for rice. As expected, the initial year results show that a majority of the respondents practiced the Healthy Seedlings technology for rice. In the second year, the numbers of adopters increased with the CARE Bangladesh group farmers, while the DAE and CARE Nepal groups showed some reductions. Nevertheless 67-71 percent adoption of the Healthy Seedlings technology in the second year after introduction indicates reasonable success for these groups. Farmer-to-farmer transfer also appeared successful outside the CARE Nepal and DAE groups. Additional indicators of farmer enthusiasm for solarization include: 55-123 percent increases in solarized seedbed areas by the CARE Nepal and DAE groups; and a willingness to purchase new plastic by 44-100 percent of respondents in the CARE Bangladesh, DAE and CARE Nepal groups.

The one exception was the BRAC farmer group where adoption plummeted to only 18 percent in the second year. The BRAC farmers have substantially larger rice areas (average 6 acres) compared to the CARE and DAE groups (average 1.5 and 3 acres, respectively). BRAC farmers commented that plastic for such large nursery areas was costly. In addition BRAC farmers as contract seed growers have little financial incentive to produce more rice. Therefore increased rice production does not serve as motivation to increase cash flow or improve livelihoods for these farmers. We assume that food security is not a major concern for the BRAC farmers, but is likely important for the CARE and DAE farmer groups. For rice and vegetables, responses to questions about the solarization process, critical factors and understanding the function of solarization indicated that training was done correctly by all transfer partners and between farmers. A few farmers in the DAE rice group (17 percent) and the CARE Bangladesh vegetable group (3 percent) reported using blue plastic instead of transparent plastic. In Nepal, 13 percent of the farmers buying new plastic commented that only poor quality plastic was available and it was prone to holes, because it was too thin. Ensuring that service providers have good quality plastic is essential for the adoption of the Healthy Seedlings technology.

Vegetables

Survey responses on Healthy Seedlings for vegetables were obtained from 97 Bangladeshi farmers (Table 6). The increase in the number of adopters between the first and second years was more dramatic than for rice. Adoption through farmer-to-farmer transfer was also quite high. As with rice, CARE Bangladesh and DAE respondents increased seedbed solarization areas from 1.5 to 20 fold for vegetables, and 55-65 percent of the farmers made the investment of new plastic for the solarization.

The increase in fruit number and fruit weight from Healthy Seedlings allows farmers to sell their produce for 50-70 percent more than fruit from non-solarized nursery seedlings (see PY2 SM CRSP Annual Report—*One Farmer's Experience*). The CARE Bangladesh survey also recorded prices that

Table 6. Adoption of Healthy Seedlings technology for vegetables, 2003-2005.

		Respondents Practicing Solarization		
Transfer	**n**	**2003-04**	**2004-05**	
		Participants	**Participants**	**Non-Participants**
CARE	51/26*	43%	98%	96%
DAE	17/3*	65%	100%	100%

*Number of participants/non-participants.

farmers were getting from sales of Healthy Seedlings relative to normal seedlings. Healthy Seedlings ranged from 7-60 Taka/100 seedlings, while normal seedlings ranged from 5-40 Taka/100 seedlings. Clearly raising market prices from 25 to 300 percent (and produce too) is a major factor encouraging farmers to adopt the Healthy Seedling technology.

Extension of Healthy Seedling Technology to NE Thailand

Root knot nematode is known to be a problem for rice production on low fertility, sandy soils in northern Thailand, which is consistent with an IRRI GIS analysis showing that the drought risk for rainfed lowland rice in Northern Thailand is severe to very severe. Two of our technologies, Healthy Seedlings and Zn enriched seed have the potential to address this problem. A three-way partnership between Mahasrakham University and the Ministry of Agriculture Rice Research Centers at Khon Kaen and Ubon Ratchathani has been developed to undertake an exploratory study with these technologies beginning with the upcoming 2005 rice season.

Micronutrient Enriched Seed of Rice and Wheat

Farmer generation and evaluation of micronutrient enriched seed of rice and wheat continued in NW Bangladesh. As reported in PY7, soil fertilization with Zn, Cu and Mo increased Mo in rice but not Zn or Cu. Nevertheless, farmers undertook an evaluation of this seed compared to non-enriched control seed. In general crop yield was increased with Mo enriched seed; by a mean amount of 0.55 t/ha (16 percent) for BR 39, 0.39 t/ha (15 percent) for BR 33 and 0.2 t/ha (6 percent) for Shorna. The increase in yield with Mo enriched seed is not entirely unexpected as we have seen rice responses to this nutrient before. Ten farmers continued with generation of micronutrient enriched seed through soil fertilization and saw a small increase in yield with addition of micronutrients.

Greenhouse experiments are underway at Cornell to determine if addition of Zn to the floodwater will increase grain Zn content of rice. Our hypothesis is that Zn will remain available if it is localized in the surface 0.5 cm of soil and remains aerobic in a rice paddy. If this strategy is successful it will provide a simpler way of increasing grain Zn content than foliar fertilization. The farmers grew wheat in the same plots following rice without further micronutrient addition in the 2003-04 winter season. Wheat seed was enriched with both Zn and Mo. Mean wheat yield in the 2004-05 winter season increased by 0.5 t/ha (17 percent) with the enriched seed compared to the non-enriched, control seed. The mean yield from non-enriched seed growing in the micronutrient fertilized plot (to generate new enriched seed) was intermediate between that of the micronutrient enriched and control seed, showing some benefit to micronutrient fertilization.

Bed Planting

Technology Transfer

In PY7 we reported on yields of wheat for the three groups of farmers (26 total) from Rajshahi and Natore districts, Bangladesh who were recruited and trained on bed planting in a triple crop rotation of wheat, mungbean and rice. With the exception of three farmers from Duary, these farmers continued the comparison between bed planting and their conventional practice on the flat through mungbean and rice seasons 2004. Mungbean yields were fairly low without irrigation; indeed no grain was obtained by farmers at Durgapur as seed did not germinate until one month after sowing due to lack of rain and it was then too late for seed production. Bed planting increased average mungbean yield at Duary and Santospur by 28 and 5 percent, respectively, and increased average rice yield between 13-16 percent at the three sites. Overall, the bed planting experience was positive with each of the three crops grown.

Following the first rotation cycle, farmers at Duary contracted with the Bangladesh Agricultural Development Corporation (BADC; government seed producer) for seed production and dropped the permanent bed—conventional practice comparison. Four of five farmers at Santospur continued and one new farmer started. At Durgapur, the number of farmers increased from 6 to 24. Two of the original six inadvertently destroyed their beds and started over with new beds. Wheat yields were again generally higher on beds than with conventional practice. Average wheat yield increased by 16 and 5 percent at Durgapor and Santospur, respectively. A comparison of wheat yields for farmers who continued permanent beds from the previous rotation cycle did not show any evidence of reduction in yields on the permanent beds in the second wheat season.

Farmer observations on the bed system were collected at all three sites. Farmers at Duary and Durgapur indicated that weeds were a problem following mungbean and suggested growing either jute, which drops it leaves and usually leaves a weed free soil at the beginning of the rice season, or Sesbania, which also suppresses weed growth. Farmers also observed that the wider spacing of rows on the beds led to more light for the plants, which they judged to be positive. The cost of land preparation for beds was initially higher than conventional practice and subsequently was reduced in subsequent years. In the initial year, the bed system would save Tk 100/bigha (1/3 acre) in tillage compared to conventional practice over the three crop cycle, and a savings of Tk 250/bigha in subsequent years.

A "Bed Planting" farmer field day was held at Durgapur in March 2005 when wheat was close to maturity. About 200 people attended including upazilla level agricultural staff, CIMMYT scientists, two TV and two daily newspaper reporters. Hanif, a farmer who was also the bed forming service provider, and the farmers discussed bed planting and shared experiences, with scientists supporting as necessary. The level of interest was high among all participants.

Workshop on Technology Transfer of Permanent Beds in the Rice-Wheat System

On 19 January 2005 a workshop was held at the CIMMYT office in Bangladesh to document impacts and experiences of permanent bed planting efforts in Nepal and Bangladesh to date. In addition we attempted to identify constraint/problem areas for additional research and to develop strategies for expanding technology transfer and promotion of permanent beds. Participants represented programs that were funded by the SM CRSP, Food and Agriculture Organization, International Fund for Agricultural Development, Asian Development Bank and CIMMYT Bangladesh, Nepal and Mexico. National institutions present were BARI, BAU, BRRI, DAE and NARC. Findings from the workshop are presented below.

Crop Productivity and Management

Many programs have worked more with beds rather than permanent beds and experience with permanent beds (PB) is limited and variable. Declining yield trends of rice and wheat with permanent beds have been observed in NW India. Rice yields were reported lower than with conventional practice. Yields were also often reported higher on fresh beds than on permanent beds. These results contrast with the SM CRSP experience with three permanent bed experiments (two in Bangladesh and one in Nepal) where yields in a triple crop rice-wheat-mungbean rotation are consistently higher on permanent beds than with conventional practice on the flat.

An FAO funded project (Sept 03-May 05) used a farmer participatory approach at six sites (Dinajpur, Jessore, Rajshahi, Jamalpur, Noakhali and Barisal) in Bangladesh to evaluate a range of tillage technologies, including zero-till, strip-till, Chinese 2 wheel power operated tiller-seeder (POTS), and bed planting relative to conventional practice. Equipment was provided and technologies were split amongst the sites so that each site compared three technologies. A farmer preference survey indicated that the POTS and strip-till drill were preferred over beds, with zero-till being least preferred. Overall results showed no yield difference between POTS, beds and conventional practice but performance varied at specific sites.

Use of residues as mulches at high rates (6 t/ha) often reduced yields in ACIAR funded experiments on light textured soils in NW India, possibly by inducing N deficiencies. In contrast limited experience in Bangladesh (CIMMYT and SM CRSP) and Nepal (SM CRSP) shows yield benefits with mulch at rates of 3 to 4 t/ha. The mulch appears to improve N use efficiency and reduce weed pressure. Chopped residues can create difficulties for irrigation if they clog the furrow and longer residue pieces may be a preventative measure.

Machinery Issues

Two basic types of machinery are available for making beds. The FIRBS bed former-planter developed by PAU, India for use with the four-wheel tractor is used mostly in NW India and Nepal. A lighter adaptation of this is used for the two-wheel Chinese tractor, and has an optional seeder/fertilizer attachment. Problems with manufacturing quality were found with the various versions of both types of bed former. It was emphasized that machinery needs to have multi-crop functionality. Providing two depth gauge wheels, rather than a single wheel, was considered a necessary modification for the Chinese tractor bed former/seeder system.

Recommendations

- The PB (Permanent Bed) technology is not mature enough for widespread technology transfer. It is at the experimental and participatory research stage. Both research and extension scientists need more experience with the technology. Incentives to farmers will likely be needed to remove perceived risk in trying the technology. These may include seed, fertilizer and assistance with machinery needs. It was recognized, however, that providing incentives complicates evaluation of technology adoption and is best avoided when the technology transfer stage is reached.
- The need to work at the cropping system level, rather than with one crop was emphasized. For the PB approach to be adoptable by farmers in Bangladesh and most other S. Asian countries it must be successful with rice.
- Machinery service providers are commonly used for land preparation and this group needs to be included from the outset in PB programs. Experience has shown that it is best to work with existing service providers rather than trying to create new service providers. This sector can be an important driver for technology adoption.
- The transition from conventional practice to permanent beds is complex and needs long-term study. Production issues that need research at this time are clod formation in heavier textured soils, weed management, nutrient management and use of residues as mulches to improve soil structure at the soil surface.

Surface Seeding of Wheat

The survey report on surface seeding in Nepal in PY7 has been prepared for publication in the Rice-Wheat Consortium series. Planned activities to revisit the technology with farmers in Rupandehi district who disadopted the technology were not implemented due to travel and safety problems associated with the Maoist insurgency.

Technology Adoption and Scaling Issues

The Challenge

Technology transfer to farmers in developing countries is a complex and difficult process. The client farmers are resource poor, have little education and lack the ready access to knowledge and the technology and financial support systems available to developed country farmers. Their sheer numbers mean that technology transfer programs must reach orders of magnitude more people than in developed countries; in Bangladesh there are 13 million farm households compared to 1.9 million in the USA.

Technology Transfer Approaches

Agricultural technology transfer programs in Bangladesh and Nepal can be categorized as the:

- Government approach, i.e., the national extension system, with its traditional agricultural production mandate;
- NGO approach, which is supported by developed country donors (governments and foundations), and generally has the broad goal of improving farmer livelihoods;
- Business development services or value chain approach, which involves the range of components that are needed to make agriculture succeed, from private sector agricultural manufacturers and input suppliers, to credit and product marketing.

Unfortunately, lack of financial resources and performance incentives, together with unwieldy bureaucracies limit the effectiveness of the national extension systems in Bangladesh and Nepal. The “rise” of the NGO community is partly a response to this situation, but is also closely linked to the availability of substantial levels of funding from the global donor community.

Our general experience is that most farmers in Bangladesh and Nepal lack the knowledge to improve crop productivity and management of natural resources. At the same time, most soil and natural resource management technologies require knowledge for successful implementation. This means that the technology transfer process has to impart knowledge and a knowledge support system must be in place to provide continuing support.

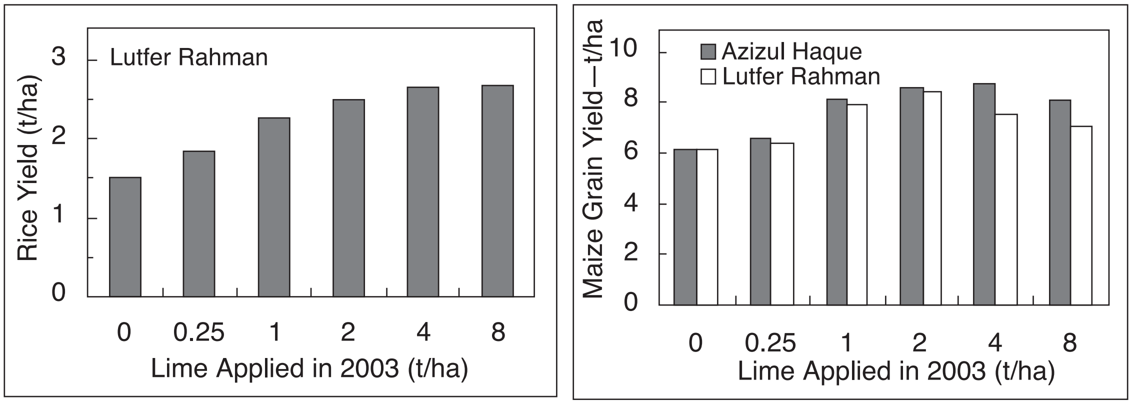

Figure 6. Effects of lime rate on yields of rice and maize at Patgram, Bangladesh.

This is important because trained farmers are expected to transfer their knowledge of technologies to four to six other farmers. An example of where this went wrong with the Healthy Seedling technology was when some secondary adopters used less costly blue plastic instead of transparent plastic for soil solarization. The farmers who passed on the technology used the correct plastic and did understand that heating of soil was the basis of the technology.

Technology transfer approaches such as farmer field schools (FFS) used by larger NGOs like CARE and RDRS provide a forum to educate farmers in management principles on a particular topic, e.g., IPM, over an extended period of time. The FFS utilizes a group study plot as a field learning laboratory for technologies such as Healthy Seedlings. CARE offers a basket of technologies and farmers are free to choose what they implement on their own farm. The FFS approach can be very effective but is costly.

Our experience in working with the NGOs is generally very positive; they are committed to their programs, they have good national staff and they work hard. CARE's commitment to employing women and to work with women farmers is particularly notable.

In contrast to CARE and RDRS, WINROCK's agriculture program in S. Asia focuses on linking smallholder agricultural production to market opportunities. Their SIMI program in Nepal uses micro-irrigation technologies to boost production of vegetables, including off-season production when market prices are high. In this case they organize the manufacturing of equipment, train farmers in its use and establish wholesale vegetable collection centers and consumer markets. The value chain approach usually requires building partnerships in order to implement programs.

The value chain approach seems more sustainable provided that it succeeds for each component in the chain. However, it may still require some third party to maintain quality and promote knowledge transfer over time. It also provides an opportunity for private sector suppliers of agricultural goods and services to assume an educational role; we have not yet had experience with this through our project, but it seems that suppliers would need to see some gain for themselves before they would participate in this way. A potential stumbling block is that the quality of service providers is often cited as a problem for agriculture in Bangladesh and Nepal.

Our adoption studies to date show that the various technology transfer processes have generally been successful. However, the sustainability of the different approaches used by international NGOs is a major question.

Drivers of Technology Adoption

The drivers for technology adoption are many and varied. For crop production, farmers are generally more responsive to technologies that improve the productivity of high value crops such as off season vegetables than they are to technologies that improve the productivity of staple crops.

Our technology transfer partners were most interested in technologies that were simple and had broad application. The Healthy Seedling technology matched these requirements. It was most readily adopted where its use provided clear economic benefits for farmers, such as increasing the value of vegetable seedlings and produce (because they were of higher quality) and helping farmers to meet early or off season markets with high quality produce.

Targeting of technologies to appropriate soil environments, farm size and economic status will enhance the probability of adoption. Two of many possible examples are:

1. Targeting technologies that increase staple crop production to food insecure households;
2. Targeting the Healthy Seedling technology to farms where seedlings have root health problems.

Having local and/or farmer advocates for a technology is very helpful. For example, a farmer who wanted to be a tillage service provider was largely responsible for the increase in bed planting at Durgapur. He promoted the technology because he saw an opportunity for himself.

At the same time, researchers and their technology transfer partners need to show persistence in developing and promoting technologies. The widespread adoption of no-tillage wheat production in NW India took more than 10 years to evolve and required a long-term commitment by scientists from CIMMYT and local universities. It also had to reach a point where the comparative advantages of the technology became important to farmers. These were savings in labor and time, and improved yields.

Encouraging technology “adoption” by providing incentives such as seed and fertilizer is a philosophy that is widespread amongst NARES in S. Asia. However, in our view, this is absolutely the wrong thing to do. It leads to the expectation of incentives and often “adoption” ceases when the incentives stop, such as with surface seeding of wheat in Nepal. It may well be necessary to provide support to farmers during farmer participatory development or evaluation of technologies, but it is important to cease this when moving from these phases to technology transfer.

Soil management technologies are always part of a bigger picture for farm households, for both their agricultural production and overall livelihoods. Technologies will have the best chance of adoption when they “work” in this larger context. Soil management technology transfer professionals should either interact strategically with existing programs or create partnerships to achieve this holistic approach.

Scaling-Up of Technology Transfer

The end-point of technology transfer is farmer adoption. However, there are several steps that usually have to be taken before reaching this point, such as developing the appropriate policy environment and providing agricultural professionals with the necessary knowledge. Our project focuses on providing knowledge to extension and NGO personnel who must facilitate the transfer of technologies to farmers.

Scaling up of technology transfer to millions upon millions of poorly educated farmers is a huge task. Ultimately, there is no easy fix, but some strategies for accelerating technology adoption are:

- Link to ongoing technology transfer programs rather than creating independent activities;
- Develop decision aid tools for farmers; an example is the leaf color chart (LCC) which is a readily understandable and easy to use nitrogen management decision support tool for a rice farmer;
- Support capacity building of technology transfer partners who have institutional stability and work at a national scale, such as the national extension system and larger national NGOs;
- Use agricultural service providers as an entry point to provide information about technologies to farmers; for example stores could promote the LCC when selling N fertilizer (a caution here is that a knowledge support system should still be identified).

Objective 2: Provide Government Agencies and Policy Makers with Information to Support Development of Programs and Policies that Encourage the Adoption of Soil Management Practices Compatible with the Long-term Conservation of Agricultural Resources

Our focus for this objective is the development of a liming program for Bangladesh, where more than half of the soils are acidic (see PY7 Annual Report). We are preparing a white paper on liming that is targeted to policy makers and are collaborating with

CIMMYT, WINROCK and Doyel Agro Complex Ltd on lime demonstration trials. The main driving force behind a liming program in Bangladesh is the need for increased production of maize for poultry feed. Liming may exacerbate Zn and B availability, but help Mo availability. All three deficiencies are commonly observed in Bangladesh.

In PY7, we categorized (and mapped) acid soils of Bangladesh into a number of representative groupings. Soils have now been collected from both high and medium up land types (used for maize cropping) at 36 representative sites and are currently being analyzed for exchangeable bases and aluminum. In general, soils pHs were slightly higher on the medium high land (mean = 5.42) than on the high land (mean = 5.14).

Lime response trials were continued at two sites in Patgram in collaboration with Doyel Agro Complex Ltd. Soil pH values showed the expected responses to liming. Following maize in 2004, one farmer (Rahman) grew rice and observed an 80 percent increase in rice yield from 1.5 t/ha without lime to 2.7 t/ha with the addition of 4 t lime/ha (Figure 6, left panel). There are several possible reasons for this response. The increase in yield with addition of 0.25 t/ha is likely a response to either Ca or Mg as soil pH was not altered by this treatment. The yield response as soil pH increases may be due to a reduction in Al toxicity or to increased Mo availability. Understanding which of these possibilities is correct is important to the development of lime recommendations.

In 2005, farmers, Rathman and Haque, saw a good maize yield response to liming; with 2 t/ha giving the optimum yield of 8.5-8.6 t/ha (Figure 6, right panel). Lime applications of > 4 t/ha and 8 t/ha decreased yield on the Rahman and Haque farms, respectively, due to induced Zn deficiency.

Liming trials carried out in Kishorgongj and Netrakona districts in collaboration with WINROCK's BREAD II program were not especially informative. Surface soil pH values were all above 5.5. Lime responses were observed visually at other sites in Comilla district. However farmers harvested the plots before yield measurements were made. A boron x lime trial was established on a farm in Kaharol upazilla in Dinajpur district resulted in complete sterility and no yield. Rice (BR32) was grown following wheat, and yields increased equally within the 1-4 t/ha lime range then decreased at 8 t lime/ha.

The results of the various liming demonstrations show:

- Positive yield response in maize to moderate liming levels (< 4 t/ha) and yield depressions at high levels;
- Positive yield response in rice; however, the mechanism is probably complex (Ca/Mg nutrition, amelioration of Al toxicity, and increased Mo availability);
- Negative effects on yields of wheat varieties that are susceptible to B deficiency.

Liming recommendations must take into account these various factors. More information is needed to establish the effects of liming on the diverse cropping systems of Bangladesh. The bottom line is, proceed, but do so with caution.

Objective 3: Continue Development of Key Technologies

Activities for this objective were limited to the programs of two students at Cornell, one in an MS and the other in a PhD program at Cornell.

Impacts of Soil Solarization on Soil Microbial Communities

Steven Culman completed his Masters degree at Cornell during PY8. His research looked at the impact of soil solarization on soil microbial communities using a mixture of conventional plating and molecular methods. As seen elsewhere, soil solarization had beneficial effects on rice seedling and main field plant growth and also on wheat growth at one site. But soil solarization did not result in a consistent increase in rice or wheat yields, perhaps due to low disease pressure at the two research station sites.

Nevertheless solarizing the soil did affect the microbial communities. The most dramatic effects were seen in main field solarized soil, and resulted in increased fungal counts, decreased nematode counts and galling, and differences in soil bacterial and fungal communities.

Terminal restriction fragment length polymorphism (TRFLP) analyses of bacterial and fungal community DNA revealed that soil solarization affected fungal communities to a greater extent than bacterial communities in rice. Additive Main Effects and Multiplicative Interaction (AMMI) modeling showed dramatic and sustained shifts in fungal community composition following soil solarization before rice. Similar shifts were not observed in the bacterial community, although trends suggested solarization may have affected the bacterial community at one site.

Characterization of *Meloidogyne* Populations and Resistance of Rice and Wheat Germplasm

Ramesh Pokharel (PhD student, Plant Pathology) studied a population of 33 isolates of root-knot nematode from Nepal; 23 isolates were from the terai and 10 were from the hills. Perineal patterns, morphometric measurements and molecular analysis of the ITS region confirmed that all isolates were *Meloidogyne gramnicola*. Two distinct genetic groups were observed based on ITS sequences representing the Hill and Terai rice-wheat production regions. Two USA rice cultivars, Labelle (susceptible variety) and La 110 (resistant variety) were susceptible to all of the Nepalese isolates, although the isolates differed in both aggressiveness and virulence. Similarly, 75 rice and 65 wheat cultivars (mostly from Nepal) were susceptible to one of the most virulent *Meloidogyne gramnicola* isolates. However, some rice germplasm appeared to show some tolerance; which is being re-evaluated. Interactions between isolates and varieties were observed for both rice and wheat. Pokharel's work will continue.

CARBON SEQUESTRATION

Project: Measuring and Assessing Soil Carbon Sequestration by Agricultural Systems in Developing Countries

Principal Investigators:

James W. Jones, University of Florida
Russell Yost, University of Hawai'i at Manoa
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Increasing the amount of carbon in soils could help counter the rising atmospheric CO_2 concentration as well as reduce soil degradation and improve crop productivity in many areas of the world. Participating in carbon markets could provide farmers in developing countries the incentives they need to improve land management, however carbon traders need assurances that contract levels of carbon are being achieved. Thus, methods are needed to monitor and verify soil carbon changes over time and space to determine whether target levels of carbon storage are being met. Because measurement of soil carbon changes over the large areas needed to sequester contract amounts of carbon is not possible, other approaches are necessary.

The program area of the SM CRSP focuses on two regions of the world: West Africa and the Indo-Gangetic Plains (IGP) region of South Asia. Both of these regions can be characterized as challenged in soil organic matter (SOM), but where technologies exist to rebuild SOM. The major driver of soil degradation in West Africa is poor utilization of limited resources, while it is deliberate destruction of soil aggregates by puddling for rice in South Asia.

The project has two groups: the universities of Hawaii and Florida focus on West Africa and Cornell University focuses on South Asia. Both groups have the same objectives and will work to accomplish them in a similar way. Some specifics differ as appropriate to the constraints and opportunities in each region. Several points of interaction are identified and meetings between the PIs and key collaborators are planned for exchange of information and methodologies as the program progresses.

A major goal of the SM CRSP Soil Carbon project by the University of Florida component is the development and evaluation of an integrated approach in which biophysical models are combined with soil sampling and remote sensing to achieve reliable and verifiable estimates of soil carbon over time and space. Although there are uncertainties associated with data and models, reliability in estimates is realized by using observations to adjust inputs and model parameters for target areas. The University of Florida group is developing methods and evaluating them in different cropping systems, soils, and climates in Mali and Ghana. Also, a major goal is to assess the potential for different management practices for sequestering carbon in soils in West Africa. The University of Florida group is working with cooperators in Ghana, Mali and Burkina Faso in field research and applying models to assess options for increasing soil C.

The University of Hawaii component of this Carbon project monitors the following soil parameters: soil water profiles (wetting front, water content), crop growth, biomass and grain yield and soil carbon content at sites characterized in terms of topography, mapping waterways, roads and trees, measurement of initial soil physical and chemical properties, as well as rainfall amounts. These soil parameters are essential for purposes of evaluating the influence of localized cropping systems on soil C at the farm and field scales. Furthermore, assessment of the spatial dependence of soil C is necessary to ensure efficient sampling and accurate estimation of these soil parameters.

The Cornell University component approaches carbon sequestration in soils based on the following hypotheses or tenets.

- Soil aggregation, which varies with soil texture, is the primary variable controlling soil organic carbon (SOC) levels in tropical soils.
- Soil texture is a good surrogate for total aggregation of soils only in the absence of tillage.
- Tillage causes loss of soil organic matter through destruction of macro-aggregates and microbial mineralization of the "physically protected" soil organic matter pool.
- Micro-aggregates and their associated SOC are stable to tillage, and this "passive or chemically protected" SOC pool represents the minimum level of SOC.

Undisturbed, native forest or grassland soils, where macro-aggregation is at a maximum, define the upper limit for SOC. In contrast, SOC in rice-wheat soils of South Asia should be close to the lower limit because puddling of soil for rice has destroyed macro-aggregates, leaving only SOC associated with the passive pool in micro-aggregates. The difference between these two limits is physically protected SOC, controlled by tillage. Unfortunately, ***the rotation of flooded (paddy) rice with wheat or any other upland crop leads to the most carbon degraded surface soils in the world*** because of the intense physical destruction of aggregates followed by aerobic conditions that enhance biological decomposition processes.

The Cornell University group is assessing the effects of tillage and residue management on carbon stocks, the soil-carbon relationships and C measurement issues.

Objective 1: Develop Practical Methods to Measure Gains and Losses of Soil Organic C Over Time in Spatially Variable Soils

West Africa

Estimating Soil C Quantities Using Geospatial Methods

The University of Hawaii group has applied a geospatial approach to the problem of estimating soil carbon tonnages, the associated uncertainty of estimates and changes in carbon over time for several small, irregularly-shaped farm regions in Mali, West Africa. The farms are participating in a project to improve soil fertility and productivity through implementation of ACN (ados/courbes de niveau) technology or ridge tillage, a management practice designed to conserve soil moisture and reduce soil erosion by reducing run-off from rainfall. Increases in carbon, critically important in these low-carbon soils of the greater Sahel region, are expected to occur as a result of increases in soil moisture and reduction of soil erosion. Samples were collected on an irregularly spaced sampling scheme at several time increments over the years 2000-2004 and analyzed for total soil organic carbon. Between 16 and 75 samples were collected at each of two soil depths (0-20 and 20-40 cm) at each time increment. Sampling positions and the boundaries of the fields were recorded with a DGPS. The areas of farm regions were later calculated automatically within GIS software (ESRI, ArcGIS 9) and soil volume calculations were based on these planar surface areas. Global estimates of carbon were based on the mean values of the carbon surface maps predicted by ordinary kriging.

Estimates of the precision of estimates are currently being developed by application of the sequential simulation method. Several secondary variables, including elevation and individual bands of Quickbird remotely-sensed multispectral imagery, have been included in the analysis through co-kriging and co-simulation. A major challenge has been the modeling of carbon variograms for sparse sample datasets. Similarities observed in experimental variogram shapes across farms, depths, and time, as well as across secondary variables have allowed variogram model parameters to be inferred for the smaller datasets. Predicted organic carbon values range from about 0.2 to 0.6 percent for the surface depth (0-20 cm) in a typical farm in the village of Sougoumba (about 9-10 tonnes carbon per hectare). Increase in carbon in the 0-20 cm depth for one farm over the years 2000-2004 was about 12 percent and was spatially variable. Elevation data, measured only at sampling locations, appears so far not to improve the estimates (as judged from cross-validation statistics). Information from remotely-sensed imagery appears not strongly-correlated with carbon but may improve estimation after stratification.

Objective 1, Output 1: The Ensemble Kalman Filter (EnKF), in Mali and Ghana

Methods for Using Remote Sensing in the EnKF

In PY7, the University of Florida group reported progress on estimation of vegetative above ground biomass for crops growing in Mali and Ghana. We were successful in using simple regression of measured biomass versus NDVI, but results were better when we included other data from the image and when we used an artificial neural network approach. Originally, our goal was to use remote sensing to estimate above ground biomass for use as inputs to the EnKF. These estimates were to be used to estimate soil C input annually over space (in a simple model) or to be used to refine parameters of a crop model (DSSAT-CENTURY, for example) in the EnKF. During this year, we re-visited that goal and concluded that it is not practical to use this approach in West Africa using existing satellite products.

Multiple images over time would be necessary to estimate above ground biomass. The frequency of cloudy days was so high that we failed to obtain images at two sites and only obtained one image at the other last year. This same pattern had occurred in the previous growing season, thus this approach was abandoned.

Nevertheless, we found that the QuickBird images that we had for two study areas (Omarobougou, Mali and Wa, Ghana) were highly useful in our mission to sample farmers fields, locate specific fields and trace their boundaries for determining areas, and selecting fields for case studies involving scaling up estimates of soil carbon over large areas. In addition, we obtained an ASTER digital elevation model (DEM) for each study area and used it to estimate slopes of fields that were analyzed.

It may be possible to use other satellite products to obtain broad area estimates of biomass much more frequently and cost effective compared to our use of QuickBird images. S. Traoré will investigate other possibilities on a related project.

Development of the EnKF Approach for Combining Measurements and Data

There could be several thousand fields in a carbon sequestration project. The ensemble approach reported in PY7 requires many calculations due to the need to develop several hundred realizations of each field in order to characterize uncertainty for model predictions and Kalman Filter estimates of soil C based on those predictions and soil C measurements at some temporal and spatial frequency. If the underlying soil C model is linear, an analytical approach can be used to evolve predictions of soil C over space and the uncertainty associated with those estimates. A third possibility is to linearize the soil C model, if it is sufficiently simple, and use what is referred to as an Extended Kalman Filter. Analytical calculations are then used, instead of ensemble simulations, to project estimates of soil C and its uncertainty over space and time. A simple soil C model, with an annual time step, was developed. In addition, equations were written to linearize the model, taking into account spatial correlations, for the Extended Kalman Filter. The simple model was parameterized using a long term experiment in Burkina Faso. We also analyzed soil C data collected at points versus composite samples for fields using geostatistics over a large area in Ghana. The question was whether point or composite sampling should be done when applying Kalman Filter techniques to assimilate measurements of soil C. This work is incomplete, but there were differences in semivariograms for the two sources of data. The trend was that the range of the semivariograms using composite samples was larger (ranging from about 1 km for one village to over 2 km for the whole area sampled in Ghana).

Work with the Tradeoff Analysis Component of the SM CRSP Project

Cooperation with the Tradeoff Analysis (TOA) team (see *Tradeoff Analysis* project in this report) was initiated this year in several ways. First, a small part of the UF budget was encumbered to support TOA team travel and work in Ghana. Secondly, J. Jones of the University of Florida traveled to Montana to meet with J. Antle of Montana State University (TOA) and his team to better understand how the biophysical model analyses could contribute to the economic tradeoff framework developed by Antle and his team. Third, the ILRI component of the UF project met with the TOA team and adopted their approach for assessing potential adoption of practices by farmers. Fourth, we made a commitment to provide simulations results for options being considered by cooperators in Ghana for increasing soil C sequestration. Finally, we agreed to cooperate in training users in West Africa. Two of our cooperators in West Africa (Naab and Traoré) attended the TOA workshop held last year in Senegal. We are planning a DSSAT training course in Accra, Ghana in October, and will devote time to expose DSSAT users about TOA and data needed for TOA using options produced by DSSAT. This workshop in October is mostly supported by researchers in the region via the Water Challenge program (ICRISAT and CIAT) and AfNet, a network of about 350 members in Sub Saharan Africa.

Objective 1, Output 2: Adapt Crop Models for Mali, Ghana and Burkina Faso (Maize, Sorghum, Millet, Peanut and Cotton)

Complete Analysis of Available Maize and Peanut Data from Wa, Ghana

The University of Florida group continued to work with the data sets from Wa. We estimated genetic coefficients for maize and sent these to J. B. Naab in Ghana for his use as well. Genetic coefficients had already been developed for peanut. Similar type of work remains to be done for Kpeve.

Use Data from Long Term Experiment in Burkina Faso for Crop Model Evaluation and Development of a Simple Soil C Model

An analysis of soil C and biomass data for the 11-year experiment was completed. The data showed that soil C decreased rapidly for all cropping systems relative to the continuous native fallow treatment. Crop rotation and fertilizer treatments were significant in determining the magnitude of soil C loss. Adding manure to N and P fertilizer resulted in higher soil C levels after 11 years compared with other treatments. These data were used to estimate parameters for a simple soil C model in which annual estimates of belowground biomass and amount of manure applied were inputs to the model; these values were measured in the experiment. Aboveground biomass was removed each year. The simple model assumed a stable soil C pool (top 20 cm only) and a dynamic pool that increased and decreased in response to annual C inputs and a decomposition rate parameter, k. All cropping system data were used to estimate the stable pool (fraction) and k (1/year) as 0.55 and 0.40, respectively. Standard errors of estimates were less than 0.02 and 0.04, respectively. The rate constant of 0.4 implies that about 80 percent of initial soil C (above the stable pool amount) would be lost after five years for this experiment.

Working with cooperators at the University of Georgia, the UF group developed files to simulate the experiment using the DSSAT-CENTURY model. The model was able to simulate yields and biomass for the cropping systems well. However, the model underestimated soil C losses during the first part of the experiment using the default parameters that we had for the soil C pools. Work needs to continue on this analysis to refine estimates of initial soil C pools and decomposition rate parameters used in CENTURY to better reflect what we learned using the simple model analysis outlined above.

Adapt the New Cotton Model to Mali

A cotton model (CSM) was in the early stages construction when this project began, and development was accelerated due to the economic importance of this crop in Mali. It is the second largest export in the country and the sole cash crop of a majority of farmers in much of West Africa. Therefore, emphasis was placed on this crop in terms of the depth and breadth of data collected for simulation in the CSM. In addition to the basic on-farm management data of a cotton/millet cropping system rotation in Konobougou, detailed data were acquired for multiple treatments at a nearby agricultural research station for an unrelated cotton project. These data include all management data (i.e., planting density, fertilizing, weeding), crop phenology (emergence, flowering, first boll), crop production (number of leaves, mass of leaves, plant and bolls) and corresponding soil moisture and weather data throughout the season. These data were available for cotton crops grown under four treatments: early planting—no fertilizer or nitrogen fertilized, and late planting—no fertilizer or nitrogen fertilized. Data are being analyzed and the new CSM cotton simulation model is being calibrated for West Africa.

Evaluate the Phosphorus Model in DSSAT

During the year, considerable progress was made on the P model in DSSAT. The UF group made it modular so that it will work for all crops; previously it worked only for maize and soybean. In addition, we worked with U. Singh of IFDC, who created an expert system that will estimate initial soil P pools and adsorption constants for fields with very limited data. Logic for setting inorganic P values was developed by Singh. We have initial estimates of critical plant P levels for growth and stresses for maize, soybean, drybean and cotton. The soil P model consists of two components, 1) inorganic P and 2) organic P. The inorganic P component operates similar to inorganic soil N, and the organic P component works with both the CENTURY soil organic module and the original DSSAT organic matter module.

Figure 7 shows results of a sensitivity analysis using soil, weather, and genetic coefficient information from Omarobougou, Mali, averaged over 20 years of simulations. This sensitivity analysis shows a typical response for soils low in available P. Experiments have been conducted in northern Ghana by J. B. Naab with combinations of N and P fertilizer levels applied to maize. Qualitatively, those results are similar to those in Figure 7. Our next step is to compare the model with his data; this is yet to be done.

Quantify the Effects of Soil Water on Organic Matter Decomposition Rate

Good progress was made by investigators at the University of Ghana on characterizing the effects

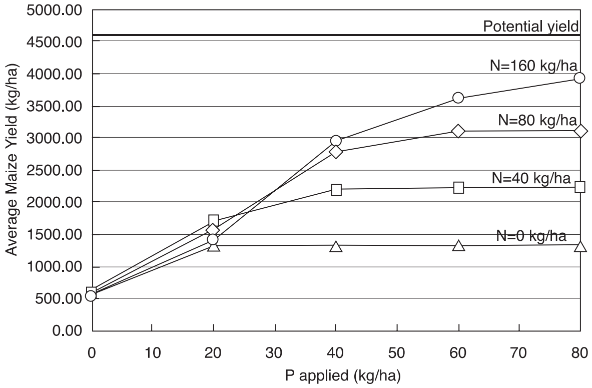

Figure 7. Simulated maize yields for different N and P levels in Omarobougou, Mali (20 years of weather data).

of soil water content on organic matter decomposition rates for different maize-based cropping systems. Carbon mineralization values, after a sixteen-week incubation period, indicated that soil moisture plays a very important role in carbon mineralization from soils. The rate of mineralization of carbon for all the residue treatments increased with increasing moisture content. Additionally, residue management type influenced the mineralization of carbon from soils, and the patterns in the data show an initial high rate of mineralization followed by a slower rate, hence suggesting different fractions of soil carbon. Figure 8 shows an example of the evolution of soil C mineralization under different soil water contents.

Improve IMPACT Model to Include C Balance and Methane Production by Livestock, Ghana

Additional data were collected to more accurately characterize different farming systems in Ghana, for farms near Wa (Northern Ghana) and Kpeve (Southeastern Ghana). A relationship to estimate the effects of livestock on greenhouse gas production was added to IMPACT—the model done by investigators at ILRI.

Refine the Runoff Model for Ridge Tillage and Conventional Fields in Mali

The spatial model for simulating runoff from fields varying in slope, infiltration properties, initial soil water conditions, and rainfall intensities was modified to include a restricting soil layer beneath the surface, induced by long-term tillage (as opposed to the dense illuvial horizon formed by accumulation of clays over time and found deeper in the profiles typical of Alfisols in this region).

The two fields in Konobougou, Mali were instrumented with sophisticated surface water flow meters. V. Walen (UF), M. Doumbia (IER) and assistants in Mali measured rainfall intensity, soil water at different depths (with TDR time domain reflectometry probes), and runoff volume from the field for all rainfall events that occurred in the growing season of 2004. Measurements were made in the field of saturated hydraulic conductivity of the soil surface and of the confining layer for each field. Average slopes of the fields in the direction of flow were measured and used as input to the model. Figure 9 shows measured and simulated runoff and infiltration for one rainfall event that was recorded. This model was used to produce a table of runoff percentages for fields of different slopes, initial soil water contents, and amounts of rainfall in storms, using typical rainfall rate vs. time obtained from the measured storms. The table was used in DSSAT to allow it to simulate these field characteristics to account for differences in runoff that would occur under ridge tillage (ACN-a*ménagements en courbes de niveau*) versus fields with steeper slopes (NA).

Assess Soil Organic Carbon in the Peanut Basin of the Nioro Area in Senegal

This University of Hawaii study was carried out between April 2003 and April 2004 in the peanut Basin of the Nioro area in Senegal. The Nioro area can be subdivided into two major physiographic units with sloping or gently sloping areas respectively. The gentle slope (1 to 2 percent) may have a length of several kilometers while the sloping areas (2 to 5 percent) are generally less than a kilometer. Three villages were selected to describe the distribution of organic matter in different land use. Djiguimar and Paoskoto were selected for their sloping landscapes and Prokhane was selected for the high input intensified agriculture practiced there Prokhane was selected to compare carbon stocks under low and high input agricultural management on gentle slopes.

The climate is of the Niora area is classified as Sudanian. Over the last years the average annual rainfall ranged between 700 to 800 mm. Rainfall is mono-modal and lasts for five months from June to

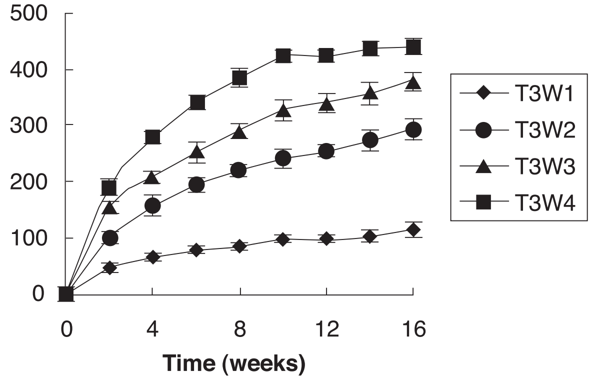

Figure 8. Cumulative carbon mineralization for Pigeon pea fallow that was slashed and surface applied (T3), for low (W1) through high (W4) soil water contents. (From Adiku; soil samples taken from experimental field in Kpeve, Ghana).

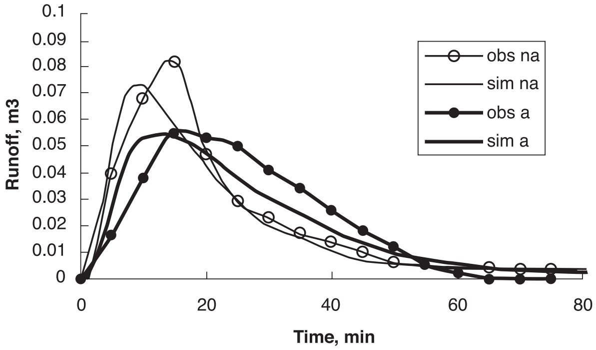

Figure 9. Simulated and observed volume runoff for ACN (a) and non-ACN (na) conditions over one storm event.

October. The plateaus are generally populated with herbs and shrubs. Two shrub species dominate the vegetation and account for 80 percent of woody above-ground biomass: *Guieria senegalensis* and *Combretum glutinosum*. *Andropogon pseudapricus* and *Pennisetum Pedicellatum* are the most dominant herbaceous plant. The slopes are covered with food crops and it's common to find the same vegetation as on the plateaus. A few numbers of trees like *acacia albida* and *Cordyla pinnata* are also found in this part of the landscape. Annual water flooding in the valley bottoms may explain the good chemical status and better physical conditions of the soils in that area. In the dry season, soils are well covered and more species of trees, shrubs and herbs are found in this unit.

Following FAO (1998), the soils are mainly classified as ferric lixisols on the plateau and haplic lixisols in the glacis. In the valley bottoms with seasonal water flooding, soils are mostly classified as a haplic gleysols.

Agriculture in the area is essentially based on intense cultivation (pressure on the land) without mineral fertilizer or organic matter input. The cultivation is mainly rain-fed, traditional and non-mechanized. The glacis, which is the sloping part situated between the plateau (high land) and the bas fond (lowland), are mostly used for agriculture. Peanut (*Arachis hypogaea L.*) and millet (*Pennisetum glaucum L.*) were the principal crops cultivated over a long period of time. In 2003, because of crop seed shortages, maize (*Zea mays L.*) was grown in the area as a result of a government program.Sorghum (*Sorghum bicolor L.*) and millet and maize are the main subsistence food crops. The plateaus with ironstones are mostly uncultivated; they are the only place where permanent fallow can be found and are the only green areas after harvest. During the dry season the fields where peanut has been cultivated are easily recognizable because no crop residues are left behind to cover the land. Peanut crop residues are as valuable in the market as the crop itself and everything is removed at harvest leaving the land uncovered and the top soil exposed to the wind erosion and water runoff when the topsoil is transported to the lower area. In other fields cultivated with subsistence crops (millet, maize and sorghum), crop residues are also removed but only the strongest stalks are taken away and used to build houses, fences, buildings so that most of the straw is left behind, and can be used as fodder for cattle. Thus, crop/livestock integration is achieved. In addition plant residues, on the top surface, may help reduce wind speed and water runoff.

Removal or burning of crop residues predisposes the soil to serious erosion. Unfortunately in the whole area the remaining crop residues are burnt *in situ* just before the start of the rainy season when preparing seedbed for the next crop. Burning is mostly done not just simply to remove straw but also to reduce diseases where it's believed that straw serves as a pathogen host. Crop residues consist of about 50 percent carbon, and carbon is volatile under most fire conditions, causing the loss of carbon to the air. Some of the detrimental effects of long term burning include decreases in organic matter, total nitrogen, total sulfur, carbon/nitrogen rations, extractable carbon, polysaccharide, ammonium and available phosphorus.

Table 7. Distribution of organic carbon in different land use areas.

Land use	Management	pH		Carbon %		Clay + silt %	
		--------------------Soil Depth (cm)--------------------					
		10	20	10	20	10	20
Cereal, valley bottom (CCBF)	no fertilizer, no tillage	5.2	5.1	0.51	0.36	11	11
Cereal, parkland (CCP)	organic input, no tillage	6.7	6.2	1.26	0.42	9	12
Cereal, peanut, inputs (CRCPHI)	fertilizer input, tillage	5.0	4.8	0.48	0.38	12	15
Cereal, peanut, no inputs (CRCPLI)	no fertilizer, no tillage	5.1	4.8	0.43	0.34	11	15
Fallow, valley bottom (PFBF)	undisturbed[1]	5.5	5.3	0.48	0.27	10	9
Fallow, plateau (PFP)	undisturbed[2]	5.4	5.1	0.62	0.52	15	18
Fallow, terrace (PFT)	undisturbed[3]	5.2	5.1	0.65	0.71	13	

[1] hydromorphic soils seasonally water flooded, uncultivated

[2] rocky plateau, uncultivated

[3] terrace, uncultivated

Soil Sampling

The topo-sequence sampled ranged from the high land (plateau) to the low land (*bas fond*). To assess the distribution of carbon through the landscape, three parallel transects have been made in a short (602 m) sloping area (5 percent) situated in the village of Djiguimar, one transect in a long (1810 m) gentle slope (< 1 percent) area and one transect in a short (685 m) gentle slope area both in the village of Paoskoto. In Prokhane where land management was the subject of study, two transects have been made, taking into account the two different types of management, low input and high input cultivation. Neighboring crop fields, fallow plots and parklands of different ages were considered as representative of the same plot, assuming they shared the same initial soil properties and management history. Soil sampling was done along the 5 transects. Every individual field crossed by a transect was considered as a different land use pattern and used as a sampling point. The transects consisted of 16 sampling points in Djiguimar, 16 sampling points in Paoskoto and 8 sampling points in Prokhane. At each sampled field, a representative area of the land was chosen. Geographical coordinates of these points were recorded using GPS.

Land Use Descriptions

Overall seven different types of land use and management were identified across the topo-sequence listed below:

1. Continuous rotation cereal peanut without or low external input (CRCPLI)
2. Continuous rotation cereal peanut with high external input (CRCPHI)
3. Permanent fallow in the plateau (PFP)
4. Permanent fallow in the terrace (PFT)
5. Permanent fallow in the bas fond (PFBF)
6. Continuous cereal cultivation in the bas fond (CCBF)
7. Continuous cereal cultivation under parkland (CCP).

Results

Preliminary results from a MS thesis (A. Niang) of laboratory analysis from soil samples collected at sampling points corresponding to different land use types and management as well as position in the landscape are reported in Table 7. Soil carbon levels were best under continuous cereal cultivation (CCP) under parkland conditions with organic matter input and no tillage as shown in Figure 10. Soil pH was 6.7 in the surface layer compared to values of 5.5 or less for all other land management types. Soil texture classes were nearly similar for each of the land types.

Evaluate Soil and Biomass Carbon as Related to Land Use System Using Satellite Images, Nioro

This was a follow up study based on the work described above. The sampling design took into account both biophysical characteristics of the research area, the farming system (cropping system, livestock, etc.) and participation of local smallholders. The Landsat images of 1972, 1985 and 2000 were used to assess the land use/land cover changes.

Trees were counted and measured (diameter breast height) on a 0.125 ha sampling area within each field and shrub biomass evaluated within three replicates of a 3-m radius circle. Under storey and litter samples were taken respectively from two subquadrats replicates. The origin and direction of these subquadrats was established randomly. Allometric

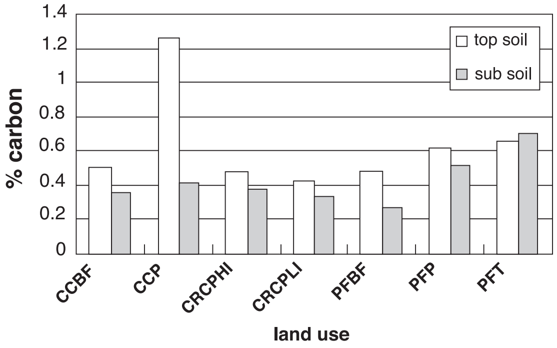

Figure 10. Distribution of carbon in different types of land use.

equations were used to quantify total biomass for trees, shrubs and roots (FAO) and biomass carbon soil samples were collected at 0-20 cm and 20-40 cm and bulk density at 10 cm and 30 cm soil depth within the same replicate subquadrats. The CENTURY model simulation for different scenarios will be used to predict soil and biomass carbon content trends. During the 2005 dry season, biomass and soil samples were done at 15 sites, throughout the Nioro area. Soil and plant samples are and will be sent to the CNRA (Commission Nationale pour la Recherche Agronomique/National Commission for Agricultural Research) soil and plant lab for analyses.

Water and Soil Conservation

The "ados" technique (ridge tillage or "courbes de niveau") was evaluated at farmers' fields for the impact of the technique on water and fertilizer use efficiency for Senegal's main crops (sorghum, millet and peanut) and crops yields. The objectives were to:

- Reduce water loss reduction by runoff on the hillside agrarian landscape;
- Analyze the feasibility of the technology by the farmers;
- Assess the ados effect on soil carbon groundwater recharge and natural vegetation.

During the 2004 rainy season, eight fields (Table 8) (four peanut, three millet and one sorghum) were included in this study. The fields were topographically mapped, waterways and roads delineated and the location of trees determined. Site characteristics included initial soil physical and chemical properties (mean soil C content, soil texture), slope, ados spacings, soil profile depth, etc. (Sene *et al.* 2004). For the two newly added fields located in Prokhane, site characterization was done in June, 2004, prior to the onset of the rainy season. Rainfall distribution was monitored. Soil fertility was low in these fields, indicated by low soil C and P content. However, soil acidity for these continuous cropping systems was not a major constraint. Prior to sowing, four hand-made ACN at a spacing ranging from 30 to 40 m were constructed across the slope to obtain three "30 m x 50 m bands", also referred to as positions 1, 2 and 3. These were compared to three other bands symmetrical to the waterway. Fertilizer application was based on crop specific fertilizer recommendations (for peanut, 150 kg/ha of 6-20-10 applied after sowing; and for millet and sorghum, *F2-20*, 150 kg/ha of 15-10-10 added at thinning plus 100 kg/ha urea applied at early tasselling). Accordingly, four rates (0, 1/2 of recommended rate, recommended rate and twice the recommended rate) of mineral fertilizer (NPK) were applied as fertilizer treatments. These four levels of fertilizer were randomly applied to four subplots located in each of the three positions within a given experimental plot. The subplots run parallel to slope orientation. The timing of the cropping operations from sowing to harvest was done as recommended by research.

In December 2004, after crop harvest, soils were sampled at two depths (0-20 and 20-40 cm) for initial soil carbon content. The grid sampling method was used to allow spatial variability analyses. These samples will be analyzed in Hawaii.

Table 8. Ridge-tillage (ACN) study sites in Senegal, peanut basin.

Site Location	Farmer's Name	Crop	Variety
Djiguimar	Aly	Peanut	73-33
Djiguimar	Babou TOURE	Peanut	73-33
K.M. Dramé	Chérif BA	Peanut	73-33
Prokhane	Tamsyr SENE	Peanut	73-33
Paoskoto	Omar KANE	Millet	Souna 3
Djiguimar	Malick DIABO	Millet	Souna 3
Djiguimar	Amath NDIAYE	Millet	Souna 3
Prokhane	Cheikh WILANE	Sorghum	F2-20

Modeling of Factors Affecting Soil C (Sub-Contract, Virginia Tech, Saied Mostaghimi and Kevin Brannan)

Mali, Senegal, The Gambia and Cabo Verde

The main objectives of this research were to:

- Adapt and implement the PARCHED-THIRST model to simulate ridge-tillage effects on water

dynamics together with collaboration in Mali, Senegal, Gambia, and Cabo Verde.
- Adapt and implement the KINEROS model of soil moisture runoff and erosion for ridge-tillage systems on order to improve the technology and adapt it to different conditions of soil, topography, and rainfall.
- Process Diviner data for *in situ*, field scale, water balance calculation and modeling in Mali and other devices in Senegal and elsewhere.
- Sample and process elevation data for improved prediction of soil C sequestration.

Training and supporting other team members in hydrologic calculations, modeling and publications were also part of this research. It was determined that infiltration data for the study sites was needed for the application of the PARCHED-THIRST model. This determination was based on anecdotal observations of soil-crusting and water ponding in the ridge-tillage fields. We plan to use the infiltration data to assess potential changes in soil hydraulic properties due to ridge tillage implementation. Infiltration data are being collected in Mali, Senegal and The Gambia. In addition to measuring infiltration rates with a standard double-ring infiltrometer, we are using a smaller double-ring infiltrometer made by Turf-Tech. The Turf-Tech infiltrometer allows for rapid measurement, thus, allowing for more measurements per field spread over a greater area. The UH group hopes to capture the spatial heterogeneity of infiltrations rates within the fields using the Turf-Tech infiltrometer. Experiments are under way in Mali, Senegal and The Gambia comparing the infiltration rates measured using the standard method to those measured using the Turf-Tech infiltrometer. These experiments will also be used to develop calibration equations, if needed, to convert the Turf-Tech measurements to those obtained using standard methods. The infiltration measurements in all the countries will be used in the modeling component of this work. Previously, we developed a climate input data set for the peanut basin of Senegal and are in the process of doing the same for Mali and The Gambia. We also have developed soil parameter files for fields in Senegal and are in the process of developing soil parameter data sets for Mali and The Gambia. The climate and soils data will be used in applications of the PARCHED-THIRST model in the coming year. After we reviewed the current state of KINEROS model, we concluded that this model was not the best-suited tool for investigating ridge-tillage. This decision was explained in the Project Year 7 Annual Report.

Mali Soil Moisture Monitoring Experiment

This experiment implemented in two fields in Mali is continuing and has been expanded to a third field. Assistance provided by IER/Mali personnel and Richard Kablan (University of Hawaii) was essential to the collection of data and the expansion of the experiment. An additional six plots (three treatments and three controls) were implemented in fields that had gravelly textured soils. The IER/Mali scientists are interested in whether ridge-tillage can be used to help reclaim degraded soils. IER/Mali personnel collected data from the multiple tubes at each of the two locations over the past two rainy seasons. Also, additional data were collected this past year by Virginia Tech and University of Hawaii personnel to develop calibration parameters for the Diviner instrument that are specific to the soils in Mali. The data reporting bottlenecks encountered in the previous year were reconciled using the automated procedures available in the Diviner unit, along with macros and other computer code developed by Virginia Tech and University of Hawaii personnel for a more streamlined data processing procedure. Efforts will be made this year to transfer the data analysis procedures to IER/Mali, so the soil moisture data could be collected and analyzed in Mali by IER personnel. The results from the soil moisture experiment for the past two rainy seasons, along with water balance calculations using the soil moisture data, are being prepared for two manuscripts. Both manuscripts will be submitted as a series to the journal Geoderma this coming year. The ground water monitoring component was not implemented due to alack of funds from USDA-ARS. Other funding sources are being sought to implement this component because we believe that ground water recharge resulting from ridge-tillage implementation could be a valuable, yet unrealized, environmental service provided by this practice.

We recorded elevation and location data using a total station during 2004 for the carbon sample locations along with the fields for the soil moisture experiments located in Mali. We referenced the spatial data to DGPS locations collected by IER/Mali personnel. Spatial analysis of the soil carbon and elevation data is currently underway by Virginia Tech and University of Hawaii personnel. Detailed DEMs are being developed for the fields where the soil moisture experiments are being conducted. The DEMs will be used in the analysis of the soil moisture data along with in the application of the PARCHED-THIRST model. The samples collected in Malian fields to estimate erosion using Cesium-153 isotope were not analyzed due to lack of funding from USDA-ARS.

South Asia

Development of Soil C-Texture Relationships

C Measurement Issues

Accurate and reliable methods to determine total soil organic carbon have been pursued by the Cornell University group's Nepali colleagues for the last two years. Results from Walkley-Black, the Mebius modification of Walkley-Black and Graham's colorimetric procedures have been compared with Cornell's combustion results (with carbonate removal). We have found that the Graham colorimetric procedure produces results that most closely agree with combustion. As a result, NARC has reanalyzed over 350 samples from an intensive sampling of the Rupandehi district, using Graham's colorimetric procedure. With reference to our earlier C measurement studies, the R2 values for comparisons with TOC combustion were 0.78 for Walkley-Black and 0.89 for Mebius, compared to 0.94 for the Graham colorimetric method.

While the LOI method is much simpler than the chemical procedures, care is needed to ensure quality results. Specifically, the ignition step needs to be done when the electricity supply is reliable to ensure uniform ignition timing (4 hours) and temperature; a balance with readability to 0.001 g is required; and desiccation of ignited samples is essential during humid, monsoon periods.

The Cornell group believes that it finally has methods for TOC determination that can be utilized effectively in developing countries. However, we have also observed that most developing country laboratories do not employ adequate quality control (QC) procedures to ensure that they have quality data; in many cases there is no QC strategy and so no way to know whether the data is good or not. This remains a big hurdle for carbon sequestration programs.

Texture Measurement Issues

In checking the quality of data for use in estimating carbon sequestration potential, the Cornell group also discovered discrepancies with the texture data. NARC labs use the hydrometer method for soil texture determination while we use the pipette method. Theoretically these approaches should yield the same results. Differences, however, were found when Sanjay Gami, a PhD student in our laboratory compared the two methods. The results show good agreement at high sand levels, but with increasing silt + clay (less sand), the relationship diverges and the hydrometer results overestimate sand content relative to the pipette method. During the initial dispersion step, the NARC hydrometer approach uses a much larger soil to sodium hexametaphosphate ratio (5:1) than the Cornell pipette method (2:1). Also less shaking is used by the NARC method than the Cornell method. We concluded that incomplete dispersion of the soil in the NARC method contributed to the texture disparities found between the two datasets.

Texture-Carbon Datasets

The Cornell group had initially planned to utilize soil texture and TOC values from NARC soil survey reports and the Land Resources Mapping Project for estimating potential carbon sequestration across the Nepal terai. However, the reliability and accuracy of these data seem doubtful given the analytical problems that we have encountered to date.

Future work will be restricted to geo-referenced texture and TOC datasets that have been validated for accuracy. These will include the Rupandehi district dataset that we have been working on, the Chitwan district soil survey from SM CRSP Phase 1 and localized surveys in the Parsa, Bara and Rautahat districts.

Soil Carbon-Texture Relationships

Previously we quantified the relationship between TOC and silt + clay texture fractions for cultivated soils in South Asia. Work in PY3 focused on gathering soil samples from native, uncultivated sites in the region, in order to better define the upper limit relationship between TOC and silt + clay fractions. Samples from the Nepal terai national forests were collected by tube auger, while in Bangladesh a hydraulic soil corer was used. Analysis of 120 native soil samples is currently underway for TOC and texture.

Characterization of Organic Carbon Gains from Sequestration Practices

Experimental data on carbon stocks and dynamics under different tillage and residue management practices in the rice-wheat system are important inputs for validation of carbon modeling approaches that the Cornell group will use to describe equilibrium levels of soil OC under different management scenarios. During PY3 soil samples were collected from additional experiments to assess the impacts of permanent bed planting and nutrient management practices on soil carbon sequestration in this cropping system. Texture and TOC analysis for the collected samples are currently underway.

Zero-till Surface Seeding Experiment, Rampur, Nepal

This experiment, established in 1999 during Phase I of the SM CRSP, examines the impact of tillage for rice and wheat (zero-till versus conventional practice) and straw mulch (mulch, no mulch in both crops) on crop productivity and carbon accumulation in soil. Carbon stocks to 50 cm depth ranged from 72 -77 t/ha, which are quite high compared to the other experiments we have studied. Because this experiment is located on the IAAS campus where cultivation is not very intensive, carbon stocks at this site are not very degraded compared to surrounding farmer fields.

Textural variation from sand lenses in some of the lower depth increments resulted in variable C stocks at depth for some replications. Consequently, no statistical differences in TOC were observed between the treatments for the whole profile. However in the more homogeneous, surface horizons (0-15 cm), significantly higher TOC levels were found in the zero-till treatments compared to conventional practice (Figure 11). Likewise, straw mulches increased C stocks significantly in the top 15 cm of soil over no mulch. Tillage or by mulch interaction trends at this site indicate that zero-till alone could increase soil C storage by 1.12 t C/ha. The effect of mulch in zero-till plots increased soil C stocks 2.91 t C/ha over the five years of the experiment, while mulch in conventional tillage plots only increased TOC by 1.7 t/ha over five years. The greater effect of mulch on increasing soil C under no-till fits with our contention that appropriate management can increase the rate of C sequestration, although the equilibrium C level will be unchanged. In effect one can change the trajectory of C sequestration but not the final outcome.

Zero-till Surface Seeding Experiment, Baireni, Nepal

This experiment has the same design as the Rampur trial and was established in 2001 in a farmer's field. Despite a heavier texture (silty clay versus silt loam at Rampur), carbon stocks to a 50 cm depth ranged from 23 to 28 t C/ha reflecting intensive cultivation and substantial carbon degradation. No impacts of tillage or mulch treatments were found on C stocks in the whole profile (0-50 cm) or in the surface horizons (0-15 cm) (Figure 12). Sub-surface variability in soil texture is also a complicating factor at this site. Only TOC in the 0-5 cm horizon showed a significant increase in the zero-till treatment relative to conventional tillage. We did not expect to be able to project carbon sequestration rates from zero-till for this soil at such an early stage in the experiment, but the data provides a baseline for comparison with later measurements.

Carbon Sequestration Rates

Measurement of carbon stocks in five experiments in Nepal over the last two years has shown that it is difficult to detect significant changes, even with very careful sampling. We were unable to find significant differences due to increased crop productivity or for experiments that had run for less than five years. Significant increases in soil C (Table 9) were associated with a change from conventional to no-tillage, cessation of puddling for rice and residue inputs. The measured annual rates of increase ranged from 0.22 to 0.58 t C/ha per year assuming a linear change over time. These compare with the global average of 0.34 t C/ha per year for the switch from conventional tillage to no-tillage (West and Marland 2002).

Effects of Tillage and Crop Residue Inputs on SOC Dynamics Using ^{13}C Labeled Materials

As part of his PhD research, Sanjay Gami is using ^{13}C labeling of rice and wheat in order to follow the dynamics of carbon decomposition from tops and roots of these crops in the Baireni and Ranighat tillage and residue management experiments. Wheat was labeled in PY2 and rice in PY3 and labeled and unlabeled residues were placed in the appropriate microplots. Soil samples were collected after rice 2004 and wheat 2005 seasons. Carbon decomposition in the microplots will continue to be monitored after rice 2005 and wheat 2006 seasons.

Straw residues were applied initially as mulches in the zero-till and permanent bed treatments and were incorporated in conventional tillage treatments. The quantity of mulch remaining after each season in the zero-till and permanent bed treatments of the Baireni and Ranighat experiments, shows

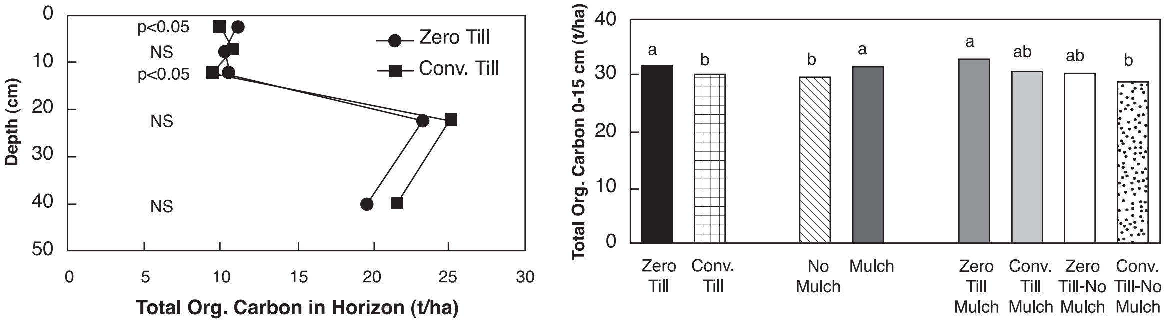

Figure 11. Soil organic carbon stocks after five years of a tillage-mulch experiment at Rampur, Nepal.

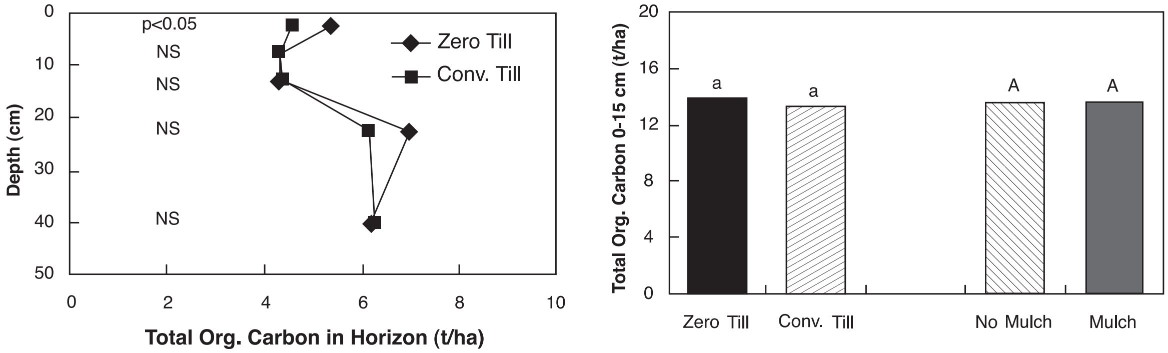

Figure 12. Soil organic carbon stocks after two years of a tillage and mulch experiment at Baireni, Nepal.

Table 9. Impact of carbon sequestration practices on the rate of soil carbon gain in double cropped rice-wheat systems in Nepal.

Carbon Sequestration Practice	Annual C Gain t C/ha/yr	Location and Duration	Soil Texture
No puddling for rice	0.38	Bhairahawa TCE; 7 yr	Silty Clay
No tillage	0.22	IAAS tillage and mulch; 5 yr	Silty Loam
No tillage plus mulch	0.58	IAAS tillage and mulch; 5 yr	Silty Loam
Residue addition with conventional tillage	0.21	Bhairahawa crop residue; 7 yr	Silty Clay

that flooded soil conditions in rice enhance straw decomposition relative to the drier conditions in wheat. Decomposition of wheat straw during the rice season was more variable than decomposition of rice straw during the wheat season. However, in general, rice straw decomposes more rapidly than wheat straw so we expect that less rice than wheat straw will remain after one complete rice-wheat cycle for each residue.

Additional information on decomposition rates of wheat and rice straws from a one-time application of residues is being collected from the crop residue experiment at Bhairahawa, Nepal.

Objective 2. Apply Methods to Assess the Potential for Soil C Sequestration for Selected Sites in West Africa

Objective 2, Output 1:

A Demonstrated Capacity of Land Use Cropping Systems for Sequestering C in Soils in West Africa under Different Rainfall Regimes

Wide Area Soil Sampling for Characterizing our Study Areas in Ghana and Mali

Between 150 and 200 fields were sampled by the University of Florida group in each of three study areas during 2004 to collect soil C, texture, pH and cropping history (Kpeve and Wa in Ghana and Omarobougou in Mali). The purpose of this work was to characterize current conditions regarding soils, land use and management practices that will serve as case studies in scaling up assessments of soil C sequestration potential and in evaluating the data assimilation methods over large areas, for scaling up monitoring programs. In July 2004, 177 fields in the Wa, Ghana site were visited, including 12 on-farm and 5 on-station experimental plots managed by Savannah Agricultural Research Institute (SARI). Jesse Naab (of Wa) who was responsible for this field survey, S. Traoré (ICRISAT-Mali), one of his assistants, and Jawoo Koo, graduate student from the University of Florida conducted the field study. In each field, *in situ* measurements were made of the following: soil sample for C, texture, and pH determination in the lab, GPS location, field boundary, digital pictures and cropping history and management. Soil samples were taken back to the laboratory in Wa for C and texture analysis.

Koo assembled all of the data at the UF. Soil C and texture values were measured in Wa and sent to Koo for integration with the other geo referenced data. Statistical and geostatistical analysis completed to date indicate a high level of correlation of soil C with texture (percent sand), elevation, cropping history (fraction of cereals in the rotations) and location. Multiple regression analyses were performed on a subset of the data to determine if soil C could be estimated from the other measured variables. By holding out some of the samples from the regression analyses, we also evaluated the prediction quality of the models using independent data from the same region.

Semivariograms were also estimated for point samples collected in the area as well as composite samples, assuming field centroids as the georeferenced points. These data are being used to estimate soil C and texture for fields over a large area in the case studies mentioned above. It is not clear yet what approach is best to estimate soil texture and initial soil C initially for fields that were not sampled; we will compare statistical and geostatistical approaches. These data will subsequently be used to initialize the models that are being used in the project (DSSAT-CENTURY, simple soil C, and hydrology). Similar data were collected at the other two sites. Preliminary results for Omarobougou, Mali are reported in *Survey Large Area for Scaling up Predictions and Monitoring Soil C Changes* later in this report. Data from Kpeve have not yet been analyzed and will not be reported this year.

Comparing Soil C Changes Under Different Maize-based Cropping Systems, Native Fallow and Bare Fallow in Kpeve, Ghana

An experiment was conducted by S. Adiku (University of Ghana) in Kpeve, Ghana to investigate the biomass and soil carbon turnover by seven fallow treatments two years into a long-term maize cropping system. Maize was planted in May each year. Natural bush fallow, which benefited from previously fertilized maize, produced about 14 tons/ha of biomass over a two-year period while other bush fallow treatments produced about 9.0 tons/ha over the same period. Planted legume fallows produced the least dry matter. Pigeon pea produced about 6 tons/ha while mucuna and cowpea produced about 4 tons/ha. Among the legumes, pigeon pea has stood out to be the most drought tolerant, and controls weeds well.

An initial decline in soil carbon occurred under all maize-fallow treatments, but the planted legumes appear to have generally maintained the soil carbon levels with minimal fluctuations over the seasons. Planted legumes, especially pigeon pea, hold promise as good fallow plants having good organic

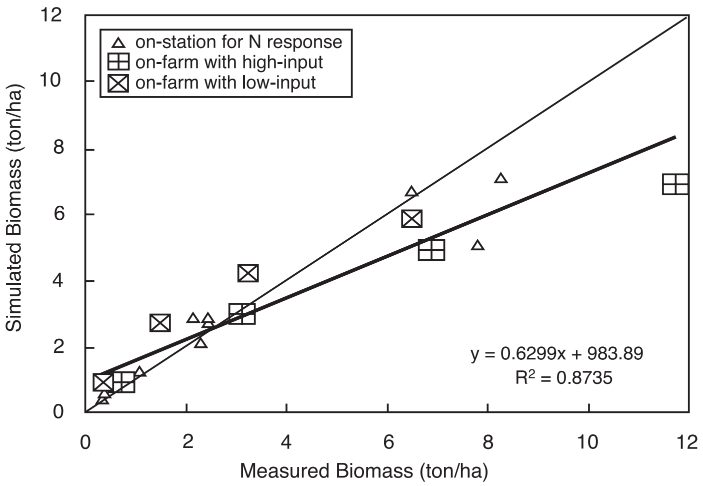

Figure 13. Measured vs. simulated total dry matter of maize from two on-farm and one on-station experiments conducted in Wa, Ghana 2004.

carbon maintenance, nitrogen fixation, weed control and seeds that could bring additional income to farmers.

Conduct On-station Experiments to Evaluate Potential for Increasing Yield and Soil C in Ghana

An experiment was conducted on-station at SARI in Wa in the upper West Region of Ghana. As in 2003, nine treatments were conducted, comprising a factorial combination of three nitrogen levels (0, 60 and 120 kg N/ha) and three phosphorus levels (0, 60 and 90 kg P_2O_5/ha). The experimental area was disc plowed using a tractor and hand harrowed using hoes before sowing. The experiment design was a randomized complete block design with four replications. Each treatment plot measured 8 m x 6 m. Phosphorus as single super-phosphate fertilizer was broadcast on 15th June 2004 and incorporated into the soil using hoes. An improved maize variety, cv *Obatanpa*, was sown on 17 June 2004 on flat seedbed. A preemergence herbicide (ROUNDUP i.e., glyphosphate) was applied soon after sowing to control weeds and manually weeded once later in the season. Nitrogen as urea was split applied at two and six weeks after sowing by burying close to the base of the maize stand. Data were collected to quantify maize growth, yield, and yield components to these treatments. Soil C samples will be taken next year to characterize treatment effects on soil C changes over time.

Conduct On-farm Trials in Ghana and Compare Options to Increase Yield and Soil C

Two on-farm trials were carried out in 2004. One was conducted on farmers' fields in Nandom, Ghana, consisting of comparisons of mucuna-maize rotations. Earlier treatments were continuous maize plus 30 or 80 kg N/ha and maize following mucuna or bush fallow plus 40 kg N/ha. Results from these trials showed higher biomass production under higher fertilizer and mucuna treatments, though yields among treatments were not significantly different. The other on-farm trials were carried out in two adjacent villages: Piisi and Nakor, located within 10 km of Wa, Ghana. Treatments on these farms were 1) continuous maize plus 30 kg N/ha, 2) continuous maize plus 80 kg /ha, and 3) maize/peanut rotation plus 40 kg N/ha. Significant effects of cropping system on dry matter production were found. Treatments 2 and 3 had significantly higher biomass production, which could result in higher soil C sequestration and higher yields. Soil C measurements will be made next year. Figure 13 shows results of comparisons made between measured maize responses to on-station and on-farm treatments with simulations from DSSAT-Century made by Koo and Naab.

Advance Studies of Soil C sequestration at Farm Level Using the IMPACT Tool

ILRI worked with cooperators in Wa and Kpeve, Ghana to collect on-farm data that would facilitate analysis of potential for soil C sequestration at the farm level, taking into account livestock. In the Kpeve study, the IMPACT household model was used whereas the economic framework suggested by the TOA group was used to analyze potential costs of implementing soil C sequestering practices in the Wa study. This work was hampered by the lack of biophysical model simulations needed to provide yield and soil C increases under different options of land use, crop management and livestock management. Thus, the analyses completed to date are for the specific farms in the two study areas, but they do not include specific options in the analyses. Instead, the analyses currently are presented in terms of opportunity costs for changing land unit management on the farms, in the Kpeve case, without considering the positive benefits associated with increased production, for example, that may occur under some management options. Nevertheless, these analyses provided an experience in which all of the information except the aforementioned values was used, and it helped define for other investigators exactly what is needed to make the analyses defendable.

In Kpeve, it was found that opportunity costs for changing current land use/management to use and management designed to sequester carbon ranged from about $280 to $23,000 per ha. The higher range of costs reflects estimates of income per ha for banana production, a valuable cash crop in this region, as well as lettuce that one of the farmers was growing. The lower ranges corresponded to maize, which suggest that carbon sequestration practices could be implemented through improved management on this crop.

Without considering the positive benefits of C sequestering practices on income and food production, the TOA-based analysis indicated that estimated carbon payments would have to be very high to justify their adoption (i.e., greater than $145 per ton C). These analyses will be modified next year to include practical options and their benefits to food production, livestock feed, and income.

Objective 2, Output 2 : An Assessment of the Potential for Soil C Sequestration for the Selected Sites in West Africa at Scales Necessary for C Trading

One of the main goals of the UF group's work is to develop methods for scaling up estimates of soil C. In the soil C Sequestration project, our aim is to develop methods for monitoring soil C over large areas. This refers to scaling up estimation methods from points or fields to large geographical areas necessary for carbon trading. Here, we outline our general plan for scaling up predictions and estimates of soil C from point samples to fields and to large areas.

Three sites have been selected for scaling up purposes in our project. Each of the three sites is approximately 10 by 10 km in size; one is near Omarobougou, Mali and the other two are in Ghana (near Wa in the upper western region and near Kpeve in the southeastern region). The sites were selected based on research that is being conducted by the three teams under the University of Florida component of the SM CRSP. Three high resolution images (Quickbird) have been obtained for Omarobougou, Mali and one for Wa, Ghana. Due to consistent cloud cover, we were unable to obtain an image in Kpeve, Ghana. Each site has fields that are being used for cropping systems being studied for changes that may be made to increase yield and soil carbon. About 200 fields were selected in each site to serve as case studies for our scaling up exercises. The teams collected information on land use history (past five years) from the farmers, delineated field boundaries and sampled fields for base line soil C, texture, pH, and field geometry (using DGPS). Slope characteristics are to be measured in the winter of 2005. Each of these three sites will be considered for case studies in which we will "scale up" for two different purposes. For the first purpose, we will estimate the biophysical potential for soil carbon sequestration in each site by simulating changes in agricultural practices over many fields assuming that practices aimed at sequestering soil C are adopted. A number of different practices and adoption scenarios will be simulated to estimate the increase in soil C aggregated over the landscape (all fields in the simulated "contract"). We refer to this as scaling up predictions of the biophysical potential for soil C sequestration at each site. These results will be analyzed relative to biophysical potential and also provided to the Tradeoff (TOA Project , Montana State University) and farming system analysis teams for integration with socio economic data to produce aggregate supply-demand curves for soil C and assess potential for adoption by farmers, respectively.

For the second purpose, the same fields will be used to evaluate the framework for monitoring soil C over large areas using the Ensemble Kalman Filter (EnKF) methods. We refer to this as scaling up soil C monitoring. For this purpose, different sampling and KF implementation schemes will be evaluated, including the use of field sampling and remote sensing information at different spatial and temporal frequencies. Thus, the EnKF method will integrate data from sampling over space and information from remote sensing to obtain aggregate soil C in all of the "contract" fields and the uncertainty associated with those estimates.

A progress report for each of the activities for PY8 follows.

Survey Large Area for Scaling up Predictions and Monitoring Soil C Changes

This output overlaps that described in *Wide Area Soil Sampling for Characterizing our Study Areas in Ghana and Mali* for Wa Ghana. Here, a summary of results from Omarobougou, collected by Traoré, Doumbia and Bostick, is presented. The purposes for these data were to 1) characterize current soil C over large areas and 2) develop geostatistical relationships that can be used to krig (and co-krig) soil properties over large areas, including many fields where measurements were not made. In late 2003, 194 fields were surveyed near Omarobougou, Mali to create a spatial database of soil C, texture and cropping history. Soil C, pH and texture measurements were made in the IER lab in Bamako by M. Doumbia. QuickBird and ASTER images were obtained and overlaid with field boundaries and soil sample data. Geostatistical analyses were performed to create semivariogram models for soil C, percent sand, and elevation as well as cross semivariogram models between variables. These relationships were used to estimate texture and soil C for 2,115 fields (containing 1,776 ha) identified in the QuickBird image. The cross semivariogram of percent sand and clay and elevation showed strong spatial correlations. Thus, co-kriging was used to estimate percent sand and clay as well as texture in each identified field. The cross semivariogram between C and elevation did not show a strong spatial correlation, thus kriging was used to estimate soil C in fields that were not measured.

Create Spatial Databases for Case Study Area for Scaling Up Predictions and Evaluating Kalman Filter Monitoring Methods

The data collected in both Wa and in Omarobougou were used to create databases for simulating potential soil C sequestration for the case study areas. For Omarobougou, model inputs were created for 2,115 fields using the soil texture fractions and C obtained from kriging and co-kriging. Soil parameter files were created using the Nearest Neighbor method, developed last year, for estimating soil water holding characteristics (based on texture and soil organic matter) and published by Jagtap *et al*. (2004). Field slopes were obtained from the ASTER image. The DSSAT model was modified to use tables of surface runoff (fractions of rainfall amounts in each storm based on analyses performed by Walen (see *Refine the Runoff Model for Ridge Tillage and Conventional Fields in Mali* section, above). For fields with slopes larger than 0.4 percent the simulations were performed using that slope, and then using a slope of 0.4 percent to represent differences in runoff potential if ridge tillage were implemented on the field. The cropping system assumed for the fields was a cotton-sorghum-maize rotation, based on land use history surveys in the area by S. Traoré (unpublished). Overall, soil C sequestration increased by over 100 kg/ha/yr over the 20 years of simulations, which amounted to 3,719 metric tons of sequestered soil C.

Results of these simulations are being analyzed. However, this is a preliminary study in that we did not yet have time to evaluate the soil databases we developed and we have not gained confidence in the simulations of cotton or changes in soil C. The exercise did, however, demonstrate the various steps necessary for scaling up predictions of potential soil C sequestration in Mali.

A similar analysis was done for the Wa, Ghana case study. However, in that preliminary study, we used all fields in which texture and soil C were measured and their slopes were available (84). J. B. Naab was in charge of the laboratory analysis after he, S. Traoré and J. Koo collected the samples and recorded data from the fields in the study.

Scale Up Implementation of the Kalman Filter Approach for Estimating Soil C Over Time for Large Areas

A paper was written and submitted for publication on implementation of the EnKF for multiple fields, taking into account correlations of soil C and decomposition rate parameters among fields (Jones *et al*., 2005, accepted). J. Koo implemented the EnKF using both a simple soil C model and the DSSAT-CENTURY model as planned. The possible advantage of the more complex model is that it predicts above- and belowground biomass depending on cropping season, soil, management and weather. Disadvantages are that the inputs required for the model are difficult to obtain (they have to be estimated from what is known about the soils, for example), it is more difficult to set up than the simple model, and it takes a long time to run even for less than 100 fields. This is because at least 200 stochastic

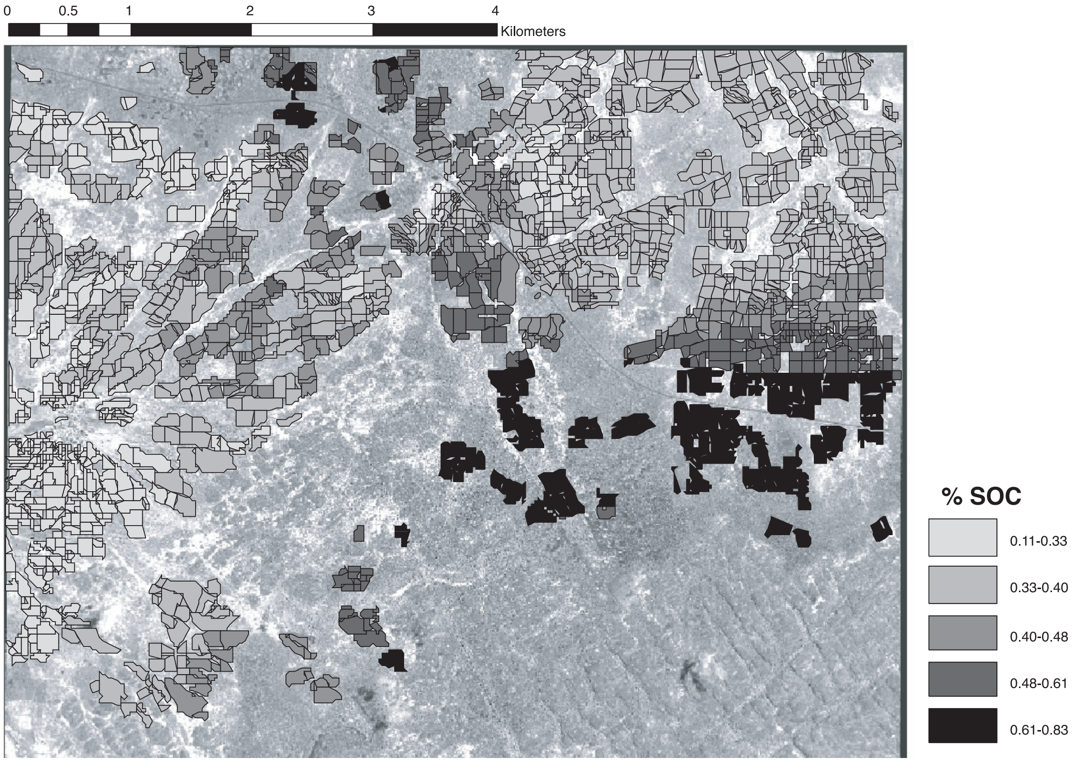

Figure 14. Map of SOC % used to initialize the EnKF simulations. Values were generated by block kriging point measurements of soil carbon in an area near Omarobougou, Mali collected by P. S. C. Traoré and M. Bostick.

realizations of each field must be simulated each year. M. Bostick applied a simple model with the EnKF using over 400 fields, and the calculation time was only a few minutes. Figure 14 shows measured soil carbon levels in the top 20 cm of soil over space in Mali. The EnKF uses these initial conditions and produces similar maps of soil carbon for each of the fields over time. Uncertainties in these estimates are also produced by the EnKF. Our analysis of these fields in Mali gives us confidence that the technique will scale up for large areas.

Objective 2. Apply Methods to Assess the Potential for Carbon Sequestration for Selected Sites in South Asia

Last year the Cornell group reported a preliminary assessment of maximum potential soil carbon sequestration for Rupandehi district in Nepal. Because of analytical difficulties with the TOC dataset, site level TOC was estimated from our texture—TOC prediction equation for cultivated soils in South Asia. We have now resolved the analytical problems and use the actual TOC data to derive a more realistic estimate of maximum potential carbon sequestration; again using the relationship between TOC and texture for native South Asian soils reported in PY7 to determine the maximum possible C content of the soils. Geostatistical methods were applied to quantify spatial structure, and kriging was utilized to map actual TOC, maximum TOC and maximum potential carbon sequestration. Total potential TOC sequestration by this analysis for the Rupandehi district is 1.96 x 10^6 t C or an average 17 t C/ha. This estimate compares with a value of 1.7 x 10^6 t C obtained last year. Our algorithm describing maximum soil TOC will be refined when data from the additional 120 sites is included and this will give us a “final” estimate for maximum soil C sequestration in Rupandehi district from the 350 point data set.

A similar exercise was undertaken with a small, localized dataset covering only 1,626 ha or 1.2 percent of the Rautahat district in Nepal. Maps of actual SOC, maximum SOC and potential C sequestration were constructed by inverse distance weighting because there were not enough points (only 26) to do adequate geostatistical analysis and kriging. Total potential C sequestration for this small area is estimated at 16,038 t C or 10 t C/ha on average. While this approach predicts somewhat lower, but comparable levels of maximum potential C sequestration as the Rupandehi example, interpolations may not be accurate, because of the paucity of data points. Additional data points from the district can be used to validate this approach and assess the soundness of the potential C sequestration predictions.

Carbon Trading Possibilities. The market value of carbon is variable. On 15 June 2005, its value on the Chicago Climate Exchange (CCX) was $4.95/tonne C, whereas its value in Europe was about $24/tonne C for emissions permits. We, and others, have measured annual soil carbon sequestration rates in the range of 0.2-0.6 t C/ha. This would generate an annual income of $1-3/ha in the USA market and $5-14/ha in the European market. Average farm size in Nepal and Bangladesh is about 0.7 ha (generous size estimate) so the average annual income per farm would be between $0.7-2 and $3.5-10 in the USA and European markets, respectively.

The CCX trades in units of 100 tonne C. For a one year contract, this would require an aggregation of between 238 and 714 farm households for the carbon sequestration rates given and using the average size farm. The cost of monitoring a carbon sequestration program must be borne by the trader, which would further reduce payments to farmers. It seems unlikely that farmers in Bangladesh or Nepal will benefit from carbon trading. On the other hand, farmers who can come with improved management and increased soil carbon contents will benefit from enhanced productivity and reduced input costs.

BIOTECHNOLOGY

Project: Assessing the Effects of Bt Crops and Insecticides on Arbuscular Mycorrhizal Fungi and Plant Residue Carbon Turnover and Fate in Soil

Principal Investigators: Medha Devare, Janice Thies and John Duxbury, Cornell University

Objective 1: Assess the Effects of Bt Corn, Cotton, and Rice on the Abundance and Diversity of AM Fungi and Compare Them to Non-Bt Isolines Grown With and Without Insecticide in Field Trials

Field studies have been established for two consecutive years in New York (corn), China (rice) and Colombia (cotton), despite the fact that a sub-contract with China was finalized only in May 2005 and the sub-contract with Colombia has yet to be finalized. Soil samples have been collected at planting, anthesis, and harvest in the corn trial; at the seedling, heading, and physiological maturity stage in rice; and before planting and at anthesis in the cotton trials. A three-year litterbag study has been initiated with corn, rice, and cotton residue at each field-site; the first set of litterbags will be excavated at physiological maturity for each crop this year, with future excavations scheduled at the same phenological point in subsequent years of the study. DNA has been extracted from the samples by technical assistant Luz Marina Londoño, at all sites, and is being stored for molecular analyses at -20°C. A molecular method developed to determine community structure of arbuscular mycorrhizal fungi (AMF) was found to be unreliable. A protocol using new primers has been developed and tested at Cornell University; all collaborators will use this protocol to assess AMF community structure in the coming months. Cornell has tested a protocol for measuring glomalin as an indicator of the abundance of AMF with soil samples from the 2004 season. Research is ongoing in the Thies Laboratory to develop monoclonal antibodies to glomalin to enable Enzyme-Linked Immuno-Sorbent Assay (ELISA) determinations of glomalin in soil. $^{13}CO_2$ pulse-labeling chambers have been constructed and a greenhouse experiment initiated to label Bt and non-Bt corn grown with and without corn rootworm pressure. At Cornell, graduate student Kai Xue is conducting the corn litterbag study and $^{13}CO_2$ pulse-labeling work, with help from Philippina Visiting Scholar Raquel Serohijos. Technical assistant (soon to be graduate student) Luz Marina Londoño is conducting research on AMF abundance and community structure.

Field Trials and Objectives

Corn—M. Devare, J.E. Thies, J. Duxbury, L. Allee, and J. Losey (Cornell University, USA)
A field trial was established at the Musgrave Experimental Farm in Aurora, New York in May 2004 and May 2005. The trial consisted of three replications of the following treatments in a randomized complete block design (RCBD): transgenic Cry3Bb “YieldGard” Bt corn resistant to the corn rootworm (CRW), the non-Bt isoline with a pre-emergent treatment of the insecticide tefluthrin applied to control the rootworm, and the non-Bt isoline without insecticide. These plots were in a field with low rootworm pressure; one replication each of the treatments was also established and sampled in three fields with high rootworm populations. Two composite soil samples consisting of 10 sub-samples across a transect of each plot were collected at planting in 2004 and 2005, and at anthesis and harvest in 2004 to a depth of about 15 cm using soil corers.

Rice—W. Wu (Zhejiang University, Hangzhou, China)
Three replicates of Cry1Ab Bt rice (KMD1) and two NoBt varieties (Xiushui 11 and Jiazao 935) were transplanted in RCBD into 3 m x 4 m plots at the experiment farm on the Hua-jia-chi campus of Zhejiang University, Hangzhou, China in June 2004. Half of each plot was treated with the insecticide triazophos to protect against stem borers. A composite rhizosphere soil and root sample consisting of four sub-samples across a transect of each plot was collected at the seedling, booting, heading and maturing stages. Samples were immediately transported to the laboratory and processed less than 6 h after removal from the field. The roots were shaken to separate soil not tightly adhering to the roots. Root-attached soil was then squeezed from the roots with a gloved hand and mixed evenly for analysis.

Cotton—E. Barrios (CIAT, Cali, Colombia)
A field trial with Bt (Bollgard® technology; variety NuCont 33B expressing Cry1Ac toxin) and non-Bt cotton (variety DP 5415) was established in April 2004 at the experimental station CORPOICA (Colombian Corporation of Agronomy Research) in Palmira (Valle), Colombia. The experimental plots measured 225 m2 (15 m x 15 m) in RCBD. Each of 4 blocks had 6 treatments (plots) for a total of 24 plots under evaluation. The treatments are a combination of the two cotton varieties above with three insecticide application regimes as follows:

1) use of insecticides to control non-target pests (i.e., non-lepidopteran pests);
2) application of conventional insecticides as normally applied in the region; and
3) application of pesticides that contain Bt as normally applied in the region.

Samples (0-10 cm) were collected for bulk and rhizosphere soil at pre-planting, anthesis, and harvest of the cotton crop. At pre-planting only soil samples were collected while during the two remaining sampling periods each year, bulk soil, rhizosphere soil and roots were collected. At each sampling point a soil monolith, including a cotton plant, was collected in order to carefully separate bulk from rhizosphere soil (soil firmly adhered to roots).

Abundance of AMF—Glomalin

A protocol to estimate abundance of AMF by extracting and measuring glomalin ("easily extractable glomalin"), using the Bradford total protein assay by Bradford (1976) and Wright *et al*. (1996), was tested and applied to all 2004 soil samples from the New York corn trial.

ANOVA and Tukey's comparison of means showed that the only treatment effect on glomalin occurred at harvest, when more glomalin was extracted from Bt compared to NoBt and NoBt+Insecticide plots, suggesting that more AMF were present in the Bt plots. The analysis indicated no significant effects of infestation at planting; however, glomalin was higher in infested than in uninfested plots at anthesis ($P = 0.05$). Exactly the opposite held true at harvest.

The variability in glomalin measurements by this method is high, and recent findings in the Thies Laboratory suggest that the method may not be specific for glomalin, but it may also extract other proteins as well. We have been working to develop an ELISA which would allow a quantitative but less variable determination of glomalin. An anti-glomalin monoclonal hybridoma line has been obtained, and a laminar flow hood is currently being prepared for tissue culture work. In August 2005, this cell line will be cultured, and the monoclonal antibodies produced will be purified and harvested for ELISA determinations. The ELISA determinations will be used to analyze glomalin content of soil samples from China: Dr. Wu will be working in the Thies Laboratory for two to three months at the end of 2005 to determine the glomalin content of his soil samples.

Abundance of AMF—Spores and Hyphal Length

Spores were enumerated microscopically after separating them from the bulk of the soil samples by wet sieving in a succession of sieves (1000 μm, 250 μm, and 38 μm) and decanting, followed by sucrose centrifugation (Sieverding, 1991). Results indicate that at planting and anthesis, Bt plot spore counts were lower than in NoBt plots ($P = 0.05$). However, spore counts were highest in the Bt plots at harvest, although results were statistically significant only for the Bt—NoBt+I plot comparison. Two rather than one person counted harvest sample spores, suggesting that the significantly higher counts at this sample point may be due to operator error. Consequently, spores in harvest soil samples will be re-extracted and counted again in the near future.

Wet-sieving of soil samples from the 2004 Bt, NoBt, and NoBt+I rice plots is ongoing in Dr. Wu's laboratory in China; spore enumeration will begin soon.

In Colombia, Dr. Barrios' Laboratory has completed spore counts and estimates of hyphal lengths for all 2004 samples. AMF hyphae were extracted from six soil subsamples of five grams each using the membrane filtering technique of Miller and Jastrow (1990). AMF hyphae collected on nitrocellulose filters (25 mm, 1.2 μm pore diameter, Millipore, USA) were stained with Trypan blue and hyphal lengths estimated using the grid line intersect method (Tennant, 1975) from 70 visual fields in each filter. In order to assess percent root colonization fine roots were cleared with 10% KOH in a water bath at 90°C for 1 hour, kept 15 min in 10% HCl and then stained with Trypan Blue in a water bath at 60°C, for 1 hour prior determination of root length colonized by the gridline intersect method (Sieverding, 1991). AMF spore number, hyphal length and percent root colonization were subjected to analysis of variance (ANOVA) at each sampling time. Additionally, t-tests were conducted for more detailed comparisons between Bt and Non-Bt cotton measurements. All analyses were conducted using SAS (SAS Institute 2000).

Results comparing AMF spore numbers, hyphal lengths, and root colonization in soils collected from Bt and Non-Bt cotton plots showed no significant differences during two seasons of cotton cultivation suggesting that there was no apparent impact of cotton plants containing the cry1Ac gene on these measures of AMF abundance in the field. The root colonization results, however, contrast with those presented by Miller (1993) indicating that plant disease resistance gained in transgenic plants would reduce the susceptibility of such plants to colonization by AMF fungi. However, hyphal length in rhizosphere soil was significantly higher than in bulk soil (Table 10). This is consistent with the literature recording greater biological activity in the rhizosphere (Curl and Truelove, 1986). The rhizosphere effect was not consistent for spore numbers although significant at Anthesis 2004 and Harvest 2005.

Table 10. Rhizosphere effect on AMF parameters in soils under Bt and Non-Bt cotton plants.

Sampling	Soil	Spore number (# / 30 g soil)	Hyphal length (m g^{-1} dry soil)
Anthesis 04	Rhizosphere	21.2 a	23.2a
	Bulk	16.1 b	14.5b
Harvest 04	Rhizosphere	14.0a	17.6a
	Bulk	16.5a	8.0b
Anthesis 05	Rhizosphere	42.0a	14.8a
	Bulk	41.8a	8.0b
Harvest 05	Rhizosphere	35.1a	14.9a
	Bulk	20.3b	9.2b

For each column, means followed by different letters are significantly different at the $P<0.05$ level (Tukey test)

AMF Community Structure

Amplification of AMF DNA by nested Polymerase Chain Reaction (PCR) using first the non-specific fungal ITS5-ITS4 primers and then the AMF-specific SSU-Glom1-LSU-Glom primer pair was unreliable and also demonstrated that these primers were not specific for AMF, amplifying negative controls (DNA extracted from Ascomycetes).

Two new primers (111F-851R; and 851F-ITS2R) were designed by downloading 18S rDNA sequences from Genebank, importing them into ARB, calculating a new tree using Glomeromycota 18S sequences and a fungal phylogenetic tree developed by Chris Jones in the Thies Laboratory, and designing probes targeting Glomeromycota when other phylogenetic groups are present. The functionality of this primer pair is being tested.

This work yielded a potential AMF-specific primer pair to use in this study: 851F-ITS2R. Although the 111F-851R primers were promising, a light band representing amplification of the Ascomycete negative control indicates that this pair does not appear to be sufficiently stringent. Once specificity and reliability of the 851F-ITS2R primer pair is ascertained, the stored DNA will be subjected to PCR using terminally-labeled primers. Restriction endonucleases will be used to cut the amplicons, and the terminal fragments analyzed by terminal restriction fragment length polymorphism analysis (TRFLP) to assess the effect of treatment on AMF communities.

DNA from soil samples collected in the Chinese and Colombian rice and cotton experiments was extracted and stored at -20°C for molecular analysis. After PCR to amplify AMF DNA with various primer pairs was ineffective, the decision was made to not waste further resources on molecular analyses in China and Colombia until a protocol is finalized in the Thies Laboratory. Once a reliable PCR protocol is established and amplicons obtained, they will be separated by denaturing gradient gel electrophoresis (DGGE) and by TRFLP in Dr. Wu's and Dr. Barrios' laboratories, respectively, to obtain AMF community fingerprints and assess the effect of treatments on mycorrhizal communities in Bt rice and Bt cotton.

Objective 2. Assess the Abundance and Community Structure of Soil Detritivore Arthropod Populations in Field Trials of Bt Corn, Bt Cotton and Bt Rice

Detritivore arthropods will be measured on corn, rice, and cotton litterbag residues each time a set of bags is sampled: at harvest in 2004, 2005, and 2006. Pitfall traps are also being sampled throughout the 2005 season in the cotton experiment, and the Berlese funnel technique will be employed on soil samples in all experiments to assess the abundance and community structure of soil detritivore arthropods.

Litterbag Study

Corn cobs, shoots and roots of plants were collected separately after harvest in 2004 from Bt, NoBt and NoBt+I plots in New York and stored at 4°C. Residues were oven-dried at 65°C until the weight of sub-samples was constant. Polyethylene mesh litterbags (12.5 x 12.5 cm; 2 x 3 mm mesh size) were filled with 7 g of cobs, 10 g of shoots and 5 g of roots with two replicates. In bags containing shoot material, the ratio of stem to leaf (3:2) was determined by measuring their relative ratios in sub-samples. Replicate litterbags were placed at the plot surface and at 10 cm depth in each plot. Three traveler bags that were taken from the laboratory to the field but not set in soil were used to estimate losses due to transportation. A complete set of litterbags was removed from the field after corn harvest; data from this set of litterbags is currently being analyzed.

In China, 5 g of rice roots and 10 g of straw sheaths collected at harvest from each plot were weighed into polyethylene mesh litterbags (10 cm x 15 cm). Straw sheaths have been used rather than leaf blades as farmers return only the sheaths to the field. Mesh size of bags containing the fine rice roots was 0.5 mm x 0.5 mm, while that of bags containing the straw sheaths was 1.0 mm x 1.0 mm. Replicate root and straw bags were placed at the surface or at 10 cm depth in each plot; a complete set will be brought back into the laboratory for analysis at rice harvest in each year of the study.

In Colombia, cotton plant material was collected at the end of the cropping season. Aboveground biomass (shoots=stems+leaves+sexual structures) and below ground biomass (roots) were initially air dried followed by gentle drying at 40°C until constant weight. Plant material was cut into 10 cm pieces. Twenty grams (20 g) were placed in 25 x 25 cm litterbags with mesh size of 1 mm for aboveground (tops) or belowground (roots) plant materials respectively. Litterbags with tops or roots were either placed on the surface or incorporated in the soil. A total of 1728 bags were distributed in the field under 2 treatments (Bt cotton, Non-Bt cotton), 12 field replicates, 4 modes of application (tops/surface, tops/incorporated, roots/surface, roots/incorporated), 6 samplings/year during a three year decomposition experiment.

The litterbags were placed in the field on 12/02/04 just prior to planting the soybean rotation. Bags were retrieved and residue remaining determined at 2, 4, 8, 12, 26, and 39 weeks after placement. Results to date are shown in Figure 15.

Bt cotton residues showed small but significantly lower dry weight losses (i.e., less decomposition) than non-Bt cotton residues only at the 8 and 12 weeks samplings (Figure 15). These results are comparable with those of Gupta and Watson (2004) who found only small differences in decomposition between Bt and Non-Bt cotton residues during 8 weeks of incubation study. In addition, the 8- and 12-week results are also comparable to microcosm lab incubation results obtained by Flores *et al.* (2005) indicating that ground Bt plant materials decompose less than Non-Bt plants. However, initial differences may be transient. The long-term design of this decomposition experiment should allow us to determine if observed differences are a result of inherent changes in Bt cotton or Bt toxin-mediated effects on soil organisms involved in residue decomposition. This is specially important as there are studies showing that this toxin may persist in the soil for several months (Tapp and Stotzky, 1998) and also recent findings by Gupta and Watson (2004) highlighting the potential of undecomposed

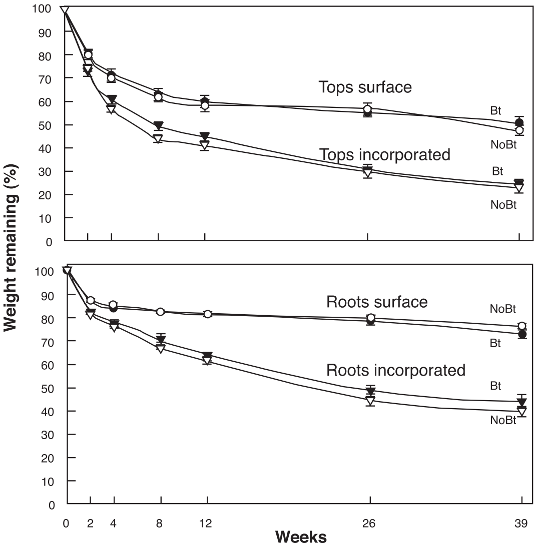

Figure 15. Decomposition of Bt and no-Bt cotton residues over a 26 week period. Above ground and root residues were placed separately in litterbags and either placed on the soil surface or incorporated into soil at 10-15 cm depth.

Bt cotton roots to provide a significant Bt toxin reservoir in cotton fields after the harvest of Bt cotton.

Objective 3. Determine Carbon Allocation in Corn, Fate of Corn Residue C in Soil and Residue Decomposition Rates for Bt Corn, Bt Cotton and Bt Rice under Field Conditions

$^{13}CO_2$ Pulse-labeling of Corn

Bt and NoBt corn has been planted in 96 pots as follows: 4 treatments (Bt and non-Bt corn with and without rootworm pressure) x 4 replicates x 3 harvest times x 2 (labeled and non-labeled controls). Three seeds of corn were planted and then thinned to one plant in each 2 gallon pot containing peat, vermiculite, and perlite (1:1:1 by vol.) with 6 g of pulverized limestone, 35 g of $CaSO_4$, 42 g of powdered $FeSO_4$, 1 g of fritted trace elements (Peters FTE 555, Scotts Co., Marysville OH) and 3 g of wetting agent (AquaGro G, Aquatrols, Pennauken, NJ). Drainage openings in the pots of treatments with pest pressure were fitted with a fine stainless steel mesh (TWP Inc., Berkeley, CA) to prevent larval escape (Clark and Hibbard, 2004). For treatments without pest pressure, pots were open at the bottom and were allowed to drain after each watering. Pots are irrigated daily, fertilized with nutrient solution weekly and the plants subjected to ambient light for 14 h. Western corn rootworm eggs (*Diabrotica virgifera*) will be procured from USDA's Northern Grain Insects Research Lab (Brookings, SD) about 10 days prior to the target hatch date. Eggs will be suspended in 1 ml of 0.15% (w/v) agar solution by a micropipette and injected at 2.5 cm below the soil surface into the appropriate treatments immediately after they arrive.

Four $^{13}CO_2$ labeling chambers were created using saran bags (Applied Research Products Ltd. Montreal, Canada) fitted with sampling septa. The bags were taped to a circular framework made of plastic hoola-hoops and attached to the greenhouse ceiling by a rope which can be pulled up to extend the chamber to a maximum height of 3.5 m as the plant grows. $^{13}CO_2$ gas will be injected through the septa for about 1 h each time. Plants will be labeled five times until final harvest: (i) weeks prior to injection of rootworm eggs when 50 percent of the plants are at the 5 leaf collar stage (V5); (ii) 50 percent at the 6-7 leaf collar stage (V6-V7); (iii) at 50 percent silking (R1); (iv) at 50 percent "milk" stage (R4); and (v) at 50 percent physiological maturity (R6). The plants will also be destructively sampled three times to measure uptake of the label and assess whether C allocation within the plant varies in Bt and NoBt plants and with and without pest pressure. Sampling times will be standardized by coupling them to plant phenology: prior to injection of rootworm eggs at V5; at R1; and at R6. Labeled aboveground corn biomass and roots will be buried in field plots in 2006 to determine the fate of corn residue C in soil.

Total Organic C and Lignin Contents

Total organic C and lignin content of Bt and NoBt rice straw was determined by the Wu Laboratory in China following the methods described by Lao (1988). These determinations are yet to be made for Bt and NoBt corn and cotton. Results of the total C and lignin content in the rice study are presented in Table 11.

The data show clearly that total C and lignin contents in the Bt rice were significantly higher than in the NoBt varieties with or without pesticide. As crop residue lignin content is negatively correlated with decomposition and nutrient release (Neely *et al*., 1991; Tian and Brussaard, 1997; Cobo *et al*., 2002), these data suggest that Bt rice could decompose at a slower rate than the NoBt varieties. Residue decomposition rates will be assessed from the litterbag study to determine if this occurs. However, it is noteworthy that C and lignin in the NoBt varieties also differed significantly, indicating that these parameters also differ between rice varieties.

Table 11. Mean total carbon (± standard deviation; n = 3) and lignin content (± standard deviation; n = 3) in rice straw at maturing. Values within a column followed by the same letter are not significantly different (P<0.05).

Treatments	Total Carbon (w/wo)	Lignin (w/wo)
Bt	47.14/3.88a	10.47/0.59a
NoBt (variety Xiushui 11)	40.71/3.03b	9.78/0.56b
NoBt (variety Jiazao 935)	36.14/2.88c	8.45/0.45c
NoBt+I (variety Xiushui 11)	40.00/3.44b	9.34/0.56b
NoBt+I (variety Jiazao 935)	37.90/1.86bc	8.67/0.41c

Project: Genetic Characterization of Adaptive Root Traits in the Common Bean, Phaseolus vulagris

Principal Investigators: C. Eduardo Vallejos and James W. Jones, University of Florida

The goals established for Objective 1, which comprise the identification of root media compatible with magnetic resonance imaging (MRI) technology and the development of a reliable protocol for analyzing roots via MRI, have been accomplished. After screening different artificial soil media, a local sandy soil was identified as one that offered minimum interference with MRI. In addition, a reliable protocol for MRI of roots with a 11 Tesla spectrometer was identified. The combination of the appropriate soil and a corresponding MRI protocol overcame two major challenges in visualizing roots with MRI technology: distinguishing soil-water from root-water, as the MRI spectrometer is set to detect signal from hydrogen, and avoiding the interference from paramagnetic mineral iron present in soil particles.

Screening for variation in root characters among Andean and Mesoamerican genotypes has been started. These include wild accessions collected from northern Argentina to Mexico, as well as some land races known to differ in growth habit and their ability of their roots to mount an adaptive response to low concentrations of phosphorus in the soil.

Objective 1. To Establish Magnetic Resonance Imaging (MRI) as a Reliable Non-destructive Procedure to Measure Root Growth and to Characterize Root Morphology in the Common Bean, *Phaseolus vulgaris*

Output 1: Identification of Root Medium Compatible with MRI Technology

NMR is based on the absorption and emission of energy in the radio frequency range of the electromagnetic spectrum, while MRI is based on the spatial variations in the phase and frequency of the radio frequency energy being absorbed and emitted by the imaged object. MRI of biological specimens is based primarily on the nuclear magnetic resonance (NMR) properties of water hydrogen, which is the most abundant atom in living organisms. This approach represents a challenge for MRI analysis of roots, as it is imperative to distinguish soil-water from root-water. A second challenge is posed by the presence of iron in mineral soils. Iron (Fe) has paramagnetic properties, due to the presence of unpaired electrons, and can cause interference in MRI. For significant interference to occur, iron has to be present in soil at an excess of 2 percent.

Several soils have been screened to identify the type that would be compatible with MRI analysis. These soils include:

- Metromix 200 (Peat moss, vermiculite, perlite, washed sand).
- Potting Mix (Peat moss, composted softwood bark, perlite).
- Cat litter (Montmorillonite).
- Feldspar quartz sand, coarse and fine.
- Mixture of quartz sand 80 percent and Hectorite clay 20 percent.
- Mineral sandy soil (local).

These media were placed in plastic 4-inch pots and were watered to field capacity. Capillary tubes of up to 1.5 mm filled with 1 percent agarose in water were inserted in the soil samples. These soils were scanned in two spectrometers:

- Siemens Allegra Scanner—3 Tesla, 60 cm bore and
- 4.7T/200 MHz MRI Spectrometer.

The Allegra scanner is a standard medical instrument, but it was unable to produce good root images. The main problem with this spectrometer is that many MRI parameters are optimized for medical purposes and are fixed accordingly by the by the manufacturer. The second spectrometer had greater operational flexibility, a more powerful magnet, and yielded high resolution images either as back projections or in 3-D.

Output 2: Development of an MRI Protocol for Intact Roots Grown in Soil

Magnetic Resonance Imaging (MRI) of various bean plants was performed at the University of Florida, McKnight Brain Institute's Advanced Magnetic Resonance Imaging and Spectroscopy Facility (AMRIS). Plants were imaged on a 4.7T Oxford magnet with a Bruker Biospin Avance console and ParaVision software. Samples were imaged in upright position with respect to B_0 in a custom built 12.5 cm ID quadrature birdcage volume coil. Scans of various soil types and water content with imbedded capillary tube phantoms were performed to determine susceptibility artifact and root visualization potential due to soil impurity and soil/phantom interfaces. Based on phantom tests, mineral sandy soil with water content near field capacity was chosen for plant growth and imaging. Fourteen day old bean seedling in a plastic pot was shimmed and localizer scans were obtained using Spin Echo (SE) with Rapid Acquisition with Relaxation Enhancement (RARE) phase encoding. Based on localizer scans three dimensional RARE scans were collected using parameters optimized for root to soil contrast. Data was rendered using Maximum Intensity Projection (MIP) and analyzed using pixel intensity thresh-holding using ParaVision XTIP Image Viewer.

Objective 2. Survey *Phaseolus vulgaris* Accessions from Andean and Mesoamerican Origin and Assess the Extent of Genetic Variation in Root Morphology, Size and Growth Rate

Output 1. Identification of Bean Genotypes with Unique Adaptive Root Characteristics that can be Exploited for Plant Breeding Purposes

An initial assessment of genetic variability for root characters was carried out by visual inspection of the roots. This preliminary evaluation was carried out as a way of pre-screening bean accessions and because the protocol for MRI analysis was not fully developed. The accessions that were screened included: the Andean breeding line 'Calima' and the Mesoamerican land race 'Jamapa.; these lines are the parents of a recombinant inbred (RI) family (F10) that can be used for mapping genes controlling root traits. In addition, we have also made observations on some the Andean landrace G19833, reported by J. Lynch as a genotype with roots that have an adaptive response to low phosphorous availability. Wild accessions from Argentina to Mexico have also been observed. F2 progenies among these lines have been generated for future genetic analysis if needed.

FIELD SUPPORT TO MISSIONS

Project: Timor-Leste Agricultural Rehabilitation, Economic Growth and Natural Resource Management

Principal Investigators: Goro Uehara and Harold McArthur, University of Hawaii

Income generation was the principal focus in the second and final year of the project. Opportunities for income generation were principally linked to agricultural activities outside those of rice and corn, the mainstays for food security in the Baucau District. These opportunities were part of the land use trials established by groups of individuals or villages in the watershed for the simple purpose of "making money." While the groups focused on establishing vegetable crops, animals and fisheries at a range of sites from sea level to the upper slopes of the watershed for that purpose, the product that offered the greatest potential was candlenut. It is a naturally growing and common tree in the watershed and Indonesia is the only importer of candlenut from Baucau where it is used principally as a food condiment.

Through the efforts of the project, GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit—the technical arm of the German Development Agency) and Oils of Aloha (a Hawaiian-based company), a candlenut oil extracting plant will be established in Baucau. Candlenut oil is a value-added product and the extracting plant would not have been possible without this USAID-funded project.

Rice and corn production on demonstration farms increased more than 2 two to 3 three fold with proper applications of N-P-K fertilizers. A portable soil test kit developed by collaborators of the SM CRSP in Thailand was distributed to agricultural district officers in Baucau and other agricultural districts. MAFF district officers received training on the use of the soil test kit and its use as inputs to diagnose macronutrient deficiency in rice and corn. The information provided by the kits, combined with economic inputs, allowed MAFF district officers to provide appropriate fertilizer recommendations to local farmers. The technology used was developed in NuMaSS. Furthermore, project staff enlisted the assistance of IRRI to implement the use of their leaf color chart (LCC) in order to diagnose nitrogen deficiency in rice.

Nurseries of nitrogen-fixing *Leucaena leucocephala* were established in collaboration with MAFF officers in Baucau in the latter stages of the first year of this project. In this project year, seedlings were distributed by the MAFF nursery to farmers and villages in the watershed, and training in the proper transplanting and maintenance of the tree seedlings was provided jointly by MAFF and UH personnel to farmers and villages in the Baucau and Viqueque districts. The MAFF forestry nurseries in Baucau (Triloka) and in Venilale (Buburaga) produced more than 14,000 seedlings that were propagated and distributed to 17 communities in the Baucau district and the sub-district of Venilale.

This project year activities were secondary to the personal tragedies that affected progress in field activities related to all three objectives of the project. The first was the untimely accidental death of team leader and agronomist, Dr. Andre du Toit on 9 February 2005 in Baucau and second, the death of Noi Sousa, four year-old daughter of Fernando Sousa, Associate Country Coordinator and Agronomist, from complications related to hemorrhagic dengue fever in April 2005. Thirdly, as a result of Dr. du Toit's passing, his wife, Carin du Toit, who served as country coordinator, decided to resign and return to the family home in South Africa.

We were fortunate to recruit Michael Jones as country coordinator in July 2005.

The following is our progress report by Objectives.

Objective 1. Increase Agricultural Productivity and Food Security

- Yield increases of rice and maize more than doubled at participating locations in the Baucau district.
- MAFF staff trained in the use of the soil test kit to provide options for fertilizer application for rice, corn and vegetable crops.
- MAFF staff introduced to fertilizer test kits for quality control of N, P and K sources (through UH project, it was found that NaCl had been substituted for KCl in Muriate of Potash fertilizers sold

in country, resulting in application toxic levels of Na^+ instead of K^+).
- Meteorological network of four weather stations established in the Baucau district. These were the only four operational stations in country except for those at the airports in Dili and Baucau.

Objective 2. Diversify and Intensify Crop Production to Generate New Income and Employment Opportunities

- Identified candlenut as a potential source of increased income for households in the watershed. A private sector entity is participating in the establishment of a GDA (Global Development Alliance) with plans to extract candlenut oil for export to its refining plant in Hawaii. (Note: The GDA is an alliance involving private and public sector entities with USAID.)
- Identified three potential niche market products. They include black rice for gourmet restaurants, keawe or mesquite honey for the eco-tourism market and coconut products for the health food market.
- Established 24 agribusiness groups in land use study involving 120 individuals. These groups identified farm systems they felt would help them generate improved income. The system typically included vegetable production and animal production, poultry, pigs, fish and small ruminants. In September 2004, 11 of 12 groups were reported as already producing income through their participation.
- An invasive weed, *Chromolaena odorata*, is now used as a green manure in vegetable production in the land use study.

Objective 3. Improve Watershed Productivity and Sustainability through the Adoption of Sound Natural Resource Management Practice

- Introduced tree nursery establishment through training exercises with MAFF, Peace Corps and CCT staff. Trees from this nursery provided seedlings to farmers in association with the land use trials, for use either as live fences, shade or animal forage.
- Developed training materials in native languages for MAFF use in working with communities in the watershed.
- Provided training in soil survey methods to MAFF staff and initiated plans to produce a digitized soil map of the country.

Capacity Building

- More than 267 individuals participated in training activities over the life of the project, including 5,696 person-hours of training to MAFF staff. Training topics included the following:
  Modern methods in extension and research
  Participatory Rural Appraisal (PRA) methodology
  Site specific nutrient management
  Soil test kit
  Soil survey
  Tree nurseries for agroforestry
  Growing agroforestry trees for livestock forage
  Compost production
  Weather data collection and crop forecasting
  Software application (Word, Excel and Geographic Information Systems (GIS))
  Global positioning systems (GPS)
  Farm budgets
  Marketing
  Risk management
- 160 farmers trained by MAFF staff on crop and soil management practices.
- Six students enrolled at the University of Hawaii through U.S. Department of State scholarships at the East West Center in Honolulu participated in the project's in-country, summer-internship program.
- Project URL established for information dissemination at http://tpss.hawaii.edu/tl. A second URL containing further information relative to agro forestry can be found at http://www.ctahr.hawaii.edu/forestry/data/timor.html.

Project: Improving Maize Productivity in the Planalto Area of Angola

Principal Investigator: Russell Yost, University of Hawaii

This one-year project will be phased out in October 2005. The report of the initial experiments carried out by the ProPlanalto project through communications with USAID/Luando prior to the actual field support award for one year follows.

The central highlands of Angola, especially Huambo province, used to be the breadbasket of Angola during the colonial era. In fact, the soils and climate of Huambo have very high potential for the production of staple crops of maize, wheat, bean and potatoes. Maize used to be the major food and cash crop followed by Phaseolus bean and Irish potato. However, following almost three decades of civilian strife, Huambo has become food insecure and maize has lost its historical status of being a cash crop. The major constraints that brought about this reduced crop productivity and low crop production are listed below.

- Destruction of basic infrastructure (i.e., roads, communication, etc.).
- Destruction of agriculture infrastructure (grain storage, irrigation systems, inputs supply system, etc.)
- Limited availability and high cost of fertilizer and improved quality seeds.
- Lack of farming implements including oxen and animal traction equipment.
- Low purchasing power of small scale farmers.
- Lack of support services (i.e., extension and investigation).

Maize (*Zea mays* L.) is a crop well adapted to agroecological zones with a well-distributed rainfall and 120 to 210 days of growing period (Carsky and Iwuafor, 1997). CIMMYT (1992) has reported low yields of 1.3 MT per hectare on average in sub-Saharan Africa due to N stress environments, the use of local varieties, low rates of fertilizers and very limited use of organic matter. Maize has a high and relatively rapid nutrient requirement, and soil N can be quickly depleted by maize when yields are high and stover is removed (Cretenet *et al*., 1994 and Sanchez, 1976). Although maize yields on farmers' fields at the central Planalto are low, soil nutrients are being mined beyond the power of the soil to replenish them. In fact, most of the small-scale farmers plant crops season after season on the same portion of the land with essentially no addition of nutrients. And even when they do abandon their farms to fallow, the time of fallow is not long enough to restore soil fertility. Average depletion of soil N by maize in South Mali was approximately 25 kg per hectare (Van der Pol, 1991). Phosphate and potassium are also depleted in the soils, to a lesser extent. Nitrogen and phosphate appear to be the most important factors limiting maize production in sub-Saharan Africa.

Irish potato (*Solanum tuberosum L.*) is a high value market crop that is being grown in the central Planalto region. There are many local varieties available, including many varieties from Europe whose performance in terms of yields per hectare and resistance/tolerance to diseases and pests are not known. This crop yields very well when fertilized, though very low without fertilizer. Although fertilizer use on Irish potato is already profitable, it is essential that the small-scale farmers use the proper type and an economic rate of fertilizer to maximize their profit and avoid the acidification of their soils and the contamination of ground water. It is noteworthy that the headwaters of the Okavango delta of Botswana originate in Huambo province.

Phaseolus bean (*Phaseolus vulgaris L.*) is also an important crop in the farming systems in the central Planalto region and is an important component of protein in the local diet. Varieties are mixed and the relative advantages of each are not systematically known. Variety performance in terms of yields per hectare and resistance/tolerance is also not well known. These local bean varieties that are grown without fertilizer yield little (e.g., 350 kg of grain per hectare), though they have a high market value. Beans are best produced on deep soils that have no nutrient deficiencies and are well drained. Improved bean cultivars of disease-free seed would perform better and increase profits.

Little or no evaluation of improved crop technologies, including crop varieties and fertilizer, has been undertaken over the past 30 years in the central highlands of Angola. Therefore, it was decided to evaluate maize, Irish potato, Phaseolus bean and wheat varieties and to determine the biological response of maize and Irish potato to fertilizer under different soil types/conditions as well as the fertilizer rates that would give an economic return to the small-scale farmer.

Materials and Methods

On-station trials were conducted during the 2003/04 growing season and the Nacas (May thru August) season 2004 at Chianga experimental station and satellite sites of Kapunge, Dango, Bailundo and Londuimbali. On-farm demonstrations/trials were carried out on farmers' fields throughout Huambo,

Table 12. Experimental locations and soil characteristics.

Site Name	Experiment Objectives	Soil							
		Texture	% Carbon	pH	% N	P mg/kg	K mg/kg	Color	Probable Soil Order
Kapunge	Research	Clay loam	1.2	5.5	0.09	6.4	121	Red-yellow	Oxisol/ Ultisol
Dango	Research	Sandy clay loam	0.54	5.2	0.03	22.6	28	Brownish-yellow	Ultisol/ Alfisol
Chiangas Experimental Station	Research	Clay	2.24	5.2	0.13	9.9	53	Dark red	Oxisol
Londuimbali[1]	Extension	Sandy loam	5.2	5.4	0.28	2.7	20	Black	Ultsol/ Ultisol
Bailundo (Cena)	Extension	Sandy loam	0.68	5.5	0.04	3.7	70	Brownish-yellow	Ultisol/ Alfisol

[1] Soil analysis carried out at the University of Hawaii

Kwanza Sul, Benguela and Bie provinces. Nacas soils that are hydric in nature are heavy and black with high content of organic matter. Soil samples were collected in 2004 throughout the experimental sites and municipalities of Bailundo, Londuimbali, Huambo and Caala and analyzed in the field using soil test kits or in a soil laboratory at the University of Hawaii (Table 12). The purpose of this sampling was to characterize the fertility status of the soils on which the experiments were conducted. Such a characterization is important to permit extrapolation of the experimental results to other locations and situations throughout the Planalto.

An effort was made to estimate the Soil Taxonomy equivalent of the soils from the experimental sites. An accurate classification requires extensive data that is not available to the ProPlanalto project or to the SM CRSP efforts. Nonetheless, it seemed prudent to attempt a classification with available climatic data from Huambo.

Climatic Conditions of Huambo

Huambo is located at about 1,600 m of altitude and has an annual bi-modal rainfall of approximately 1,200mm. Mean monthly temperatures are lower from May to August with a taxonomic isothermic temperature regime; i.e., relatively little seasonal variation in temperature yet relatively moderate temperature. Analogous climates are very widespread in other high elevations in the tropics, such as potato growing regions of S. America, Asia and Eastern Africa. The impact of such temperatures is that crops such as potato and wheat can be successfully grown. A typical 120 day cycle maize crop may require 140 to 160 days to reach maturity in this cool environment.

Treatments and Experimental Designs

Varieties of maize, Irish potato and Phaseolus bean were evaluated using a split plot design with fertilizer as main treatments and varieties as sub-treatments. However, varieties of Phaseolus bean and wheat were tested under irrigation conditions in the randomized, complete block design. Treatment combinations of fertilizer levels and varieties of maize and Irish potato were tested using a randomized complete block design. The rainy season maize fertilizer trials involved ten fertilizer rates with three fertilizer types and three maize varieties, whereas the cooler season (May thru August) maize fertilizer experiments had seven fertilizer rates, three fertilizer types and two maize varieties. Likewise Irish potato fertilizer trials involved six fertilizer rates, three types of fertilizer and three Irish potato varieties during the rainy season, and six fertilizer levels, two types of fertilizer and two varieties during the Nacas (May thru August) season. The trials, which were set up during the dry season, including during Nacas were irrigated.

Fertilizer Application

The basal fertilizer 12-24-12, single superphosphate (10.5% P_2O) and one third of the urea (46% N) where needed were applied at planting time. Side dressed urea was split for maize trials, the second one-third applied at about 45 days after planting and the other one-third at approximately flowering time. For Irish potato trials, the fertilizer 12-24-12, single superphosphate and urea were applied at planting and the rest of the nitrogen approximately one month after planting.

Economic Analysis

Maize or Irish potato yields per hectare times farm gate price per kg of the commodity was used as an estimate of gross benefit. Multiplying the amount of fertilizer per ha by the cost of one kg of fertilizer at the farm level and adding fertilizer application cost was used to determine the total cost of fertilizer. The net benefit was estimated by subtracting total cost of fertilizer from the gross benefit. An analysis of variance was performed on net benefit and variable cost of fertilizer per ha to determine which fertilizer doses and crop varieties gave the highest economic return to the farming household using the economic dominance analysis (Harrington, 1988).

Conclusions and Recommendations

Maize open-pollinated varieties ZM521 and ZM621 and the hybrid SC713 performed better during the 2003-04 main growing season. However, Kalahari, Dento de cavalho and local varieties had lower yields under fertilizer conditions. Maize ZM521 and SAM3 yielded more on farmers' fields compared to the local variety or Kalahari. In fact, Kalahari was the worst with or without fertilizer. The hybrid SC401 was the best performing variety during the Nacas campaign. Matuba, which yielded the same as SAM 3, ZM521 and ZM421, was found to be a suitable variety for the May thru August (Nacas) season in the central Planalto. However, a very short cycle variety of maize compared to Matuba or ZM421 should be sought since the cold weather that prevails during the Nacas season tends to prolong the cycle of maize (maize growth cycle averaged about 160 days compared to typical maize with an 120 day cycle). Maize yields during the Nacas season were higher compared to the regular growing season as the result of high organic matter, better water use and an extended period of insolation due to low night temperatures. It is too early to recommend hybrids to the small-scale farmers even though they have performed better on the station, because the small-scale farmers have not yet mastered crop production management and would not be able to afford to buy seed every year. Kalahari has not presented any yield advantage over ZM521 or SAM 3 whose seeds are being currently produced in the central Planalto. Therefore, it should not be introduced into Angola.

Maize varieties responded better to the mixture of single superphosphate than they did to the commonly used fertilizer 12-24-12, perhaps due to the presence of sulphur in a single superphosphate. There generally was no response to potassium since this nutrient seems to be available in most of the soils of the central Planalto. The need exists to test other appropriate types of fertilizers, such as Diammonium phosphate (18-46-0). The availability of other fertilizers on the Angolan market would help farmers make the correct fertilizer decision and avoid losing money unnecessarily by incorporating an incorrect fertilizer type. It is interesting to note that the hybrids responded better to fertilizer, especially at high rates, than did the open-pollinated varieties. Maize production, especially with open-pollinated varieties, was not profitable at a farm gate price of USD 0.17/kg. If the railway and roads leading to Lobito are rehabilitated, recommendations to grow maize ZM521 under an economic dosage of N100-P50 will be made to those small-scale farmers who are less resourceful. The Nacas season maize yields were higher and more profitable, unlike maize produced during the regular season. Optimal fertilizer rates that offered maximum benefit were N50-P50 (or N150-P50) and N150-P100 for Matuba and the hybrid, respectively. Imported Irish potato Romanos, Diamante and Picasso produced higher economic yields per ha with fertilizer than did the local varieties (i.e., Boa Nova Regional, Kanjangala and Tchingembo). However, during the rainy season, local varieties, such as Tchingembo, that are tolerant to powdery mildew disease, performed better than introduced varieties from Europe. Imported varieties of Irish potato are not recommended for use during the rainy season unless they are treated with fungicides (e.g., Ridomyl). Romanos was a better performing variety on farmers' fields throughout Bailundo, Londuimbali, Caala and Huambo municipalities than Boa Nova Regional or any other local varieties during the Nacas season. It should probably be released in the rural area of Huambo. However, Boa Nova Regional, which produced a higher number of tubers, most of which were of no economic value, seems to be degenerate and should be consequently discarded. A real problem exists for having good quality Irish potato planting material, and thus, an Irish potato seed company is urgently needed in Huambo province.

An economic dominance analysis of Irish potato indicated that N110- P120-K60 and N220-P240-K120 (regular season) and N80-P100 and N160-P200 (Nacas season) were optimal fertilizer rates that offered maximum net benefits. These optimal fertilizer rates varied with Irish potato varieties and season and so did the net benefits. In fact, the variety Romanos that had greater yields compared to Picasso or Boa Nova regional also gave higher net returns. Likewise during the May thru August Nacas season, Irish potato yields were higher and also tended to be more profitable than during the regular growing season. Unlike maize, Irish potato at a farm gate price of USD 0.20/kg was more profitable, due to its higher yields/ha. If the economy of the country improves and roads and railways are rehabilitated, the transportation costs of fertilizer will be reduced and the farm gate price of produce might increase. Irish potato would then become much more profitable. Irish potato showed no response to potassium, most likely because this nutrient was not limiting in soils throughout the experiment area, except at the Londuimbali satellite site. This also reinforces the need to test and introduce to the Angolan market other, more appropriate, high analysis fertilizer types, such as Diammonuim phosphate (18-46). Recommendations should also be made to farmers not to rely only on ammonium sulfate, which quickly decreases soil pH, but rather to use other nitrogen fertilizers like urea that acidify less.

The yields of Phaseolus bean A286 are relatively low and generally similar to local varieties. Therefore, Phaseolus bean germplasm from CGIAR centers and within the region should be tested and introduced to the Angolan market. Manteiga, the preferred bean variety at Luanda market, should be produced with fertilizer in order to increase its production yields.

Soil analysis using soil test kits, and especially using a soil laboratory is very important to more effectively characterize the fertility status of the soils on which experiments are conducted. Results can then be extrapolated to locations and situations different from those of the experiments. Toward this end, the soil laboratory at Chianga station is being equipped and will be soon fully operational. Tests of the Nutrient Management Support System (NuMaSS) decision-aid are also recommended to assist in the diagnosis of nutrient adequacy, fertilizer prediction and the evaluation of net benefits associated with fertilization on local food crops.

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TRAINING

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Name	Home Country	Gender	Degree
Cornell			
Jagat Adhikari	Nepal	M	MS
Subash Adhikari	Nepal	M	MS
Steven Culman	USA	M	MS
Sanjay Gami	Nepal	M	PhD
Rajan Ghimire	Nepal	M	MS
Ramesh Pokharel	Nepal	M	PhD
Kai Xue	China	M	PhD
Florida			
Carrie Alberts	USA	F	MSc
Welch M. Bostick	USA	M	PhD
Jawoo Koo	S. Korea	M	PhD
Valerie K. Walen	USA	F	PhD
Montana			
Denis Arica	Peru	M	MS
Guillermo Baigorria	Peru	M	PhD
Renzo Barron	Peru	M	MS
Reinier Ellenkamp	Netherlands	M	MS
Kara Gray	USA	F	MS
Abibou Niang	Senegal	M	MS
Cecilia Romero	Peru	F	PhD
Roberto Valdivia	Peru	M	MS
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Alejandra Mora Vallejo	Chile	F	PhD
Thailand			
W. Nilawonk	Thailand	F	PhD
N. Sipaseuth	Laos	M	PhD
S. Yampracha	Thailand	F	PhD
University of Bamako			
Souleymane Kanta Kiari	Mali	M	Ing.
Seriba Konaré	Mali	M	Ing.
University of Ghana			
N.K. Amon	Ghana	F	MSc
Stephen Narh	Ghana	M	MSc
University of Hawaii			
A. Sidibe-Diarra	Mali	F	PhD
Hamidou Konare	Mali	M	PhD
Antonio Querido	Cabo Verde	M	PhD

Non-Degree Programs

Name	Home Country	Gender
Cornell		
Raquel Serohijos	Philippines	F

Workshops

Workshops	Location	Date	No. Attended
Carbon	Mali	2004	15
NuMaSS	Panama	2/22-23/05	36
SE Asia		1/24-25/05	6
Mindanao		12/9-10/04	3
Rice-Wheat	Bangladesh	6/24/04	36
Nepal		10/8/04	26
Bangladesh		10/28/04	22
Bangladesh		10/30/04	20
Nepal		4/6/05	15
Nepal		4/8/05	15
Bangladesh		3/20/05	200
Bangladesh		2/20/05	86
Bangladesh		4/21/05	200
Tradeoff Analysis	Nairobi, Kenya	9/04	22
Panama City		2/05	6
Field Support to	Dili	9/14/05	2
Missions, Timor-Leste	Manatuto	9/6/05	13
Fatulia, Venilate		7/29/05	20
Baucau		5/10-11/05	30
Baucau		4/26-27/05	30
Baucau		2/28/05	11
Uaitobono		2/25-27/05	7
Vermasse		12/10/04	13
Gariuai		12/9/04	14
Fatulia, Venilale		12/8/04	20
Baucau		12/6/04	12
Triloka, Baucau		12/6/04	20

PROJECT MANAGEMENT

Management Entity (ME)

The University of Hawaii serves as the Management Entity for the Soil Management CRSP. Dr. Goro Uehara serves as Director and Dr. Gordon Y. Tsuji serves as Deputy Director. As the Management Entity, the University of Hawaii administers grant funds received from the Agency for International Development under Grant No. AID/LAG-G-00-97-00002-00. The Management Entity is responsible for the overall implementation of the research program and for coordination of project activities under seven sub-agreements with participating institutions and two direct projects at the University of Hawaii. Principal investigators prepare annual work plans and budgets associated with each of their respective project objectives and submit them to the Management Entity for transmittal to the Technical Committee for review and evaluation.

The Management Entity reports on the overall progress of program activities and represents the SM CRSP in negotiations with AID and in meetings and teleconferencing of the CRSP Council. The CRSP Council consists of directors of the nine different CRSPs that are administratively managed by both the Office of Agriculture and the Office of Natural Resource Management in the Bureau for Economic Growth, Agriculture and Trade (EGAT) of USAID.

Operationally, the office of the Management Entity is in the Department of Tropical Plant and Soil Sciences in the College of Tropical Agriculture and Human Resources at the University of Hawaii.

Administratively, the Management Entity utilizes the services of the Research Corporation of the University of Hawaii (RCUH) to implement and manage its sub-agreements with participating institutions. The RCUH is a non-profit organization established by the Hawaii State Legislature in 1965 to support "off-shore" research and training programs of the University of Hawaii. The University of Hawaii has oversight responsibilities of the RCUH.

The CRSP Guidelines, established in 1975 by the Board for International Food and Agricultural Development (BIFAD) for USAID, modified in 1996 and in 1999, guide the ME, and federal regulations are referenced in the administrative and fiscal management of the SM CRSP by the Management Entity. A revised version of the Guidelines was distributed in August 2000. Those guidelines direct each of the CRSP programs to establish a Technical Committee, a Board of Directors, and an External Evaluation Panel. The office of the Management Entity is responsible for administrative and logistical support to members of these "bodies." A description of the role and composition of each follows.

Participating Entities

Board of Directors (BOD)

The CRSP Guidelines states: "The Board consists of representatives or all of the participating institutions and may include individuals from other organizations and host country institutions. The AID Program Officer and the ME Director serve as ex-officio members. The institution, which serves as the ME, will have a permanent member on the Board. Board members are selected by their participating institutions on the basis of their administrative responsibilities and relevant expertise. They should not be chosen solely to represent their respective institutions or projects, but to function in the objective interest of the CRSP. The Board operates under a defined charter to deal with policy issues, to review and pass on plans and proposed budgets, to assess progress, and to advise the ME on these and other matters. While the ME institution has the authority to make final decisions relative to program assignments, budget allocations and authorizations, the ME must, in the collaborative spirit, carefully consider the advice and guidance of the Board and other CRSP advisory groups. Any departure form the Board's recommendations should be justified, recorded in minutes of the meeting, and reported in writing by the ME."

The Board of Directors had their annual meeting in October 30, 2004 in Seattle. John Havlin of North Carolina State was re-elected to serve as Chair of the Board with Ramesh Reddy as Vice-chair. As Board Chair, Havlin participated in the annual meeting of the principal investigators and members of Technical Committee in Kona, Hawaii from July 13 to 15, 2005.

Members and officers of the Board of Directors include:
- Dr. John Havlin, North Carolina State University, Chair
- Dr. Andrew Hashimoto, University of Hawaii

- Dr. Thomas McCoy, Montana State University
- Dr. Ramesh K. Reddy, University of Florida, Vice-chair
- Dr. Philip Thornton, ILRI, Nairobi, Kenya

Minutes of meeting are available by accessing the SM CRSP web site at the following URL, http://tpss.hawaii.edu/sm-crsp.

Technical Committee (TC)

The CRSP Guidelines states: “The Technical Committee is established with membership drawn primarily from principal scientists engaged in CRSP activities, known as principal investigators (PIs), and host country scientists involved in CRSP or IARC activities. The ME Director and the AID Program Officer serve as ex-officio members. The TC meets from time to time to review work plans and budgets, program performance, to propose modifications in the technical approach to achieve program objectives, and to recommend allocation of funds. The TC reports its findings in writing to the ME who will share them with the BOD.”

The meeting of the Technical Committee was held in Kona, Hawaii at the Royal Kona Resorts Hotel from July 13 to 15, 2005 to review annual reports for PY8 and work plans and budgets for project year nine (PY9).

Members of the Technical Committee include the following:

- Dr. E.B. (Ron) Knapp, Retired, CIAT, Chair
- Dr. Thomas Walker, Michigan State University, Maputo, Mozambique
- Dr. John Antle, Montana State University
- Dr. James W. Jones, University of Florida

Dr. David Hess, Director of the Office of Natural Resource Management (NRM) in EGAT, and Mike McGahuey, Jr. of AID/EGAT/NRM/LRM, who serves as the SM CRSP’s Cognizant Technical Officer (CTO), joined Board members, Drs. John Havlin and Philip K. Thornton and Drs. Goro Uehara and Gordon Tsuji of the ME, at the annual meeting of the project in Kona. Modification No. 16, received in May 2005, added $2.8M to the budget for PY8. The total is unchanged from that reported for PY7.

Each PI presented their annual progress report and work plans with budgets to members of the TC over the three-day period.

External Evaluation Panel (EEP)

The CRSP Guidelines states: “The EEP is established with membership drawn from the scientific community to evaluate the status, funding progress, plans, and prospects of the CRSP and to make recommendations thereon. In accordance with the CRSP guidelines, the panel shall consist of an adequate number of scientists to represent the major disciplines involved in the CRSP, normally no more than five members. This number will vary with program size and cost-effectiveness. The term of office shall be long-term to retain program memory. A five-year term is recommended for the initial panel and subsequently rotated off on a staggered time base. Provisions should be made for replacements for low attendance, for resignations or for other reasons. In instances where a minor discipline is not represented on the EEP, the Chairman may request the assistance of an external consultant from the ME.”

“Panel members will be internationally recognized scientists and selected for their in-depth knowledge of a research discipline of the CRSP and experience in systems research and/or research administration. International research experience and knowledge of problems and conditions in developing countries of some members are essential. The members are selected so that collectively they will cover the disciplinary range of the CRSP, including socio-economic components that can influence research and technology adoption. Panel members should be drawn from the United States (some with experience in agricultural research and knowledge of the Land Grant University system) and the international community and should include at least one scientist from a developing host country. Availability to devote considerable time to EEP activities is an important criterion for membership.”

The EEP did not meet in PY8. We did learn that an EEP report was required even though the current SM CRSP grant expires after 10 years. Three former members of the EEP have agreed to serve along with two new members. The members are as follows:

- Will Blackburn, Regional Director for the Western Region, USDA/ARS/CREES

- Eric Craswell, Executive Director, Global Water Project, University of Bonn
- E. Bronson Knapp, Agricultural Systems Scientist (retired), CGIAR
- Amit Roy, President, International Fertilizer Development Center
- James Tiedje, Professor and Director of the Center for Microbial Ecology, Michigan State University

The Board of Directors will develop a Scope of Work for the review process. An organizational meeting is planned at a meeting tentatively set for Washington, DC in December 2005. Site visits, as part of the review, will take place in first half of 2006.

USAID/CTO

Mike McGahuey, Jr. serves as the principal CTO for the SM CRSP. Carrie Stokes and Robert Hedlund will provide backstopping support to McGahuey during period of assignments outside of Washington. Jeff Brokaw, Team Leader for the Land Resources Management group in NRM, will also provide support in the absence of any or all of the CTOs.

CRSP Council

Principal communication links among the CRSP programs are established through the CRSP Council. Directors of nine CRSPs constitute membership of the CRSP Council. Current chair of the Council is Dr. Irv Widders, Director of the Bean Cowpea CRSP at the Michigan State University with Dr. John Yohe of the INTSORMIL CRSP at the University of Nebraska serving as Vice-Chair.

With the re-bidding of ME's for the IPM and SANREM CRSPs completed, we had one returning ME director for the IPM CRSP and a new director for the SANREM CRSP. Members of the Council are as follows.

Director	***CRSP***	***Institution***
Michael Carter	BASIS	Wisconsin
Irv Widders	Bean and Cowpea	Michigan State
Tag Demment	Global Livestock	California, Davis
John Yohe	INTSORMIL	Nebraska
Donald Plucknett	IPM	Virginia Tech
Tim Williams	Peanut	Georgia
Hillary Egna	Pond Dynamics	Oregon State
Theo Dillaha	SANREM	Virginia Tech
Goro Uehara	Soil Management	Hawaii

The CRSP Council serves as a communication link among the nine CRSPs and as a conduit for information flow to and from USAID and other organizations such as NASULGC (National Association of Universities and Land Grant Colleges). Communication involves teleconferencing, e-mail correspondence through the Internet, and meetings as necessary, typically on an annual basis. The INTSORMIL staff at the University of Nebraska created a web site for the CRSP programs. The URL for the site is http://www.ianr.unl.edu/crsps/.

FINANCIAL SUMMARY AND EXPENDITURE REPORT

Financial Summary

Modification Mod#14 added \$2.8M to the core budget (Table 13). Modification #15 provided an updated list of approved countries or international destinations. There were no prior listing of approved destinations in any of the previous modifications. The list allows (1) the CRSP to enter into memorandum of agreements for support of host country participation and collaboration and (2) travel to these destinations without having to seek prior approval from the Office of Acquisitions and Accounting (OAA).

Table 13. Incremental funding awards to the SM CRSP for the period covering February 11, 1997 to September 30, 2005.

Award	PY	Amount	Period
Initial Grant	1	\$2,467,975	Feb 11, 1997-Sept 30, 1997
Mod # 1	1 & 2	\$1,131,025	Oct 01, 1997-Apr 30, 1998
Mod # 2	2	\$2,500,000	May 01, 1998-Apr 30, 1999
Mod # 2[a]	2	\$200,000	May 01, 1998-Apr 30, 1999
Mod # 3[b]	2	\$1,000,000	May 01, 1999-Jul 31, 1999
Mod # 4	3	\$2,500,000	May 01, 1999-Apr 30, 2000
Mod # 5[c]	3	\$200,000	May 01, 1999-Apr 30, 2000
Mod # 6	4	\$2,500,000	May 01, 2000-Apr 30, 2001
Mod # 6[c]	4	\$100,000	May 01, 2000-Apr 30, 2001
Mod # 6[d]	4	\$200,000	May 01, 2000-Apr 30, 2001
Mod # 7	5	\$2,146,428	May 01, 2002-Feb 10, 2002
Mod # 8	5	N/A	Feb. 11, 2002-Sept 30, 2002
Mod # 9	6	\$636,188	July 25, 2002-Oct 25, 2002
Mod # 10	6	\$2,123,505	Oct 25, 2002 -Sept 30, 2003
Mod # 10[e]	6	\$140,307	Oct 25, 2002-Sept 30, 2003
Mod # 10[f]	6	\$600,000	Oct 25, 2002-Sept 30, 2003
Mod #11	7	\$3,000,000	Oct 1, 2003-Sept 30, 2004
Mod #12[g]	7	\$1,800,000	Oct 1, 2003-Sept 30, 2004
Mod # 13[h]	7	\$140,000	Oct 1, 2003-Sept 30, 2004
Mod #14	8	\$2,800,000	Oct 1, 2004-Sept 30, 2005
Mod #15	8	N/A	Oct.1, 2004-Sept 30, 2005

Notes: Superscripts a, b and c refer to field support funds received by the SM CRSP from the Office of Disaster Relief, the AID mission in Bangladesh, and the AID mission in Ethiopia, respectively. Superscript d and e refer to supplement funding to the core budget from AID for impact assessments and Biotechnology respectively. Superscript f refers to supplemental funding to the SM CRSP core budget for the following year. Superscript g and h refer to field support funds received by the SM CRSP from the AID mission in Timor-Leste and Angola respectively. Mod #15 refers to the updated listing of approved international destinations under the Soil Management Collaborative Research Support Program's Global Plan.

Expenditure Report

Tables 14 a, b and c list the cumulative annual expenditure reports and cost sharing reports by institution and allocation of funds from the ME to each participating institution. In 14a, the UH totals reflect expenditure reports for two projects at UH with Russell Yost as PI, buyins from Timor-Leste and Angola, plus residual expenses from a subgrant from NASA via the SANREM CRSP (University of Georgia). Similarly, the expenditure report totals for Cornell (CU) reflects the combined expenditures of three projects and of two projects at the University of Florida (UFL).

The cumulative summary report includes those from phase 1 (1997 to 2002) involving Texas A&M, Florida and NifTAL (Hawaii).

Table 14. Financial summary statement ($'000) of expenditure, cost sharing and funding for PY 8 (Oct 1, 2004 to Sept 30, 2005) from vouchers received.

a. Summary of Expenditures reported during PY 8 (Oct 1, 2004 to Sept 30, 2005)

Institution	MSU	NCSU	CU	TAMU	NifTAL	UFL	UH	ME	Total
	545	214	725	0	0	119	710 (*SM CRSP*)	481	2,794
							8 (*NASA*)		8
							605 (*Timor-Leste*)		605
							112 (*Angola*)		112
Total	545	214	725	0	0	119	1,435	481	3,519

b. Cost Sharing for PY 8 (Oct 1, 2004 to Sept 30, 2005)

Institution	MSU	NCSU	CU	TAMU	NifTAL	UFL	UH	ME	Total
	108	56	216	0	0	7	106 (*UH*)	N/A	493
							73 (*Timor-Leste*)		73
Total	108	56	216	0	0	7	179		566

c. Summary of Cumulative Core Funding (February 11, 1997 to September 30, 2005)

Institution	MSU	NCSU	CU	TAMU	NifTAL	UFL	UH	ME	Total
Mod #2	194	1,000	483	361	190	58	0	214	2,500
	0	0	0	0	0	168	0	32	200[a]
Mod #3	39	173	604	57	36	0	0	61	1,000[b]
Mod #4	142	765	773	293	143	0	0	384	2,500
Mod #5	0	0	0	0	0	0	0	200	200[c]
Mod #6	176	876	523	276	173	95	0	380	2,499
Mod #6[d]	0	0	0	0	0	0	0	200	200[d]
Mod #7	138	784	470	200	140	74	0	34	2,146
Mod #8	0	0	0	0	0	0	0	0	0
Mod #9	130	63	14	0	0	71	145	87	637
Mod #10	423	188	474	0	0	219	486	334	2,124
Mod #10[e]	0	0	0	0	0	0	0	140	140[e]
Mod #10[f]	0	0	0	0	0	0	0	600	600[f]
Mod #1	553	250	712	0	0	350	1,222	503	3,590
Mod #12[g]	0	0	0	0	0	0	1,800	0	1,800[g]
Mod #13[h]	0	0	0	0	0	0	140	0	140[h]
Mod #14	557	250	660	0	0	290	622	421	2,800
Mod #15	0	0	0	0	0	0	0	0	0

Notes: Superscripts a, b and c refer to field support funds received by the SM CRSP from the Office of Disaster Relief, the AID mission in Bangladesh, and the AID mission in Ethiopia, respectively. Superscript d and e refer to supplement funding to the core budget from AID for impact assessments and Biotechnology respectively. Superscript f refers to supplemental funding to the SM CRSP core budget for the following year. Superscript g and h refer to field support funds received by the SM CRSP from the AID mission in Timor-Leste (East Timor) and Angola respectively. Mod#15 refers to the updated listing of approved international destinations for the Soil Management Collaborative Research Support Program's Global Plan.

FIELD SUPPORT, COST SHARING AND LEVERAGING

Field Support

Field support is also referred to as “buy-ins.” These are additional activities undertaken by the SM CRSP at the request of a USAID field mission. Funds to support these additional activities are provided by the mission to the ME institution through the Office of Procurement (OP), now the Office of Acquisition and Accounting (OAA). In PY7, the mission in Dili, Timor-Leste extended the initial 6-month sub-grant to 24 months and the mission in Luanda, Angola reached agreement for a one year sub-grant award. Interestingly, both are lusaphone or Portuguese speaking countries. Timor-Leste has two national languages, Portuguese and Tetun.

Timor-Leste

The action plan for the first six-month program was extended by 18 months for a two-year program. Total funding provided by the mission was $2.4 million for the 24 months. The project entitled “Timor-Leste Agricultural Rehabilitation, Economic Growth and Natural Resources Management” involved the recruitment of two full-time staff members to be posted in-country and involved the conduct of a participatory rural appraisal to guide project researchers in the conduct of activities to increase productivity, improve household incomes and preserve and sustain their forest resources in the Seical watershed, Baucau Agricultural District.

Project startup was hindered early on by administrative hurdles in personnel recruitment and in transferring funds to non-U.S. affiliated banks in Timor-Leste. With the assistance of OAA, most of these hurdles were overcome over the first year.

The project’s URL, http://tpss.hawaii.edu/tl, serves as the information source on this activity.

Angola

Field support from the mission in Angola evolved after the participation of Angolan scientists in a workshop on site-specific nutrient management held in Mozambique from March 22 to 26, 2003. Ricardo Maria, a MS candidate at the University of Hawaii from Mozambique, organized the workshop. Mr. Maria received support through a scholarship provided by the INTSORMIL CRSP via USAID/Maputo. The workshop in Maputo was conducted in Portuguese by the host institution, INIA, and Russell Yost, PI for NuMaSS activities in Africa.

Charles Sloger, CTO for the SM CRSP, Yost and Ken Lyvers of the USAID mission in Luanda were instrumental in facilitating this field support activity for 12 months at a cost of $140,000.

Cost Sharing

Table 14b lists the cost sharing contributions from each of the participating U.S. institutions involved with the Soil Management CRSP. The total reflects the 25 percent matching requirement specified in the CRSP Guidelines (1975, 1999) of the modified total direct costs (MTDC). The following costs are exempt from cost sharing:

1. Funds to operate the ME.
2. Funds committed under terms of a formal CRSP host country subagreement, including facilities, host country personnel services, and equipment and commodity purchases by a participating U.S. institution for use by a host country entity or by the U.S. institution in a host country.
3. Costs for training participants as defined in ADS 253. Provisions for such training normally would be made in the formal sub-agreements.
4. Hospital and medical costs of U.S. personnel of the CRSP while serving overseas.

Matching may include in-kind support such as facilities and utilities to salaries/wages and fringe benefits costs.

Leveraging

Leveraging refers to unanticipated technical and material support provided to the project by host country and partner organizations. In this respect, leveraging is an indicator of acceptance of project goals and objectives. Leveraging is reported in terms of costs of human, fiscal and material resources from collaborating and cooperating institutions, organizations, agencies, and individuals. Values related to these costs are best estimates reported by principal investigators and their collaborators and are reported as equivalent U.S. costs in the following list by projects.

Project	Leveraged funds (est)	Subtotals
Carbon Sequestration		
NASA and SANREM CRSP	250,000	
IER, Mali	50,000	
ICRISAT, Mali	25,000	
NARI, The Gambia	25,000	
SARI, Ghana	50,000	
University of Ghana	15,000	
INERA, Burkina Faso	10,000	
BARI, Bangladesh	25,000	
BRRI, Bangladesh	25,000	
NARC, Nepal	25,000	
IAAS, Nepal	25,000	500,000
NuMaSS		
Kasetsart University	50,000	
Philippine Rice Research Institute	50,000	
IER, Mali	50,000	
NARI, The Gambia	25,000	
INIDA, Cape Verde	25,000	
INIA, Mozambique	15,000	
International Rice Research Institute (IRRI)	25,000	
ISRA, Senegal	50,000	
UCR, Costa Rica	50,000	
PROINPA, Bolivia	25,000	
CIAT-MIS	25,000	
INIFAP, Mexico	50,000	440,000
Trade-off Analysis		
International Potato Center (CIP)	50,000	
Wageningen Agricultural University (WAU)	42,000	
ISRA, Senegal	10,000	
Ecole Nationale d'Economie Applique	5,000	
Ecoregional Fund (ISNAR)		
Panama	50,000	
Kenya	120,000	
Sahel Agr Research Institute	5,000	
Consortium for Agr Mitigation of GHG	10,000	292,000
Rice-Wheat		
CIMMYT, Bangladesh	50,000	
IFAD, Cornell	50,000	
NARC, Nepal	25,000	
BARI, Bangladesh	50,000	
BRRI, Bangladesh	25,000	
CARE, Bangladesh & Nepal	25,000	
BRAC, Bangladesh	15,000	
RDRS, Bangladesh	10,000	
LiBird, Nepal	15,000	
FORWARD, Nepal	15,000	280,000
Biotech		
CIAT	15,000	
Zhejiang University	15,000	30,000
Field Support		
Timor-Leste		
MAFF	50,000	
GTZ	5,000	
Villages in Baucau Agricultural District	31,000	86,000
Angola		
World Vision	25,000	
CLUSA	25,000	
CRDA	25,000	75,000
TOTAL		1,703,000

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ACRONYMS

ACN	Aménagements en courbes de niveau; aka, ridge tillage
ATDP	Agro-based Industries & Technology Development Project (USAID Bangladesh)
BADC	Bangladesh Agricultural Development Corporation
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BRAC	Bangladesh Rural Advancement Committee
BRRI	Bangladesh Rice Research Institute
CARE	International non-governmental organization
CIAT-MIS	International Tropical Agriculture Center-Integrated Steepland Management
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CSM	Cropping System Model
CO_2	Carbon dioxide
CRSP	Collaborative Research Support Program
CSD	Chinese seed drill
CT	Conventional tillage
CURLA	Regional University Center for the Atlantic Coast
DAE	Department of Agricultural Extension (Bangladesh)
DAP	Diammonium phosphate
DFID	Department for International Development (UK)
DICTA	Agricultural Science and Technology Directorate
DLD	Department of Land Development
DOA	Department of Agriculture
DSR	Direct seeded rice
DSSAT	Decision Support System for Agrotechnology Transfer
DT	Deep tillage
ECEC	Exchangeable cation exchange capacity
EMBRAPA-CPATU	Brazilian Agricultural Research Enterprise-Humid Tropics Research Center
ENEA	Ecole Nationale d’Economie Applique
FFS	Farmer Field School
FAO	Food and Agricultural Organization
FHIA	Honduran Foundation for Agricultural Research
FORWARD	Local non-governmental organization (Nepal)
GIS	Geographic Information Systems
GO-Interfish	CARE rice-fish program in Bangladesh
HKI	Helen Keller International
HYV	High yielding variety
IAAS	Institute for Agriculture and Animal Science (Rampur, Nepal)
IBTA	Bolivian Institute for Agricultural Technology
ICRAF	International Center for Research in Agroforestry
ICRISAT	International Center for Research in the Semi-Arid Tropics
ICTA	Institute for Agricultural Science and Technology
IDIAP	Panama Agricultural Research Institute
IDRC	International Development Research Centre
IER	Institut d’ Economie Rurale, Mali
IHCAFE	Honduran Coffee Institute
INIA	Instituto Nacional des Investigacões Agricolas
INIAP	National Agricultural Research Institute
INIFAP	National Forestry and Agricultural Research Institute
INPOFOS	Potash & Phosphate Institute
INTA	National Institute for Agricultural Technology

ISRA	Institut Senegalaise de Recherces de Agricole
ITC	Candelaria Community Technical Institute
KU	Kasetsart University
ILRI	International Livestock Research Institute
IMPACT	Integrated Modeling Platform for Animal-Crop sysTems
INIAP	National Agricultural Research Institute, Ecuador
INIA	National Agricultural Research Program, Peru
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
ISRA	Institut Senegalaise de Recherces de Agricole
KARI	Kenya Agricultural Research Institute
KU	Kasetsart University
LEI	Landbouw Economisch Institute
Li-BIRD	Local Initiatives for Biodiversity and Development
MOU	Memorandum of Understanding
NARC	Nepal Agricultural Research Council
NARES	National Agricultural and Extension Systems
NGO	Non-Governmental Organizations
NO_x,NO, NO_2, N_2O	Nitrogen oxides
NT	Normal Tillage
NuMaSS	Nutrient Management Support System
NUTMON	Nutrient Monitoring
OC	Organic carbon
P	Phosphorus
PROINPA	Foundation for Andean Products Research and Promotion
RDRS	Rangpur-Dinajpur Rural Service
RT	Ridge tillage
SHABGE	CARE vegetable program in Bangladesh
SM CRSP	Soil Management Collaborative Research Support Program
SOC	Soil organic carbon
SOM	Soil organic matte
SRI	System of Rice Intensification
SS	Surface Seeding
TDR	Time domain reflectometry
TOA	Tradeoff Analysis
TPR	Transplanted rice
TRF	Thailand Research Fund
UCA	Central American University
UCR	University of Costa Rica
UNA-Catacamas	National Agricultural University
UNA-Nicaragua	National Agrarian University
UNICAM	‘Campesino’ University
UNIDERP	Univ. for Development of the State and the ‘Pantanal’ Region
VT	Virginia Polytechnic Institute and State University
WB	Walkely-Black method for carbon determination
WRC	Wheat Research Centre (Bangladesh)
WUR	Wageningen University Research Center
Zamorano	Pan-American School, Honduras
ZT	Zero tillage (surface seeding)