Soil Management Collaborative Research Support Program

Project Year 9 Annual Progress Report

2005 - 2006

Cornell University
Montana State University

North Carolina State University
University of Florida
University of Hawaii

SOIL MANAGEMENT
COLLABORATIVE RESEARCH SUPPORT PROGRAM

PROJECT YEAR 9
ANNUAL PROGRESS REPORT

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Photo on cover page taken at Fansiakoro, Mali by Richard Kablan
Title: Field Preparation for ACN (amenagement en courbes de niveau)

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EXECUTIVE SUMMARY

Agricultural performance of developing countries remains far below that of the technically advanced nations and efforts to narrow the gap have been disappointingly slow. High crop yields can be achieved with modern farming methods, but most developing country farmers do not have access to or do not find it profitable to purchase and employ inputs and practices farmers in developed countries use routinely and take for granted.

The first challenge for agricultural researchers is to find globally applicable ways to make performance-enhancing inputs and practices accessible and affordable and to enable farmers to use them optimally on a site-specific basis.

When reading this report it is useful to ask whether the approach being described is globally applicable, enables users to solve problems site-specifically, benefits them economically and leaves the environment unharmed or in better condition than before.

A second challenge is to strengthen human and institutional capacity of developing nations so they too can add to the next generation of performance-enhancing technologies and practices.

The performance-enhancing technologies described in this report are science- or knowledge-based decision support tools. Knowledge is a powerful development aid because it is globally applicable and can be repeatedly used without wear. It is this knowledge and the impact it can have on individuals and societies that enables farmers in technically advanced countries to be more productive than their counterparts in developing nations. Knowledge enables individuals to make better choices and decisions for themselves and the society in which they live, and decision support tools are devices in which specialized knowledge is captured, condensed and packaged so that users that lack this specialized knowledge may access and apply it to make better management decisions.

NuMaSS, a Nutrient Management Decision Support System described in the opening pages of this report, is such a tool. Proper use of fertilizer alone can double food production in developing countries, but for the reasons given earlier fertilizer is not often used in developing countries. NuMaSS was designed to make fertilizer use profitable and operate globally on a site-specific basis. NuMaSS can operate globally because knowledge is globally applicable, but the amount and kind of fertilizer required varies from farm to farm and even within a farm. For this reason, the single fertilizer formulations recommended by national programs often do more harm than good, and NuMaSS is designed to help individual farmers make better fertilizer use decisions.

Individual farmer actions are often constrained by policy decision made at higher government levels. In the Tradeoff Analysis section, a training program on the use of a decision support system to enable government planners to make better policy decisions is described. This approach, developed and tested earlier in Latin America, has been successfully transferred to Africa where future policy makers are being trained to use it, from Senegal in West Africa to Kenya in East Africa.

Technology adoption needed to sustain productivity is another issue that development programs often face. Efforts to sustain the green revolution gains in the rice-wheat cropping system of the Indo-Gangetic Plains through adoption of yield sustaining practices are described in the Rice-Wheat section. This project clearly shows the continuing need for maintenance research to sustain the benefits of the green revolution in countries with growing populations.

In Africa and in South Asia, land degradation contributes to declining agricultural performance. In the Carbon Sequestration section, efforts to reverse this trend by fostering practices that simultaneously captures water, sequesters carbon, increases crop yield, restores species diversity and recharges ground water are described. Here again, knowledge-based tools are applied to predict outcomes of alternative management strategies. Host country researchers learn to use these globally applicable tools to improve agricultural performance on a site-specific basis. Replacing costly trial-and-error approach to research and development with new, science-based tools by developing country institutions is the first step in using the power of knowledge to achieve desired ends.

In the Biotechnology section, the findings of two biotechnology projects that focus on the unseen, below-ground portion of crops are described. Plant genes are generally manipulated to alter or protect the above ground parts of plants. These two projects deal with two questions. First, do genes, altered to protect plants against pests that attack above ground portions of plants, negatively affect beneficial organisms that live symbiotically with plants and, second, can crop performance be improved by designing better roots?

And lastly, the Timor-Leste project was completed in this project year. A final activity, involving a workshop with MAFF personnel and the National University of Timor-Leste and requested by the MAFF director, was held on the application of NuMaSS as a follow up to the use of soil test kits. The candlenut enterprise, initiated during the sub grant period, was successfully established and the first shipment of candlenut oil sent to the U.S. in April 2006. This remains an ongoing endeavor.

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, Laos	Russell Yost, Tasnee Attanandana, Madonna Casimero	University of Hawaii Kasetsart University Philippine Rice Research Institute
Adoption of the Nutrient Management Support (NuMaSS) Software Throughout Latin America	Honduras, Ecuador, Brazil, Panama, Nicaragua, Mexico, Bolivia	T. Jot Smyth and Deanna L. Osmond	North Carolina State University
Program Area 2. Tradeoff 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 and Jetse Stoorvogel	Montana State University Wageningen University and Research Center
Program Area 3. Rice—Wheat Systems			
Enhancing Technology Adoption for the Rice-Wheat Cropping System of the Indo-Gangetic Plains	Nepal, Bangladesh	John Duxbury and Julie Lauren	Cornell University 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, Bangledesh	James Jones, Russell Yost, John Duxbury and Julie Lauren	University of Florida University of Hawaii 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 and 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, James W. Jones and Melanie Correll	University of Florida 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

NUTRIENT MANAGEMENT SUPPORT SYSTEM (NuMaSS)

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

Principal Investigators:
Russell Yost, University of Hawai`i at Manoa
Tasnee Attanandana, Kasetsart University
Madonna Casimero, Philippine Rice Research Institute

Introduction to Southeast Asia and Africa Activities

Collaborators in the *Philippines* are adapting the Thailand-originated concept of simplifying soil series identification so it can be carried out in the field by farmers and land managers. Work is underway in the large province of Isabela and on the island of Mindanao. Collaborators in this effort include not only PhilRice, but also the Universities of Leyte State University, University of the Philippines at Los Banos and the University of Southern Mindanao. The Bureau of Soil and Water Management has also been a partner in the recent effort to simplify the field identification of the established soil series of the Philippines.

In 2005, the Philippine team embarked upon the development of a simplified key to the soil series in the provinces where the NuMaSS is being tested. Using key soil characteristics such as color, texture, pH and other features, such as presence of stones and concretions, extension workers and farmers have been able to identify their soil series and associate it with the nutrient status, hydrology and suitability of the soil to crops grown.

A prototype of the guidebook for the simplified key to the soil series of Isabela was developed and validated. More improvements are being undertaken to include the recommendations of farmers and extension workers, while initial activities to develop the key to the soil series in North Cotabato, South Cotabato and Negros Occidental have been done.

In its third year of implementation, the UH group focused on further testing, comparing and adapting the NuMaSS in farmers' fields. The on-farm trials were expanded further to include non-acid uplands where rice and corn are commonly grown on the three islands of Luzon, Visayas and Mindanao in the Philippines. Overall, fertilizer recommendations with NuMaSS had a good prediction rate for corn and rice on the sites, except in Isabela and Leyte where drought occurred during the cropping season.

The soil chemical characteristics continued to improve in the Visayas and Mindanao. In the farm sites where the NuMaSS on-farm trials were first established in 2002, a slight decline in the pH, P levels and an increase in the aluminum saturation were observed in one village. This observation is an indication of the declining effect of the residual lime applied in 2002. Lime was again applied to improve the aforementioned soil chemical properties.

The response of rice to NuMaSS recommendations was positive in 2005 in North and South Cotabato, for both the acid upland and non-acid upland sites. The target yield of 2.5 t/ha was attained with the NuMaSS treated plots having a yield increase of 1.4 to 2.5 t/ha compared to the farmer's practice. Drought prevailed in Isabela and Leyte provinces resulting in low corn yields and failure to attain the target yield of 5 t/ha. Despite this, however, NuMaSS-treated plots had significantly higher yields than the farmer's practice, regional recommendation and the control. The yield of NuMaSS-treated plots was higher by 1.7 t/ha compared to the farmer's practice and the regional recommendation and 3 t/ha higher than the control. This result indicates that with NuMaSS farmers can produce more stable yields compared to their current practice. In 2005, the price of corn was high resulting in good profits by farmers in Isabela despite the low yields attained.

In South Cotabato, North Cotabato and Saranggani province in Mindanao Island, fertilizer recommendation with NuMaSS resulted in more than 5 t/ha corn grain yield in these sites. Yields obtained from sites with NuMaSS recommended treatment raters were higher by 0.5 to 0.8 t/ha compared to farmers' practice. The same trend was seen in Don Salvador Benedicto, Negros Occidental. The yield obtained in the NuMaSS-treated plots was significantly higher than the control, farmer's practice and the regional recommendation. A 100 percent yield increase was attained in the NuMaSS plots compared to the control.

The dominance analysis showed that NuMaSS provided the best fertilizer management option for farmers growing corn in Isabela, Negros Occidental, North Cotabato, South Cotabato and Saranggani provinces. In Isabela, though the target yield was not attained, the farmers obtained higher profits compared to the regional recommendation and the farmer's practice.

In Leyte, aside from the low yields, the high cost of fertilizer and contributed to the negative returns obtained in all treatments. This result was similar to previous years, which indicates that the current version of NuMaSS does not provide a suitable fertilizer management option for the corn farmers in Matalom, Leyte. The cost of fertilizer continues to increase in the Philippines and farmers are concerned that they may not be able to afford the cost of inorganic fertilizer in the coming years. Organic fertilizer sources will be studied and in next year's on-farm trial, a certain percentage of the fertilizer will be sourced out using organic fertilizer generated from the farm to reduce costs.

The Minus One Element Technique (MOET) for the uplands was also tested in some sites. Results were promising in that the plants were able to manifest key characteristic symptoms of nutrient deficiency of the elements missing in the fertilizer formulation. As NuMaSS is somewhat weak in quickly diagnosing nutrient deficiencies, the MOET is a complementary tool for the quick diagnosis of nutrient deficiency in the soil. It can diagnose nutrient deficiencies fast through a real time response of plants to missing elements.

Lime is now a commercial product widely available for managing the acid soils of Isabela province. No lime was commercially available in 1997, when the project began, but is now available for the new cropping systems for the previously marginalized farmers in the uplands of the Philippines; an area which comprises an estimated 5.5 million ha.

In *Thailand*, a Thailand Research Fund financed program is extending the site-specific nutrient management concepts developed in collaboration with the SM CRSP NuMaSS project, from maize to rice and sugarcane, with spectacular results.

A researcher (N. Sipasueth) from the Lao National Agriculture and Forestry Research Institute continues his PhD dissertation at Kasetsart University under the supervision of Prof. Tasnee Attanandana and R. Yost. The study is to determine the causes for the consistent over prediction of N requirements by NuMaSS and DSSAT Nitrogen modules over the last two years. Initial results of the thesis study indicate that the over prediction may be related to large amounts of nitrate in the soil profile, not accounted for in the input data to DSSAT and NuMaSS software. There also seems to be more soil N mineralized than expected by the software default parameters. An alternative method of measuring soil N seems very promising and is being tested. A result from another dissertation project was an algorithm that, for a range of rock phosphates and a range of soils, predicts the amounts of rock phosphate needed to restore nutrient P availability to levels needed for maximum production. And yet another project (a PhD dissertation) focuses on predicting fertilizer potassium requirements using algorithms of the type already in PDSS. This algorithm has been incorporated into the PDSS software and is being field-tested in both Thailand and Mali. Two MS students are working on P evaluation in paddy soils, using the Pi strip and the other measuring N mineralization under paddy rice conditions.

In *Laos,* a Regional Workshop will be held on NuMaSS adaptation and application in the context of Site Specific Nutrient Management. Scientists from the Philippines (4), Thailand (4) and about 20 local Lao scientists will participate in the workshop, which will be held in the Bachieng area near Pakxe in the Southern Province of Champassack. This will be the first workshop that the Lao component of the NuMaSS Project has hosted and will be an opportunity for NAFRI scientists to show their successes under the NuMaSS Project.

Two new MS level graduate programs were initiated in early 2006, and under a fast-track MS program at Kasetsart University, the students will conduct two seasons of experiments. The thesis topics are to provide a local test and calibration of NuMaSS predictions for some of the newly identified and characterized zones in Laos. These zones include an estimated 60,000 hectares of Oxisols near Pakxe, Champassak Province and a region of Ultisols north of Vientiene that comprises some 36,000 ha. A soil-sampling visit was conducted to Xiengkouang Province near the famous Plain of

Jars. Results indicated highly weathered soils and extreme P deficiency.

In *Mali*, the majority of the activities under NuMaSS take place through direct funding from the University of Hawaii in the form of support for the graduate assistantship of Ms. Aminata Sidibe-Diarra. Ms. 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 Maliand the initial results of the model were promising. However, the initial results suggested a substantial over-prediction of amounts of rock phosphate and a laboratory study will be carried out to test the hypothesis that the over prediction may be due to non-realistic incubation conditions.

Preliminary testing of the K algorithm developed in Thailand is being tested in Mali and will continue in the 2006-2007 season. A Malian scientist (Adama Bagayoko) spent a short study tour at the University of Hawaii to analyze his data and learn English for possible entry into a MS graduate program at UH. Two Malians scientists (Doumbia and Berthe) have contributed substantially to the French translations of the NuMaSS-PDA handheld software.

In *Ghana*, yield comparisons of NuMaSS fertilizer recommendations have indicated predictions of fertilize amounts lead to substantially higher yields than farmer's practice and other local options. In addition, NuMaSS recommendations provide more benefit in the better environments according to the stability analysis of fertilizer treatments.

The mission buy-in in *Angola* was completed in 2005 and the project has been completed. In summary, the SM CRSP project successfully introduced the NuMaSS, introduced the concept and practice of soil test kits for in-field nutrient assessments, provided a laboratory consultant to train and initiate soil and plant laboratory analyses and provided a visible spectrophotometer and lamps for chemical analysis. Soil P buffer coefficients are being determined on the group of 25 soils to compare field estimates of P requirement with those of the PDSS software. Satellite imagery was obtained and used to evaluate the potential transferability of experimental results. Project results will be published in *Soil Science*.

In *Mozambique*, The SM CRSP partnered with the INTSORMIL CRSP to enable the completion of Ricardo Maria's MS graduate program at IIAM (Instituto de Investigação Agrária de Mozambique). Mr. Maria's thesis was almost entirely supported by the INTSORMIL CRSP through a buyin with the USAID mission in Maputo. This thesis program was completed in December 2004 and Mr. Maria returned to Mozambique in December. His thesis results have been accepted for publication in *Soil Science*. These results indicated that there are some regions with relatively acid soil conditions, which are likely to require either alternative crops or the application of liming materials, especially for cotton, an important crop in many regions. The soils were moderately weathered with few cases of extreme P sorption and deficient levels of Ca and Mg.

To test and adapt NuMaSS and PDSS for Mozambique conditions, on-farm and on-station experiments were conducted in four locations during the 2005/06 cropping season. The experiment sites were located in Sanga district in Niassa province, Monapo in Nampula province, Nhamatanda in Sofala province and Gondola in Manica province, representing three different Mozambique agro-ecological conditions. Soil samples in experiment sites were collected and analyzed for soil physical and chemical properties in an IIAM central laboratory before planting. In addition, the samples were analyzed in the field with soil test kit for soil pH, nitrate, ammonia and phosphorus.

A field day was conducted in the Gondola district in central Manica province. The participants came from NGOs, Sussudenga research station personnel, farmer associations and district and provincial extension services. The farmers were able to clearly observe crop response to different fertilizer rate application and the technology's potential and limitations, as well as crop performance, were discussed.

To complement SM CRSP activities for the next cropping season, the legume sector of Sussudenga research station has demonstrated interest in establishing a local seed multiplication program as well as legume trials.

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

Southeast Asia

Philippines

Test, Support, Promote and Adapt the NuMaSS Software

On-farm trials were set up in upland areas where rice and corn are major crops grown by farmers on the three large islands of Luzon, Visayas and Mindanao. Two cropping seasons trials were conducted in all of the sites. In Luzon, nine on farm trials located in three villages, namely, Morado, Sta. Victoria and Antonio, Ilagan, Isabela Province. In the Visayas, the on-farm trials were set up in two sites in two provinces, namely, Matalom and Bontoc, Leyte province and Don Salvador Benedicto, Negros Occidental province. Five on-farm trials were established in Leyte and four were set up in Negros Occidental. In Mindanao, ten on-farm trials were established in three provinces, namely, North Cotabato, South Cotabato and Sarangani Province. Except for Mindanao, where ten farmers planted rice during the wet season, corn was planted in both wet and dry seasons in all sites in Luzon and the Visayas.

Before the start of the planting season, a briefing with farmer cooperators was done to discuss the results of the previous season and plan for the following season. Feedback from farmers was gathered and was considered as input in planning for the next season's activities. For the new farmer cooperators in the expansion sites, a briefing was held to orient new collaborators on the project as well as the role to be performed by each involved institution and farmer's groups.

Whenever possible, field days were conducted before crop harvest to promote the NuMaSS in the villages. The field days served as a venue for more farmers to learn about the project. Farmer cooperators served as resource persons and described to other farmers their experiences and provided feedback about their assessment of the different treatments. An open forum and discussion followed where farmers from other villages could ask questions and express their impressions about the project.

Soil Sample Collection and Analysis

To decentralize the analysis of soil samples taken from the field, soils laboratories located in the collaborating universities were tapped to help in the analysis. In the Visayas, particularly Matalom and Bontoc, Leyte, soil samples were analyzed at the Leyte State University Soils Laboratory. In Mindanao, soil samples were taken to the University of Southern Mindanao Soils Laboratory for analysis. The main purpose of decentralizing the soil analysis was to fast track the release of results, to check the consistency of results obtained from the three laboratories and to check the performance of the NuMaSS recommendation in the field trials. Soil samples were collected separately from each plot one month before the cropping season for new sites. In old farms where the on-farm experiments had been established since 2003, soil analysis after each preceding season 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. For T4, variable amount of N, P, K and lime was applied depending on the NuMaSS recommendation. With the consistent good performance of NuMaSS compared to the farmer's practice (FP) and the regional recommendation (RR), upscaling activity was initiated where two large plots measuring 5,000 m^2 were used to compare the performance of NuMaSS with the farmer's practice. In addition to the old sites in Antipaz, North Cotabato and in Koroandal and Tampakan, South Cotabato, new sites were added in PY9 to include Carmen, North Cotabato and Malungon, Saranggani Province. The NuMaSS was also tested in areas that were suitable for corn growing (pH 5.6 to 6.8, with good soil chemical properties). In all sites, the farmer's practice used in the trial was the prevailing fertilizer application rate agreed upon by the farmers during the consultation meeting. The regional recommendation was obtained from the local agriculture office. Plots for each treatment remained permanent in each field throughout the years of implementation of the project.

Soil Properties

In the first two years of implementation, on the old farms in Ilagan, Isabela, improvements in the chemical soil properties, particularly pH, P, exchangeable bases, acidity and aluminum saturation, were seen with the application of NuMaSS generated fertilizer recommendation. The soil pH was increased in all sites, indicating a reduced soil acidity, which can be attributed to the increasing availability of exchangeable cations like calcium and magnesium from the lime applied. The soil P content was noticeably reduced after the 2005 WS, which can be an indication of declining soil fertility associated with the increasing acidity of the soil. A similar trend was seen in the new sites in the villages of San Antonio, Morado and Manaring, Ilagan, Isabela. This must be reversed to mitigate the decline in the corn yields of farmers in the area.

In the Visayas, an increase in the pH and a significant increase in the soil phosphorus content were seen. The calcium content also increased, but a decline was seen in the magnesium concentration. The ECEC was still higher compared to the initial analysis and the aluminum saturation continued to decrease. Despite the improvements in the soil chemical properties, yields obtained in Leyte were below the target yield of 5 t/ha for corn and 2.5 t/ha for upland rice. With this non-attainment of target yields in Leyte over the past two years, another site was chosen in Don Salvador Benedicto, Negros Occidental to represent the Visayas area. The soil chemical characteristics in the fields selected were very similar to that found in Leyte. A significant increase in the chemical properties was observed after the first cropping, an indication of the positive impact of applying lime and the right amount of fertilizer generated by NuMaSS.

In Mindanao, continued improvements were seen in the soil chemical properties, particularly in Antipas, North Cotabato and Tampakan, South Cotabato, after the fourth cropping season. In the new sites, the initial results of the analysis of the soil chemical properties in Carmen, North Cotabato and Malungon, Sarangani Province seemed to be favorable for corn growing.

Dry Season Grain Yield for Corn

The on-farm trial was established only in Ilagan, Isabela during the dry season because of drought problems. During this season, the target yield of 4 t/ha for hybrid corn was not attained. As a consequence, lower yields were obtained in both sites but a distinct trend was observed. Despite the low yields, the NuMaSS treated plots yielded significantly higher than the regional recommendation and the farmer's practice. In Isabela, yields obtained in the NuMaSS plots had more than a 3 t/ha and 1.7 t/ha yield advantage compared to the control and the regional recommendations, respectively. Removing the N from the NuMaSS recommendation resulted in a 1.3 t/ha yield reduction. Without lime application, yield was reduced by 1.5 t/ha while the removal of P resulted in a 2 t/ha yield reduction.

Significantly lower biomass, ear length and ear fresh weight were obtained in the control, RR and FP compared to NuMaSS. Removing an element from the NuMaSS recommendation also resulted in a significant reduction in the above-mentioned parameters.

West Season Grain Yield

Corn. The drought in Isabela and Leyte lasted until the wet season. Though rainfall was scarce in Isabela, farmers decided to plant corn that resulted in very low yields. The yield obtained in the on-farm trial was also low. Similar to the observation during the dry season, the plots applied with NuMaSS generated fertilizer recommendation obtained significantly higher yields than the control, farmer's practice and the regional recommendation. The yield in the NuMaSS plot was 1 t/ha higher than the regional recommendation and 1.3 t/ha than the farmer's practice. The removal of N from the NuMaSS recommendation resulted in the reduction of corn yield by 1.2 t/ha. The absence of P application resulted in a 3 t/ha reduction of yield indicating that the most critical element in acid sulfate soils is phosphorus. In Matalom, Leyte, the impact of drought on corn yield was very distinct. Yields obtained were variable and very low. Yield obtained in the plots applied with fertilizer generated by NuMaSS was 2.8 t/ha. The yields obtained across all treatments did not differ significantly.

The yields obtained from Don Salvador Benedicto, Negros Occidental were very high. NuMaSS had a very good prediction of the fertilizer requirements of corn in this site. The application of NuMaSS fertilizer recommendation increased corn yield by 3 t/ha, and 2 t/ha compared to the control, farmer's practice and the regional recommendation, respectively. The removal of N, P and lime resulted in a 2 t/ha reduction in corn yields.

In Mindanao, NuMaSS also had a very good prediction of the fertilizer recommendation for corn. The NuMaSS treatment had higher corn grain yield averaging 6.5 t/ha, 12.6 percent higher than yields obtained from the farmer's practice plots. The lime application resulted in higher yields under highly acidic conditions. In non-acid areas, the application of NuMaSS generated fertilizer recommendation had an average yield of 5.6 t/ha and was 5.9 percent higher than the farmer's practice yield.

Rice. In 2005, rice was planted in three sites in Mindanao—Antipas, North Cotabato and Tupi and Koronadal, South Cotabato. NuMaSS showed high yields of 4 to 5 t/ha across the three sites. In Antipas and Koronadal, the NuMaSS demo farms yielded 5 t/ha, more than 1 t/ha higher than the target yield. In Tupi, yield obtained was 3.90 t/ha. Yields obtained when N was removed were reduced by 15 percent compared to the plots applied with NuMaSS generated fertilizer recommendation. However, the removal of P from the recommendation resulted in yields that were 95 percent less than the NuMaSS yield. In plots where K was removed, yield was reduced by about 80 percent. These results indicate that P is the most critical in upland rice yield. The current farmer's practice in the sites, with regards to fertilizer management in upland rice, is zero application. Yield levels under this practice were less than 2 t/ha.

Peanut. The yield of peanut was not significantly affected by the application of gypsum across all fertilizer treatments. The biomass yield, however, obtained in the plots applied with gypsum, was significantly higher than plots without gypsum.

Economic Analysis

Results obtained in the dominance analysis of the different fertilizer treatments varied across sites. Though yields obtained in Isabela were below the target yield of 5 t/ha in both wet and dry seasons, the economic analysis showed that NuMaSS was dominant over the control, farmer's practice, regional recommendation, NuMaSS-N, NuMaSS-P and NuMaSS-lime. This result indicates that NuMaSS was a better fertilizer management practice compared to current farmer's practice and the regional recommendation. Despite low yields, NuMaSS was a more profitable fertilizer management option for farmers as it brings a more stable yield than the control, farmer's practice and regional recommendation under drought conditions. NuMaSS was not a viable fertilizer management option for farmers in Leyte because of the high cost of fertilizer and lime. The regional recommendation was more profitable than NuMaSS because of the additional cost incurred with the application of lime in the NuMaSS treatment. In Don Salvador Benedicto, Negros Occidental where very high yields were obtained, the NuMaSS also performed better than the farmer's practice and the regional recommendation. Though higher fertilizer rate and lime application were required in NuMaSS, resulting in higher input cost for the farmer, the significant increase in yield far outweighed the increase in fertilizer cost and better profits were obtained (Figure 1). NuMaSS was also dominant over farmer's practice across all sites in Mindanao (Figure 2). In favorable corn areas like Isabela, Negros Occidental, South Cotabato, North Cotabato and Saranggani province, where high yields can be obtained and the response of corn to the NuMaSS fertilizer recommendation was very high, adopting the NuMaSS generated fertilizer recommendation is very beneficial for farmers as it brings higher yields and profits. Recently, a drastic increase in the cost of fertilizer in the Philippines has occurred. Farmers are feeling the impact of this increase. NuMaSS relies on the application of inorganic fertilizers to increase corn and rice grain yields, and thus farmers are concerned about the sustainability of fertilizer management recommendations from NuMaSS. This suggests that a need exists to look at the profitability of the NuMaSS recommendation with a view to developing alternative options for farmers to generate higher profit with NuMaSS. To decrease fertilizer costs, farmers might be taught how to use farm wastes like rice straw as organic fertilizer for rice. Including organic fertilizers is an important input into the NuMaSS modules and becomes essential with the rapid increase in the cost of inorganic fertilizer in the local market.

Thailand

The Extension of Site-Specific Nutrient Management from Maize to Rice and Sugarcane

The site-specific nutrient management for irrigated, rainfed rice and sugarcane is an extension of the work on maize, which has been successfully disseminated to the farmers for the past five years. Site-specific nutrient management consists of three

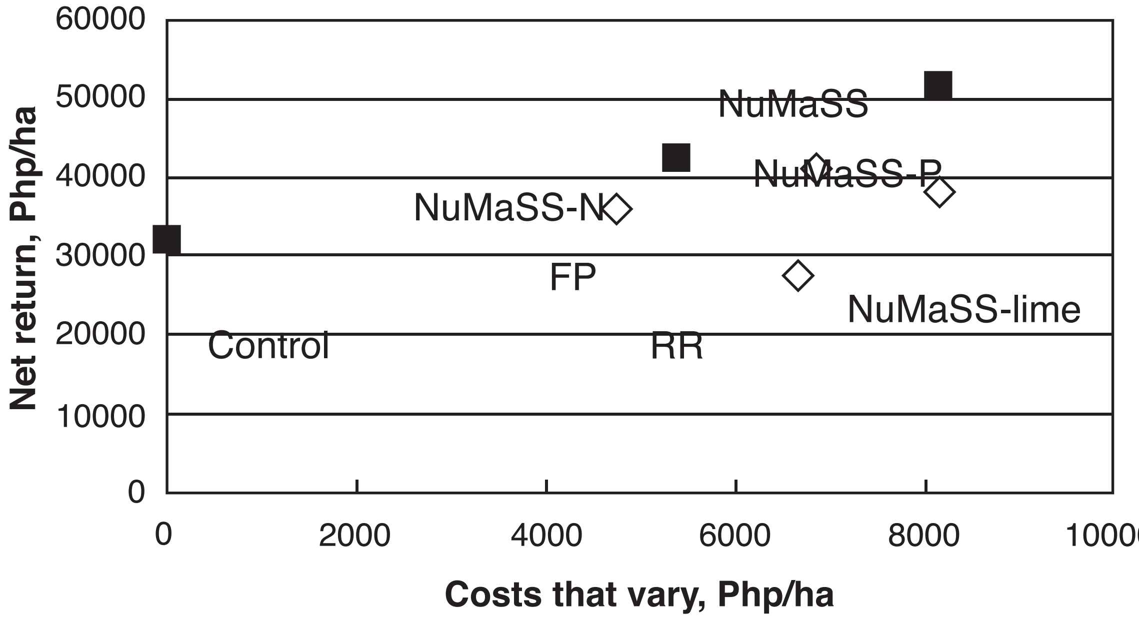


Figure 1. Dominance analysis of fertilizer treatments in the on-farm trial in Matalom, Leyte. WS 2005.

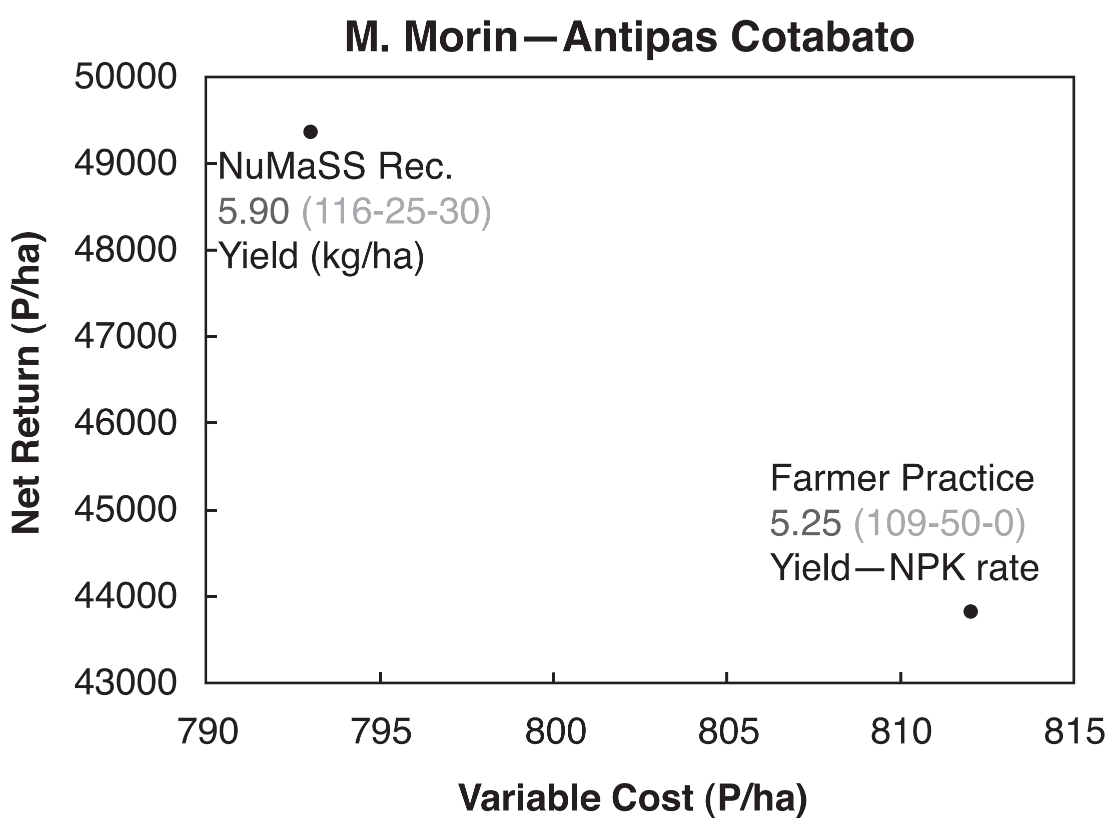


Figure 2. Dominance analysis of two fertilizer treatments in the on-farm demonstration trial in Antipas, North Cotabato.

components: soil series identification, soil testing by soil test kit and fertilizer recommendation which was developed from DSSAT, and PDSS for NP and the Department of Agriculture's recommendation for K fertilizer recommendation. The current work by the UH group emphasizes the need to build the capacity of farmers so that the technology is sustainable. The conceptual, academic and practice forum was performed to increase the farmers' capability, the farmers' self-reliance, their ability to work together, their ability for interactive learning and for learning how to initiate information sharing networks.

Maize is currently planted on about 0.8 million hectares in Thailand, reduced from 1.6 million hectares three/four years ago. Drought conditions are more severe and a deficit of maize production, due to the climate and the increasing price of chemical fertilizers and other inputs, exists. The site-specific nutrient management technology was established and disseminated to maize growers in 14 provinces but only a limited number of those farmers accept and practice it. Thailand has approximately 10.4 million hectares under rice cultivation (Office of Agricultural Economics, 2002) of which about 1.28 million hectares is used for irrigated rice in the dry season (Royal Irrigation Department, 2003). Farmers grow two to three crops of rice per season. About one half of the rice production in the country is produced from the irrigated area. The average yield of dry season rice is about 4,281 kg/ha (Office of Agricultural Economics, 2002). The general fertilizer recommendation for non-photo sensitive rice is 16-20-0 on clayey soils and 16-16-8 or 16-8-8 where the rice is grown on sandy soils at the amount of 156-218 kg/ha in combination with urea at the rate of 63-94 kg/ha. This recommendation rate is approximately 63-75 kg N/ha (Department of Agriculture, 2000). To produce one ton of rice, the nutrient requirements of NPK are 19, 5 and 36 kg, respectively (Yoshida, 1981). The current recommended fertilizer for rice results in an accumulation of phosphorus in the soils. Moreover, most of the farmers in the irrigated area apply too much nitrogen fertilizer (75-100 kg N/ha) that is higher than the government's recommendation. They also use chemicals and soil amendments, such as hormones, bio-fertilizer and surfactant, that has resulted in a high cost of production and has lead to pollution of the environment. Thailand imported 3.5 million tons of chemical fertilizer in 2002, which cost about US$523 million. Most of this fertilizer was used on irrigated rice (Department of Agriculture, 2003).

Sugarcane is increasing in popularity in Thailand because of the crop's potential for bioenergy production in addition to sugar manufacturing. The sugar factories produce about 5.4-6.0 million tons of sugar per year, of which more than 3 million tons are exported. Sugarcane plantations cover about one million hectares, with an average yield of 50-56 ton/ha (Office of Agricultural Economics, 2002). This low average yield is due to rain fed conditions and farmers' lack of knowledge on soil and fertilizer management (Department of Land Development, 1991).

A site-specific fertilizer recommendation, which includes soil testing, is a new practice for rice and sugarcane farmers, although maize farmers have adopted it (Attanandana and Yost, 2003). The lack of farmers' knowledge, insufficient laboratories and limited supportive research are constraints to the practice of site-specific nutrient management in rice and sugarcane production in Thailand. Therefore, the UH group has attempted to adapt and transfer the results of site-specific nutrient management with maize to both irrigated and rain fed rice and sugarcane.

Materials and Methods

Experimental sites and development of the technology. Three provinces in the North and Central regions of Thailand, namely, Pitsanulok, Suphanburi and Cha Cheong Sao, which are major irrigated rice provinces, were chosen for the study. The two provinces in the Northeast, Nakhon Ratchasima and Khon Kaen, were chosen as the representative sites for rain fed rice study. The major soil series in those five provinces were surveyed and identified. Khon Kaen, which is one of the areas of sugarcane production in the Northeast, was chosen for the sugarcane study. The decision-aids, DSSAT (Tsuji *et al.*,1994) and PDSS (Yost *et al.,* 1992), were used to simulate the NP fertilizer recommendations, while the Mitscherlich-Bray equation of the K fertilizer calculation was adopted from the Department of Agriculture (Attanandana *et al.,* 2004). All of the three nutrient requirements were combined as the package of NPK fertilizer recommendation for the farmers. The soil series were identified and the soils were collected for NPK testing. The simulation on the rates of nitrogen fertilizer recommendation was obtained from DSSAT V4.0.

Field experiments. Nitrogen (N) is one of the most expensive fertilizers used on rice. Accordingly, it was chosen for the first field studies and field experiments on various rates of N were conducted by farmer leaders under the supervision of local officers in each province. Crop response to phosphorus and potassium were also investigated in selected soils low in phosphorus and potassium. Twenty-nine sites were selected for the nitrogen study on irrigated and rain fed rice, while the phosphorus and potassium response studies on rice were conducted in six and five sites, respectively. For sugarcane, 14 study sites were included in the study: six sites were used for nitrogen responses, four sites for phosphorus and four sites for potassium.

Farmer leaders. Action research by farmers was emphasized in this study and was taught to the farmers and researchers. Farmers were encouraged to conduct field experiments with the advice from local researchers.

Conclusions

Site-specific nutrient management (SSNM) has been disseminated to the maize farmers for five years (Figure 3). A higher yield, reduced cost of production and higher profits were clearly observed. The same concept was introduced to selected rice and sugarcane farmers in the North, Northeast and Central regions of Thailand. Preliminary results indicate improvement of the farmer leaders' management, their thinking and their way of living. The farmer leaders became more self-reliant and formed groups and networks to help each other. The farmers started to improve their soil as well.

Field tests on nitrogen, phosphorus and potassium application to 80 rice and sugarcane fields revealed very little crop response. This will determine low NPK recommendations in the revised version of the site-specific NuMaSS software. The results of N response experiments at 12 sites in the three provinces showed that maximum yields occurred with lower levels of application than predicted from a DSSAT simulation, except on one soil in which the N response was higher than the predicted value. In the case of rain fed rice, the observed nitrogen response was less than predicted, except for three soils in which the nitrogen response was higher than the predicted values.

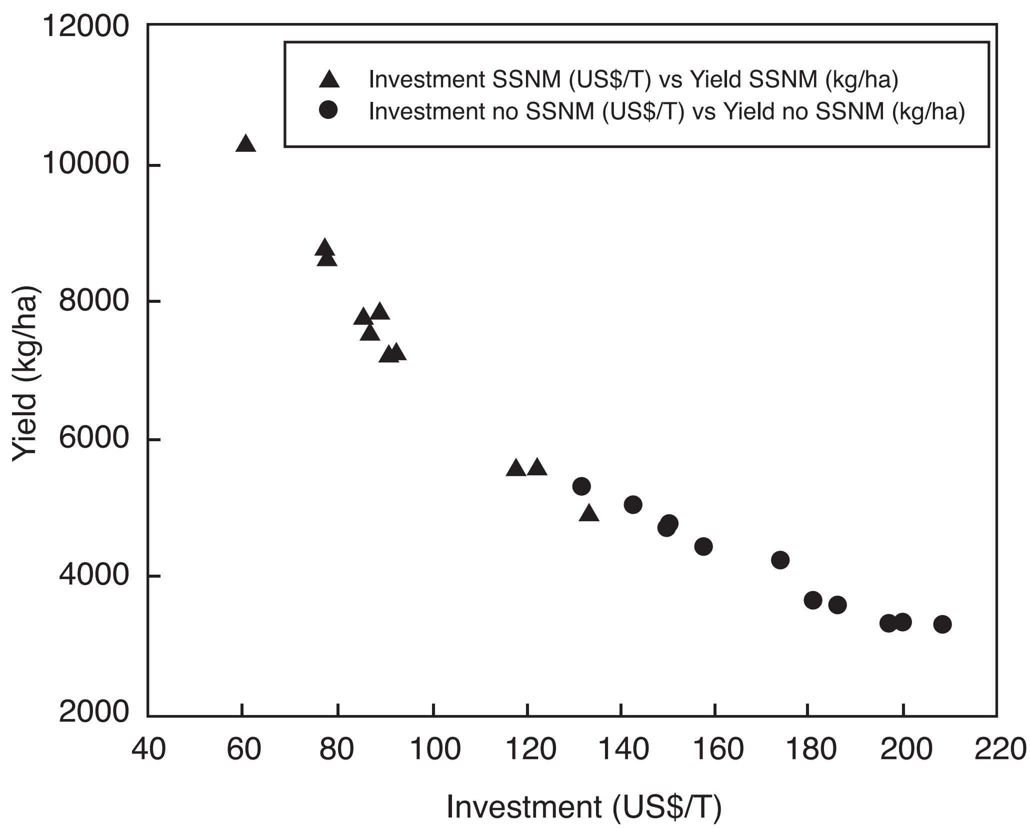


Figure 3. A comparison of investment and yield of SSNM and no SSNM plots. Maize, Province of Nakon Ratchasima.

Table 2. Response of nitrogen and yield of no N plot of some soils studied.

Soil series	Nitrogen rate to maximum yield (kg/ha)	Yield of N_0 plot corresponding (kg/ha)
Saraburi (Sb)	27.5	3875
Nan (Na)	16.3	6119
Kula Rong Hai (Ki)	87.5	1563
Nong Boon Nak (Nbn)	141.9	1931
Pimai (Pm)	12.3	2238
Tung Samrit	12.1	2363

The ammonium release patterns carried out in a separate study provided an explanation for the low crop response to applied N for most of the soils studied. It was noted that rice grown on high-release ammonium soils responded to low levels of nitrogen fertilizer application. Conversely, the high response of rice to nitrogen fertilizer was observed with low ammonium release soils, except for Pimai and Tung Samrit soils. In the latter two cases, the farmers controlled the water during fertilizer application and also applied organic fertilizer to one of them, which resulted in low response to nitrogen fertilizer, even though the ammonium release was low (Table 2).

An economic dominance analysis of the different treatments was used as an indicator of the most cost-effective fertilizer management, enabling the farmers to invest profitably in production. The analysis was done by calculating the net return and variable cost of different treatments. One of the benefits of a dominance analysis is the alternative choice given to the farmers with different treatments of fertilizer application. The results showed that several options exist for the farmers. One option is suitable for farmers who want a low investment, while the other two are more suitable for farmers who have more to invest and would like a higher net return.

The soils in Khon Kaen province showed some response to phosphorus with an increase in rice yield. However another sandy soil in Nakhon Ratchasima showed no response to P even though the P content of this soil is very low. The clayey soil in Suphanburi also showed no response to P with low to medium P content. There was, however, a strong response to potassium by rice in the St and Re soils in Khon Kaen province. With a reduction for the need of chemical fertilizer on irrigated rice, chemical fertilizer businesses will experience losses, because most of the imported chemical fertilizers are used for irrigated rice.

The significance of soil management by green manure and filter cake incorporation was clearly seen with the reduction of chemical fertilizer application rates in sugarcane. The sugarcane responded to a low level of nitrogen fertilizer that was even lower than the DSSAT N recommendation. The response of sugarcane to lower nitrogen on three Msk soils was attributed to the soil management practice in which the farmers used green manure to improve their soils. The data on Pp and Stuk soils of Prachak and Janesuk revealed also a low level of N response and good yield. This might have been due to the filter cake that was applied to the soils every year. In the case of Pp soil of Sombat, the farmer had no soil improvement and burned cane leaves, resulting in a higher level of nitrogen response and a lower yield compared to the farmers who had good soil management. Sugarcane showed little response to phosphorus in Msk soil. The application of 25 kg P_2O_5/ha resulted in a yield of 53 and 79 t/ha for the two sites on which the farmers used green manure before sugarcane planting each year. There was no response on the Pp and Stuk soils, where the farmers used the filter cake to maintain the soil fertility. There was no response of sugarcane to potassium on the field where filter cake was applied even though the soils were low in potassium. In the field where green manure was applied, the sugarcane showed a low response to 35 kg K_2O/ha of potassium. Sugarcane grown on another Msk soil did not respond to K even though the soil K was low.

The DSSAT V4.0 was used to simulate the nitrogen fertilizer recommendation for irrigated and rain fed rice and sugarcane. The field test results indicated low nitrogen response on the crops at many sites. The nitrogen fertilizer recommendation was adapted by selecting the fertilizer rates for each soil that was lower than the previous recommendation based on the field data results. The first nitrogen recommendation for irrigated rice is shown in Table 3. A lower amount of fertilizer N was recommended. A second revision will be made again after the demonstration plots data are obtained. Including the demonstration plot results will modify the nitrogen fertilizer recommendation. The interpretation of initial nitrogen by soil test kit will also need to be modified.

Table 3. Nitrogen fertilizer recommendation (original) of some soils in the three provinces compared with the revised version (kg/ha).

Soil series	Very low N		Low N		Medium N	
	Original	Revised	Original	Revised	Original	Revised
Nan	113	75	63	38	25	25
Phan	100	75	50	25	0	13
Bang Nam Preo	88	75	50	25	0	13
Rangsit	88	75	38	25	0	0
Nakhon Pathom	100	75	50	38	25	13
Derm Ban	113	88	63	25	25	13

Laos

Test and Evaluate the Site-Specific Nutrient Management under Laos Conditions

After rice, maize is the most the important cereal crop in the Lao PDR. Maize is also increasingly used for animal feed, and maize starch is used in industrial areas. Maize will continue to play a major role in food security and the demand for maize grain for animal feed will become even more important in the years to come. However, maize production in Laos has factors that limit crop productivity, such as low nutrient contents of the soil, soil loss and runoff, soil acidity. Maize farmers lack the knowledge of soil and nutrient management, which have been a cause of low crop yields and soil degradation. These problems must be solved if Laos is to establish an appropriate technology for improving maize production. To increase the maize yield in the different soil types of the mentioned area (Laos), research is needed on its specific nutrient management.

Site-specific nutrient management (SSNM) is an approach to effectively use fertilizer by dynamically adjusting the application and management of nutrients to crop needs at specific location 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 according to basic soil data analysis adjusted to specific locations and seasons.

For SSNM to occur, it will be necessary to evaluate the nutrient management of maize under Laos' conditions, with the aim of identifying appropriate and sustainable technologies that can be transferred to farmers in different agro-economical conditions.

Study Site

The experiments were conducted in Bachieng upland station, Champasak province, in the southern central part of Laos. The site is characterized by tropical monsoon wet and dry climate (FAO/UNESCO, 1979) and a Ustic moisture regime (Van Wambeke, 1985), which is classified into two distinct seasons. One, the rainy season, runs from May to October and, two, the dry season, runs from November to April. Total rainfall in the study area was similar (about 1700 to 1900 mm per year). The maximum temperature in April is 41.50 °C; the minimum in January is 3.10 °C); and the mean value is about 26 °C. The mean relative humidity was about 75 percent in the month of March, with the lowest humidity at 67 percent and the highest in August of 85 percent.

The soil surface of the study area sloped slightly (2-5 percent). The climate type is tropical savannah. The land use was fruit tree and leguminous crops. Groundwater was >2 m in the wet season, with runoff very slow.

Methodology

Sixteen to twenty soil samples were collected from this site, at a depth of 0-20 cm, before land preparation and after harvest. All soil samples were sent to SSLCC (Soil Survey and Land Classification Center) laboratory for physical and chemical properties analysis.

The soil samples were used as the basis for nitrogen, phosphorus and potassium data prediction used in NuMaSS and in PDSS (Phosphorus Decision Support System) (PDSS).

Maize yield and soil data will be analyzed by IRRISTAT or SAS programs for statistical analysis. Yields from trials using best farmer practice and best national rates will be economically analyzed with recommended rates derived from DDSAT, NuMaSS and PDSS for N, P and K.

Summary of Results

The grain yield of the control treatment was 1.3 t/ha. When N, P and K were added (80-50-50 kg/ha), the yield increased by 200 percent compared to the control. But when only N and P were added, there was no yield increase and the yield was not significantly different compared to the treatment T3 (80-50-00). The addition of commercial organic fertilizer alone increased yield to 2.1t/ha, which was a 61 percent increase compared to the control. The combinations of inorganic fertilizer and organic fertilizer were not significantly different from the fertilizer treatment only. All treatments were significantly higher than the no fertilizer and organic fertilizer. The results of this experiment illustrate that when added rates of N,P_2O_5,-K_2O (80-50-50 kg/ha) and N-P_2O_5 (no K) were applied, yield increased by 200 percent compared to the control, and by 85 to 100 percent when compared to the organic fertilizer (Table 4).

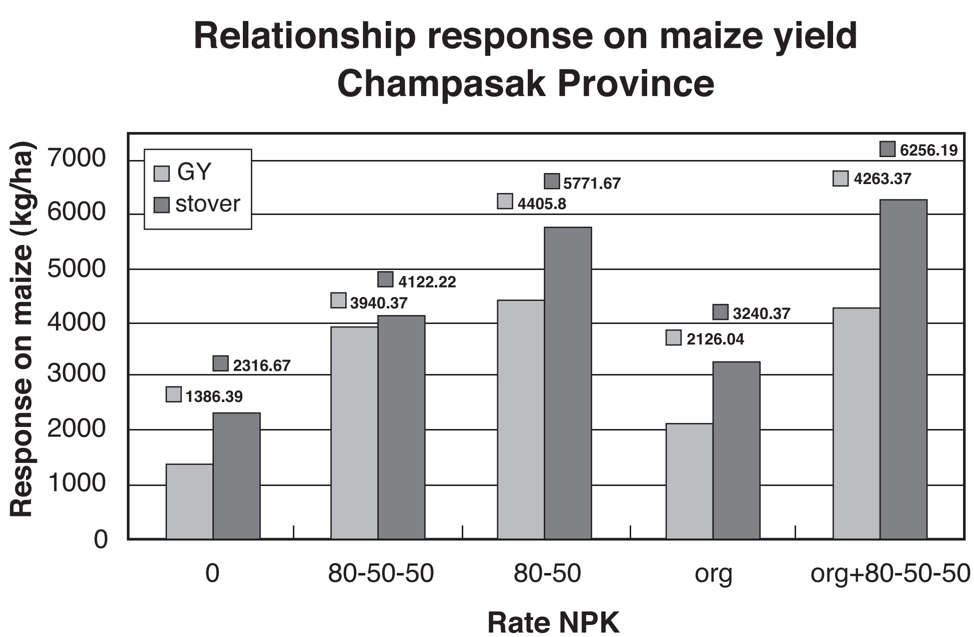
Conclusions

The first results of the application of NuMaSS and PDSS in the Bachieng district, Champasak Province will enable us to evaluate the effect of the base requirement for fertilizer efficiency. The N, P and K as determined by NuMaSS and PDSS could reduce the amount of fertilizer needed, while increasing the crop yield.

Cereal crops grow well in undulating areas with fine, moderately well-drained soil of clay or silty clay texture. Soil nutrients may be lost by leaching and run off under high rainfall. The yields seem to indicate there is little response to commercial organic fertilizer (COF) and there doesn't seem to be much response to potassium. A single application of COF didn't improve soil fertility but did increase soil organic matter.

The economic analysis of the yield, investment and profit of the first year experiment illustrates that the profit potential of maize yield in Champasak site was high for TR3 (no K) only. Improved yields with T3 and its lower cost make it a better economic practice than that obtained with COF in T4 and T5.

Table 4. Relationship response of NPK rates and maize yield in Champasak Province.



Africa

Ghana

The NuMaSS Experiments at SARI (Savannah Agricultural Research Institute station at Wa, Upper West Region of Ghana)

Farmers in the Upper West region of Ghana make use of indigenous resources and insufficient fertilization to manage soil fertility to sustain crops' yields. From the farmers' perspective, soil carbon is synonymous with soil fertility, which may decline over time and adversely affect yields if measures are not taken to retain crop residues and apply some inorganic fertilizers or manure. Coupled with the shortened fallow season and frequent bush fires, the situation may worsen with negative impact on food security.

The objective of the study in Ghana was to use the NuMaSS as a research tool to guide the recommendation of supplementary inorganic fertilizers in cropping systems. Following the exploratory survey in 2003/2004 cropping season, actual field experiments were set up to test the hypotheses:

1. That NuMaSS predicts low P fertilizer rates in fields with greater soil carbon.
2. That treatments that depended on NuMaSS fertilizer recommendations are more sustainable in terms of cost-effectiveness than treatments that are based on regional fertilizer recommendation as the former considered the initial soil fertility status.

Two on-station and one on-farm experiments were carried out.

Experiments

On-station, Experiment 1. Experiment 1 was a groundnut-maize rotation located off-station at Bahamu, a few kilometers from the main station at Wa. The treatments were: 1) regional fertilizer recommended rate for continuous maize, 2) full NuMaSS fertilizer recommended rate for continuous maize, 3) full NuMaSS fertilizer recommended rate for maize and nil for groundnut in rotation and 4) nil for groundnut followed by full NuMaSS fertilizer recommended rate for maize. The regional recommended fertilizer rate was the reference plot. Replications are four and plot size is 8m by 6m with a randomized complete block design.

On-station, Experiment 2. Experiment 2 was a continuous maize fertilizer study situated at the same site. The treatments were: 1) regional fertilizer recommended rate, 2) full NuMaSS fertilizer recommended rate, 3) half NuMaSS fertilizer recommended rate and 4) a quarter NuMaSS fertilizer recommended rate. Again, the regional recommended fertilizer rate was the reference plot. Replications were four and plot size 8m by 6m with a randomized complete block design. In the Upper West in general, farmers often cultivate maize either with animal manure, compost or inorganic fertilizer despite low amounts of the latter. Thus, the use of the regional fertilizer recommended rate, as reference, may be somewhat justified.

On-farm, Experiment 3. The third experiment was a groundnut-maize rotation sited on ten farmers' fields at Tumu in the Sisala district. The treatments are as in Experiment 1 and NuMaSS fertilizer recommendation relied on specific soil properties of the site (Table 5). Among the plant nutrients,

Table 5. Baseline soil properties of ten farmers' fields at Wa in the Upper West region of Ghana.

Farmer Name	% Soil carbon	% Clay	Soil properties Extrac. P (μg/g)-	pH	% N
1. Bukari Sallifu	0.42	7.53	2.00	6.10	0.028
2. Issifu Kazia	0.50	7.20	1.62	6.66	0.051
4. Yakubu Adama	0.61	6.87	1.98	6.20	0.065
5. Adamu Imoro	0.58	7.19	1.31	5.95	0.107
6. Alhassan Saani	0.57	6.65	1.45	6.37	0.056
7. Immam Yakubu	0.75	8.04	9.80	6.05	0.093
8. Alhassan Adamu	1.05	9.39	11.08	7.23	0.149
9. Ali Salifu	1.02	3.53	11.18	7.60	0.065
10. Amadu Salifu	1.30	8.53	12.95	7.86	0.168
s.e. for comparison	0.18	1.57	2.32	0.53	0.042
LSD (0.05)	0.38	3.30	4.87	1.12	0.089

phosphorus was the most critical as illustrated in Table 5. With respect to the on-farm trials, check plots were not absolutely necessary since crops outside the trial area could serve the same purpose as check plots.

Results and Discussion

On-station, Experiment 1. Initial soil properties of this site were: mean soil carbon=0.80% and standard error (s.e.=0.06); mean available P=8.31 μg/g, s.e.= 0.39; and mean pH=5.35 with s.e.=0.28. Soil carbon was relatively high and comparable with soils of the Sahel that range between 0.2 and 1.0%. Threshold of available P in soil of the tropics is usually 10.0 μg/g; therefore, there is not much deviation from the threshold value. Also, soil pH tallies with typical Sahelian soils. According to Sanchez *et al*. (1982), these soils do not have any serious limitations to crop production. With judicious management that encompasses crop residue retention after harvest and modest supplementation of plant nutrients, high and sustainable yields are realistic targets. Fertilized maize yields on-station were between 2,500 and 5,000 kg/ha over a seven-year period in the Upper West region (SARI, 1992).

On-station, Experiment 2. At the site of Experiment 2, the soil is similar to that of Experiment 1 in terms of available P (mean P= 7.38, s.e.=0.90 and mean pH=6.43, s.e.=0.33). However, at this site, C=0.46% and s.e.=0.03 which is almost half that of the Experiment 1 site. Given the importance of soil carbon in the Sahelian soils, it would be expected that sustainable yields would not be viable at the site of the second experiment. Consequently, one wonders why there are not significant differences between full and the quarter fertilizer as prescribed by NuMaSS (Table 6). Information presented in Table 6 clearly makes economic sense to use the amount recommendation by NuMaSS.

On-farm, Experiment 3. In the Upper West region, the conventional cropping system is groundnut followed by maize. The on-farm trial sites were purposely selected to have fields that were previously cropped to groundnut.

The conventional farmer's practice without fertilizer yielded 769 kg/ha. With the addition of fertilizer based on the NuMaSS recommendation, a 3.5-fold increase in yield occurred (i.e., 2720 kg/ha). Although, yields were slightly greater with the application of fertilizer suggested by NuMaSS on continuous maize, they were not significantly different from those of the national rates (Table 7). Previous experience in the USA has demonstrated that rotations generally have comparative yield advantage over sole cropping. In addition rotation with a legume component supplies N and increases soil carbon indirectly (Varvel, 1994).

Stability Analysis

Clearly, there is no significant difference between maize yields in Treatments 3 and 4 (Table 7). Drawing from studies elsewhere, it could be hypothesized that treatments which depended on

Table 6. Maize yields as affected by NuMaSS fertilizer recommendations.

Treatments	Yield	Significance level[1]
NPK + SA fertilizer (T1)	1790	a
[2]Full NuMaSS recommendation (T2)	1330	a
½ of NuMaSS recommendation (T3)	1310	a
¼ of NuMaSS recommendation (T4)	2060	a

[1]Different letters show significant yields at 5% probability level.
[2]Full NuMaSS rate for maize was 44 kg P/ha +10 kg N/ha.

Table 7. Maize yields in groundnut-maize rotation as affected by NuMaSS fertilizer recommendations.

Treatments	Yield	Significance level*
Maize-groundnut rotation only (T1)	760	c
Maize-groundnut rotation +NuMaSS fertilizer recommendation (T2)	2720	a
Continuous maize + national fertilizer recommendation (T3)	2395	b
Continuous maize + continuous maize plus full NuMaSS fertilizer recommendation NuMaSS fertilizer recommendation	2470	b

*Different letters show significant yields at 5% probability level.

NuMaSS fertilizer recommendations will be more sustainable in terms of cost-effectiveness as it considered the initial soil fertility status (Yost *et al*., 1988). The national system is typically based on blanket fertilizer recommendation regardless of baseline fertility levels. This system largely ignores the fact that the majority of farmers use other organic soil amendment such as compost, household refuse including wood ash, green manure or animal manure.

Crop residues and bush burning have become rampant in the Upper West region. Added to these is the removal of harvested residues from the fields for other uses, exposing the soil surface to water and wind erosion. The correlation between soil carbon and P is 0.93, between soil carbon and pH, 0.87, and between total N, 0.82, implying that the loss of surface soil carbon may render the soils unproductive.

Angola

Angola is recovering from nearly 30 years of war that has left the country without food, education and economic means. The ProPlanalto Project of WorldVision, Chevron-Texaco, USAID and three Angolan institutions (The Agricultural Research Service, IIA; the Agricultural University, Agostinho Neto University; and the Extension Service, IDA) was organized to begin the restoration of the highly successful pre-war agricultural production systems in order to end the famine that has struck many Angolan families and households. Modern varieties of maize, potato and beans were brought in, local seed producers were found, fertilizer experiments were conducted and a soils laboratory was constructed, furnished, equipped and supplied. A goal of the SM CRSP intervention was to assist in this restoration by illustrating and training in the use of information technologies and participatory development to improve the provision and management of nutrients and fertilizers. Information technology tools such as decision-aids and geospatial analysis were introduced. Participatory methods of using soil test kits, farmer-to-farmer visits and farmer empowerment were used to used to illustrate that the country and its scientists can leap-frog into the use of current technology and knowledge management skills if they so choose. Maize yields of up to 9000 kg/ha and potato yields as high as 16,000 kg/ha were obtained under ideal conditions. Indications are that irrigation is available during the dry season potentially providing sustainable water supply for year-around irrigation. Soils from the experimental sites were characterized using *Soil Taxonomy* to facilitate sharing of production system technology and expertise.

Mozambique

Testing and Adaptation of NuMaSS and PDSS Software

Soil nutrient decline is one of the main limiting agricultural productions in Mozambique. A growing awareness that current agronomic practices, which rely on crop nutrient cycling, cannot satisfy the food demand of Mozambique's growing population has occurred. Improving soil nutrient management through integrated soil nutrient management based on knowledge of crop requirements and soil condition will become increasingly essential for sustainable crop production in Mozambique.

To test and adapt NuMaSS and PDSS for Mozambique conditions, trials were conducted on-farm and on-station in four locations during the 2005/06 cropping season. The experiment sites were located in Sanga district in Niassa province, Monapo in Nampula province, Nhamatanda in Sofala province and Gondola in Manica province. These locations represent three different agro-ecological conditions of Mozambique.

Soil samples in the sites were collected and analyzed for physical and chemical properties in IIAM central laboratory before planting. In addition, the samples were analyzed in the field with a soil test kit for soil pH, nitrate, ammonia and phosphorus.

Experimental Design and Treatments

The experimental design used in on-station trials was a complete randomized block and for on-farm trials was a randomized design using three or more farmers within a similar environment. The crop used in these experiments was maize, *Matuba* variety. The treatments tested in Nhamatanda were:

- Control (O NPK)
- One half predicted (20:28:14 kg/ha of NPK)
- Predicted (40:56:28 kg/ha of NPK)
- Two times predicted (58:84:42 kg/ha of NPK)

Due to lack of soil data at planting stage for Sanga and Monapo, the treatments tested were similar to those applied in Nhamatanda. Crop yield data and soil analyses are being processed.

Field Days

Field days provide great opportunities for exchange experiences between farmers, field extension workers and researchers. It helps researchers to select technologies that fit a given recommendation domain.

A field day in Gondola district in central Manica province was conducted to test farmers' perceptions about crop performance under fertilized conditions with different fertilizer rates predicted by NuMaSS and PDSS. The participants came from ONGs, Sussudenga research station, farmer associations and district and provincial extension services. The farmers were able to clearly observe crop response to different fertilizer rate applications. Both the potential and the limitations of the technology, as well as crop performance, were discussed. Some of the farmers had already experienced fertilizer use from neighboring Zimbabwe where they lived as refugees during the civil war. To complement SM CRSP activities for the next cropping season, the legume sector of Sussudenga research station has demonstrated an interest in establishing local seed multiplication program as well as legume trials.

Training of Extension Workers

In recent years, a number of training programs have been oriented for post-graduate degrees, but little has been done to develop the skills and knowledge of field extension workers. A training needs assessment has pointed out the need for updated skills of field extension workers in soil nutrient management and post harvest handling. Under the SM CRSP program, five training workshops were conducted on soil nutrient management, pest and post-harvesting technology during the 2005/06 cropping season in central, northern and southern Mozambique. The aim of the training was to understand the soil-plant-nutrient relationship and to create awareness of soil fertility problems.

Over 50 participants, ranging from extension supervisors and field workers, attended the training. The training module included: 1) The soil-plant relationship, soil quality and the role of macro and micronutrient for plant growth and development; 2) Predicting fertilization needs and soil amendment; 3) Diagnose soil fertility in the field using soil test kit; and 4) Group discussion of soil nutrient management based on soil test kit results and laboratory data.

The results of the course evaluation indicated that the topics addressed were relevant to trainees' needs and expectation. The extension workers thought that the inclusion of a soil test kit for each extension team could be very beneficial, as it would provide the basis for advising farmers about soil condition of their fields, which in turn could reduce the cost of production for those farmers who apply fertilizer.

Training of Central Laboratory Staff in Soil Data Scrutiny

For many years, the Mozambique central laboratory has been using a flow analyzer for routine soil analysis. Recently, with the support of the SM CRSP principal investigator, the USAID funded the purchase of an atomic absorption spectrophotometer. Under a PROAGRI (the national agrarian program) grant the IIAM central laboratory will be equipped with a new NIR spectroscopy for soil and water analysis. These tools will increase the IIAM capability of soil analyses. However, no IIAM central laboratory personal have any agricultural background or a university degree. To improve understanding of soil analysis data computation, a three-day intensive training course was conducted with the support of SM CRSP. The aim of the training was to replace the traditional hand soil data computation with computer software, develop better understanding of soil analysis parameters and to develop a soil analysis database.

Workshop and Planning Meetings

In 2004, the SM CRSP organized the first national workshop in soil nutrient management as a starting point in developing a national network of researchers and extension workers who would deal with soil fertility issues. A follow-up to the 2004 workshop as organized in 2005 at the II National Workshop on Soil Nutrient Management was arranged. The aim of the workshop was to: 1) share experiences among Mozambique soil fertility scientists and extension workers through presentation of research and extension works on soil conservation and nutrient management, 2) identify partnerships among different institutions and ONGs and 3) develop a national research agenda on soil fertility. The participants of the workshop came from ONGs, Government Extension services, the National Agrarian Research Institute (IIAM) and the International Research Centers' country representatives (ICRISAT, ICRAF).

The results of the group discussion were analyzed by a core group, which will provide the basis for developing a national strategic plan for implementation under the regional consortium (SOFESCA) and the national agrarian program (PROAGRI). For implementation of the SM CRSP and SOFESCA 2005/06 activities, a regional meeting was conducted in central Mozambique. Participants of the meeting came from the Provincial Directorate of Agriculture, Sussudenga Research Station and NGOs actively involved in research at the provincial level.

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

Southeast Asia—Thailand

Field Test Rock Phosphate (P) Algorithm

Phosphorus (P) deficiency in flooded acid sulfate soils of Thailand is one of the limiting factors causing decreases in rice growth and yield (Attanandana and Vacharotayan, 1984). In order for rock phosphate to become available for crops, there are at least two reactions that are critical: dissolution of rock phosphate and sorption of the dissolved rock phosphate. Rock phosphate has been recommended for rice cultivation in acid sulfate soils of Thailand (Department of Agriculture, 2004). The extreme acidity of acid sulfate soils, in which soil pH can be less than 3 to 4, is a logical choice since acidity is key to the dissolution of rock phosphate. In addition to soil and rock phosphate characteristics, dissolution of rock phosphate depends on many factors such as crop species, crop management and climate conditions (Sidibé *et al*., 2004). Other soil properties that control the dissolution of rock phosphate include soil pH and P sorption capacity.

Rock phosphate solubility, fineness and porosity were the important factors controlling RP dissolution (Yost *et al*., 2003). The solubility of RP can be measured by a 2-percent citric, 2-percent formic acid and neutral ammonium citrate (N. Chien, 2005, personal communication). Generally, increasing RP solubility as measured by chemical extractions increased the RP dissolution in the soils; however, many factors in the soils and their interactions have been shown to affect the agronomic effectiveness of RP. This study was to determine if the dissolution of rock phosphate in acid sulfate soils is the primary reaction that influences the effectiveness of direct application of RP and if dissolution can be predicted for rock phosphates and soils. Since rock phosphates are highly variable in their chemical and physical composition, an algorithm must quantify the effects of both soil and rock phosphate properties in order to estimate the dissolution of RP. The objectives of the study were: 1) to determine which properties of acid sulfate soils and RP materials are the major influences on RP dissolution and 2) to develop the algorithm and model to estimate the dissolution of a range in RP materials in six representatives acid sulfate soils of Thailand.

Six acid sulfate soils, representing the most important acid sulfate soils in the Central Plain of Thailand, were selected for the experiments. These were Rangsit very acid (Rsa), Ongkharak (Ok), Rangsit (Rs), Sena (Se), Maha-phot (Ma) and Chachangsao (Cc) soil series.

Four rock phosphates (RP) were used in this study. A local rock phosphate from Kanchanaburi province and Gafsa rock phosphate from Tunisia were the high reactivity rock phosphates for the study. Tilemsi and Taiba rock phosphate from Mali and Senegal were medium and low reactivity rock phosphates, respectively (Yost *et al*., 2003).

Summary

The direct application of rock phosphate depends on two reactions: dissolution and sorption. Soil acidity and RP solubility were the key factors affecting the differential dissolution of the four RP materials in six flooded acid sulfate soils as estimated by the difference in NaOH extractable P in soils incubated with rock phosphate. It was found that the higher calcium carbonate equivalent in some RP materials sharply decreased the RP dissolution in five acid sulfate soils but not in the Mahaphot soil. High dithionite extractable iron and organic matter in Mahaphot soil, electron acceptors of iron reduction, led to a sharp increase in soil pH during flooded. The pH of Mahaphot soil increased quickly after flooding and thus the calcium carbonate in RP probably has less effect of neutralizing the acidity in this soil. Soil acidity as measured by soil pH and KCl-extractable Al and rock phosphate solubility measured by a second extraction of 2-percent citric acid and particle size of RP were the key factors in the RP dissolution model. However, the availability of RP also depends on the sorption of the dissolved RP by the soils. The effects of sorption of the dissolved rock phosphate will be studied in field conditions. The suitability RP also depends on other factors: plant species, climate and field management. Thus a rock phosphate model developed from rock phosphate and soil properties effect on dissolution is a preliminary study. An estimate of the agronomic effectiveness of direct application of RP needs to include the sorption factor and then be tested in field conditions.

Africa—Mali

Calibration and Simulation of the K Algorithm for NuMaSS

Table 8. Rates N, P, K and lime added to seven treatment areas.

N°	Treatments	Rates kg/ha			
		N	P	K	Lime
1	Check	0	0	0	0
2	NuMaSS	91	26	0	1000
3	NuMaSS 1/2 K algorithm	91	26	9 ,95	1000
4	NuMaSS K algorithm	91	26	199	1000
5	NuMaSS 2 K algorithm	91	26	398	1000
6	NuMaSS K QUEFTS	91	26	78	1000
7	NuMaSS K Quadrants	91	26	1953	1000

Fertilizer recommendations in Mali as well as in many other countries of West Africa were made according to Chaminade's method (1965). For socio-economic reasons, extension officers corrected deficiency levels of major nutrients. These blanket recommendations, however, when applied, lead to continued soil nutrient mining. Potassium K is not included in these recommendations because the soils often contain sufficient levels. Potassium is important for the function of the stomata, pore-like openings of the plant leaves, through which transpiration of water and uptake of gaseous carbon dioxide occurs. Adequate potassium nutrition of the plant is necessary to ensure the integrity of the water economy within the plant. The needs for the plant K are obtained at the expense of the soil potassium supplies. Potassium export in continuous cropping system averages 35 g potassium per kg of biomass resulting in soil depletion of that element.

The overall objective was to develop nitrogen-, phosphorus-, potassium- and lime-specific recommendations for food crops in Mali. Specific objectives were to:

- Calibrate and simulate the K- algorithm; and
- Evaluate and compare the effects of K rate predictions by 3-Quadrants, QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) and the NuMaSS model on soil properties and crop yield.

The experiment was conducted at the agronomy research station at Sotuba, Mali. Sotubaka maize was diffused in 1995 and adapted in areas where the annual rainfall is higher or equal to 800 mm. Its maturity cycle is 115-120 days and the average grain yield is 5 to 7 tons/ha. The soil at the station is an Alfisol with the pH strongly acidic (pH > 5.5) and the exchangeable K low (< 0.2cmol(+)/kg Sanchez, 1982).

The experiment was a randomized complete block design arranged in three replications. The seven treatments were compared (Table 8) and the data analyzed using the anova technique of the Statistical Analysis System (SAS).

Conclusions

The effects of potassium on biomass yield showed significant differences. The relationship between the K rate and the biomass maize yield indicated that as the K rate increases, biomass yield increases. K deficiency symptoms were not observed in the plant.

The effects of the treatments on grain yield did not show significant differences between NuMaSS; NuMaSS 1/2 K algorithm; NuMaSS 2K algorithm and NuMaSS 3 –quadrant (Figure 4).

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

Introduction to Latin American Activities

In *Mexico* on-farm comparisons of fertilizer N and P recommendations for sorghum by NuMaSS, local practices and other potential alternatives confirmed results of extensive N x P fertilization trials: a response to N only when yields exceeded 3 t/ha and no response to P under dryland or irrigated conditions. NuMaSS recommendations for N in sorghum

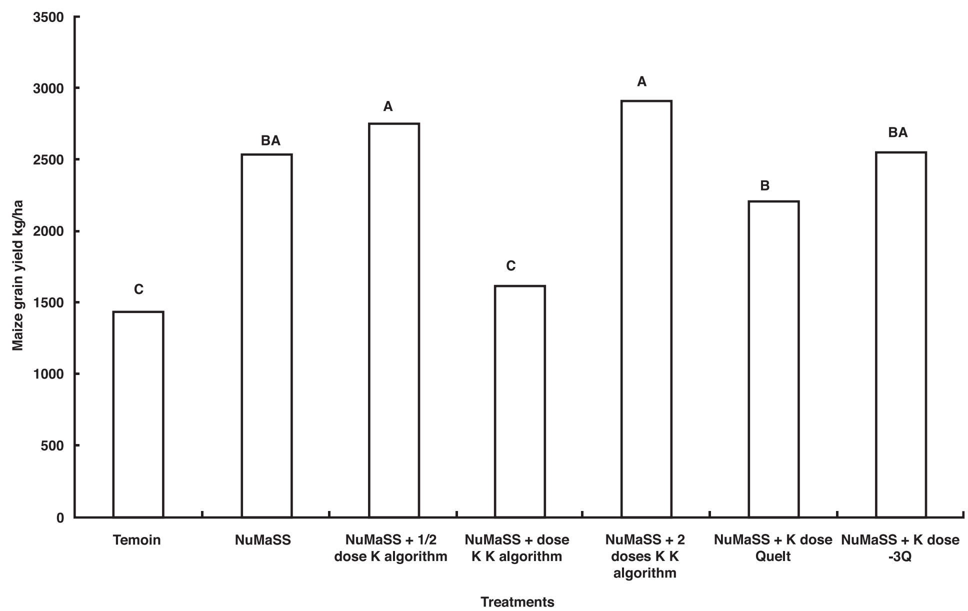


Figure 4. Effects of selected treatments on maize grain yield.

and irrigated corn or cotton, and for P in corn were comparable or superior to other recommendation strategies.

In *Honduras* and *Nicaragua* completion of the second cropping season on a network of N fertilization trials provided soil and crop N coefficients for the six most common maize varieties grown in the region. Along with the interim release of the Data Base Editor Module for NuMaSS, these coefficients enable users to customize the software's database and make site and varietal-specific fertilizer N recommendations within their regional domains. Six NGOs working with FAO in subsistence farming communities of Honduras were trained in NuMaSS and are using the customized database to develop N recommendations for their demonstration trials with farmers.

In *Panama* similar development of soil and crop N coefficients for local upland rice varieties is approaching completion. Preliminary testing of the customized NuMaSS database indicates that software recommendations will lead to a reduction in N fertilization relative to current local recommendations. Soil P coefficients were also finalized for Alfisols in the corn production region of Azuero.

Despite severe frost problems in the highlands of *Bolivia*, residual fertilizer P applied to a preceding potato crop met the needs of the succeeding wheat crop. The latter crop only required supplementary N fertilization. On-farm tests of NuMaSS N and P recommendations for potato suggested that local seed producers could reduce their fertilizer costs by excluding K fertilization and adjusting their P fertilization based on initial soil test data and clay content. The second potato crop on P fertilization in Andisols of *Ecuador* reveals that reliance only on residual fertilizer P applied to the previous year's crop reduced yields by 42-75 percent across four test sites. Preliminary estimates of soil P coefficients show promising trends for the use of oxalate extractable Al as a proxy-soil variable to adjust P recommendations in these soils with amorphous clay mineralogy.

Results for the first crops harvested from trials in the clayey Oxisols of the humid tropical region of Paragominas in *Brazil* suggests that P is the primary nutrient constraint in these degraded pastures, and soil P coefficients are adequately predicted by the existing NuMaSS algorithms. Yield response to N fertilization by corn and upland rice is largely dependent on variety and, surprisingly, soil acidity is not an important constraint. Critical soil test levels for P, K and acidity were developed for cowpea through continuation of trials in the sandy Oxisols. These coefficients will enhance the limited NuMaSS database for this crop and improve software usage for this cash crop in the densely populated region of Northeast Pará.

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

INIFAP, Mexico

N x P Fertilization Trials from 2005

Only 165 mm of rainfall was received during the growing season, and dryland crop yields were average to below-average. Eight of the 10 test sites for the factorial N x P trials were cropped with sorghum, while two were cropped with either irrigated corn or cotton. As with previous sorghum crops, P fertilization and the interaction between N and P fertilization did not influence sorghum yield on any of the five dryland or three irrigated test sites. However, N fertilization improved sorghum yields on six of the eight test sites where optimum yields ranged from 3.3-4.7 t/ha. The two sorghum sites without a yield response to N fertilizer were under dryland production and yielded less than 3 t/ha, a yield level which is consistent with previous crop-year results for separating sites which are non-responsive from those which are responsive to N fertilization.

Contrasting with sorghum, a significant yield response up to 120 kg N/ha and 60 kg P/ha occurred at the test sites cropped with either irrigated corn or cotton. Yields reached 8.2 t/ha for corn and 4.3 t/ha for cotton seed. Whereas the absence of a sorghum yield response to P led us to conclude that an Olsen-extractable critical soil P level in these soils was < 11 mg/kg, corn and cotton critical levels may be higher.

Residual soil NO_3-N at 0-30 and 30-60cm depths were determined from composite samples across N and P treatments for each replication at each site, prior to planting sorghum in 2004 and 2005. The value of these measurements for estimating native soil N supply was investigated by regressing kg/ha of NO_3-N against kg/ha of N accumulated in sorghum grain and stover of treatments that did not receive any fertilizer N inputs. No significant relation between soil NO_3-N, at either sampling depth, and crop N uptake, for either crop-year or water management system, was observed. Residual soil NO_3-N from N fertilization of the 2004 sorghum crop may have confounded estimates of native soil N supply to the 2005 crop via composite samples taken across N treatments (0, 40, 80 and 120 kg/ha); however, this same confounding effect would not be present in soil samples taken for the 2004 crop before N fertilization was initiated at the 10 test sites. Residual soil NO_3-N in 2005 ranged from 32-83 and from 86-176 kg/ha at 0-30 and 0-60 cm depths, respectively.

On-farm Strip Tests in 2005

Replicated comparisons between NuMaSS and other local fertilizer recommendations were conducted at two dryland and two irrigated sites for sorghum and one irrigated site each for corn and cotton. Local recommendations included the standard Texas Agricultural Experiment Station—Weslaco (TAES) and two modifications wherein fertilizer N recommendations were reduced based on residual soil NO_3-N to 30- (TAES-30) and 60-cm (TAES-60) sampling depths. The INIFAP recommendation and a control without fertilization were also included. Recommendations for both TAES and INIFAP consider water management regime and N fertilization higher for irrigated than dryland conditions; NuMaSS N recommendations are based on targeted crop yield which was lower for dryland sites with sorghum (4 t/ha) compared to irrigated sites for all crops (6 t/ha sorghum, 7 t/ha corn and 1 t/ha cotton lint). Potassium fertilization was not recommended for these soils by any of the tests.

Mean yields for dryland sorghum were below 3 t/ha and no differences exist between the unfertilized treatment and the different N and P recommendations (Figure 5). NuMaSS and TAES-60 correctly recommended no fertilization under these conditions. With irrigated sorghum, yields with N recommendations ranging from 63 to 120 kg N/ha were similar but superior to that of the control. Among the recommendations with N fertilization, there was no yield difference between those with and without P fertilization.

Corn yields with fertilizer N and P recommendations were superior to the unfertilized treatments (Figure 6). Among the fertilizer recommendations, yields significantly increased with N recommendations from 73 to 161 kg/ha. Superior yield for the NuMaSS versus INIFAP recommendation is attributed to higher N fertilization of the former, since both contained similar amounts of fertilizer P (42 and 40 kg/ha). As with irrigated sorghum (Figure 5), adjustments of the TAES recommendation for residual NO_3-N to a 60-cm depth (TAES-60) had a detrimental effect on crop yields. Tests at additional sites, especially with corn, are needed before determining if the TAES-30 recommendation is a viable alternative to that of NuMaSS. Seed cotton yield was improved significantly with all recommendations of N with or without P fertilization, but there was no difference among the different amounts of applied fertilizer.

Crop yield data across 14 site-years in the 2004 and 2005 seasons indicate that NuMaSS recommendations performed equally well or superior to those of INIFAP and TAES for irrigated sorghum, corn and cotton. As with the N x P trials, fertilizer response by dryland sorghum depends on whether rainfall favors yields exceeding 3 t/ha.

CIAT-MIS Consortium, Honduras and Nicaragua

Yield Response to Fertilizer N and Legume Cover Crops

Field trials to develop varietal and soil coefficients used by NuMaSS for N recommendations on corn were continued in the 2005/06 season at La Ceiba, Yorito, Catacamas and Candelaria in Honduras, and at San Rafael and San Dionisio in Nicaragua. The crop at La Ceiba was severely damaged by hurricane Wilma and there was no response to fertilizer N for the second consecutive crop at Catacamas. The two years of collective data have enabled the development of robust estimates for key crop and soil coefficients used by NuMaSS to provide fertilizer N recommendations for the corn varieties that are used extensively throughout the two countries. Coefficient values for each variety are summarized in Table 1 along with the default values used by NuMaSS whenever such information is not locally available. The importance of developing crop and soil coefficients for local varieties and soils is illustrated in Table 9 via comparisons of N recommendations by NuMaSS for a 4.5 t/ha grain yield using either the software's default coefficients or the varietal and soil coefficients for each location. Differences in the software's default recommendations range from 0 to 197 kg N/ha. The value of site-specific N recommendations versus regionally constant "recipes" is also evident when comparing fertilizer N rates to achieve optimum yields among field trial sites. Required fertilizer N ranged from 0 to 125 kg/ha. As reported under Objective 2, a new database editor module allows users to customize the NuMaSS software by adding these varietal and soil coefficients for their specific regions.

Bolivia, Costa Rica and Ecuador

N and P Requirements for Wheat in Bolivia Inceptisols

Fertilizer trials initiated with potato in 2004 were continued in 2005 with a comparison of yield response by two local wheat varieties, 'Tepoca' and 'Totota 80'. This cropping cycle is in keeping with the three-crop rotation of potato-oats/wheat-lima bean practiced by local farmers. Fertilizer N rates for the N trial were 0, 33, 66, 99, 132 and 165 kg/ha, but the P trial evaluated wheat response to the residual of fertilizer P (0, 28, 56, 84 and 139 kg/ha) broadcast-applied to the previous potato crop. Yields for both trials were severely affected by a frost late in the grain filling stage, with mean trial yields of 1628 kg/ha for N and 2122 kg/ha for the P trial. Since improved N supply prolongs the growth cycle, grain filling was more advanced and yields were higher for treatments with the lowest N rates. However, straw yields and tiller and panicle counts suggested an N response up to 66–99 kg/ha. Similar plant measurements suggested no response to fertilizer P, but yields for 'Totota 80' were superior to that of 'Tepoca'.

On-farm Tests of NuMaSS Recommendations for Potato

Software recommendations of fertilizer N and P for potato were compared with a fixed formulation (72, 63 and 72 kg/ha of N, P and K) used by a local potato seed company (SEPA) in two replicated on-farm trials. The NuMaSS recommendation for a 20 t/ha target yield included 80 kg/ha of N and fertilizer P (62 or 80 kg/ha) adjusted for initial soil test P and clay content at each site. One site had 21 mg/dm^3 of Mehlich-1 P and 32% clay, whereas the other site had 11 mg/dm^3 of Mehlich-1 P and 52% clay. Additional treatments included a control without fertilizer and 50 and 150 percent of the NuMaSS recommendation. A treatment with the SEPA formula minus fertilizer K was also included, because soil tests for both sites indicated adequate K supply.

There were no significant yield differences between treatments at the site with 32% clay, but the yields at the site with 52% clay increased from 10 t/ha without fertilizer to 20 t/ha with either the NuMaSS recommended N and P or the SEPA-K treatment. Furthermore, there was no significant yield improvement with either 150 percent of the NuMaSS

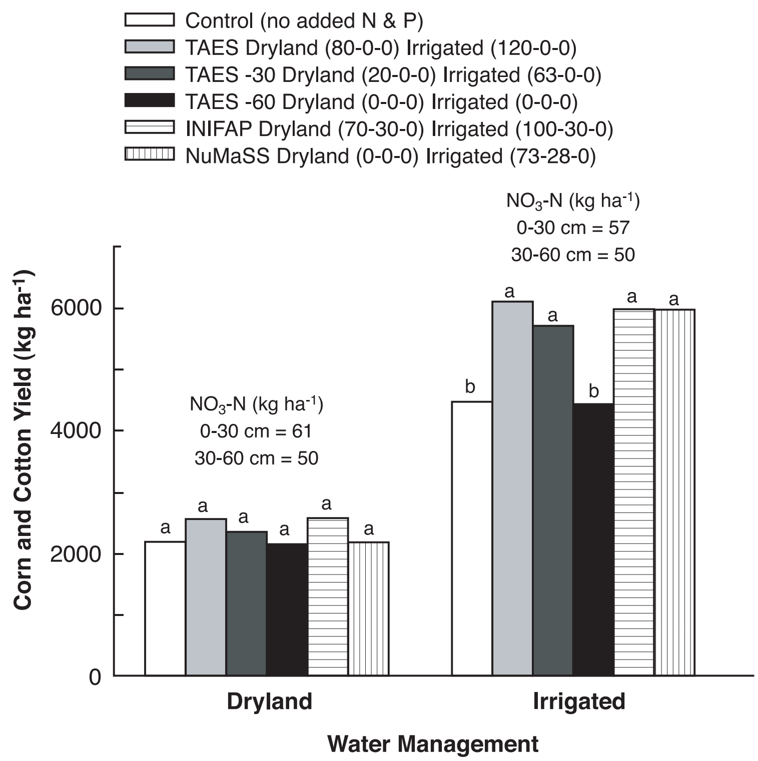


Figure 5. Dryland and irrigated sorghum yields in 2005 as a function of different fertilizer recommendations.

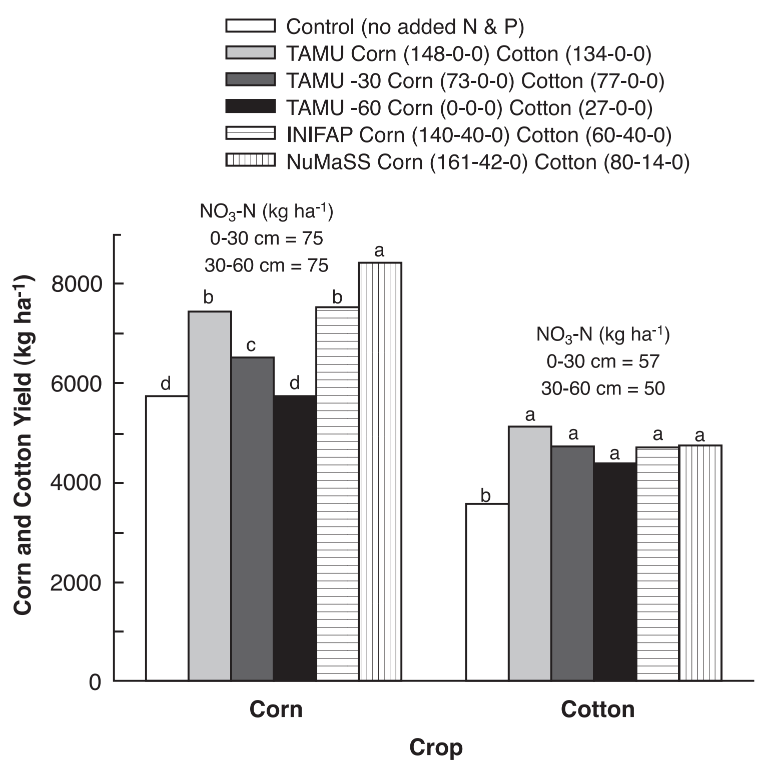


Figure 6. Irrigated corn and cotton yields in 2005 as a function of different fertilizer recommendations.

Table 9. NuMaSS default and site/varietal-specific crop and soil coefficients and associated software fertilizer N recommendations in Honduras and Nicaragua.

Variable	NuMaSS Default	Location					
		Candelaria	Catacamas	Talgua	Yorito	S. Dionisio	S. Rafael
Variety	—	*D. guayape*	*HS 15*	*DK 53*	*HB 104*	*NB 6*	*N. blanco*
Yield w/o N, kg/ha	2468	1700	5600	5200	1400	3000	2450
Opt. yield, kg/ha	3320	4100	5600	7400	3100	4100	6600
N for opt. yield, kg/ha	—	50	0	105	95	60	125
Grain:stover ratio	0.84	0.69	0.77	1.34	0.77	0.76	1.17
% N grain	1.24	a	1.47	1.44	1.40	1.68	1.43
% N stover	0.57	0.61	1.15	0.65	0.71	0.70	0.51
Soil N supply, kg/ha	97	a	154	75	36	66	46
% fert. N recovery	44	a	c	49	30	32	74
N Recom.[b], kg/ha	0	a	0	4	197	124	38

[a] Determination pending completion of plant tissue N analysis.
[b] NuMaSS fertilizer N recommendations using either the software's default values or the site- and variety-specific values; for purposes of comparison, a target grain yield of 4500 kg/ha was used for all recommendations.
[c] Unable to be determined due to lack of yield response to fertilizer N.

Table 10. Oxalate-extractable Al and preliminary estimates of soil P buffer coefficients and critical levels for each trial site in Andisols of Ecuador.

Site	Oxalate-Extractable Al	Olsen P Buffer Coefficient	Soil P Critical Level	
			Olsen	Mehlich-3
	%	kg soil P/kg fertilizer P	------mg/dm^3------	
Cochabamba	2.0	0.054	13	6
C. Contadero	0.8	0.109	18	27
Quinua Corral	0.5	0.202	–[a]	–
Santa Ana	0.2	0.179	39	84

[a] Denotes failure to meet convergence criteria in the non-linear regression used to estimate the P critical level.

recommendation or the complete SEPA formula including K. A yield reduction to 15 t/ha with 50 percent of the NuMaSS recommendation, suggests that the software's recommendation approached near-optimum levels.

P Management for Potato in Andisols

Among the five ongoing P fertilization trials (one in Costa Rica, four in Ecuador), optimum yields for the second potato crop in 2005 on the sites in Ecuador were in the order of 25-30 t/ha and required a second P application ranging from 79-96 kg/ha (Figure 7). The importance of fresh P applications to each crop are apparent when considering that yields with only 132 kg P/ha applied to the first crop corresponded to 58, 25, 45 and 53 percent of the respective maximum yields achieved at the Chaupi, Santa Ana, Quinua and Cochabamba sites when P was re-applied prior to planting the second crop.

The working hypothesis for these P trials in Andisols with amorphous clay mineralogy is that soil amorphous Al, such as that extracted with oxalate, are a potential substitute proxy variable for NuMaSS estimates of soil P buffer coefficients and critical levels to that of clay percent currently in use for soils with crystalline mineralogy. Preliminary estimates of these NuMaSS coefficients for trials in Ecuador are encouraging, as both buffer coefficients and critical levels tend to increase with decreasing soil levels of oxalate-extractable Al (Table 10).

IDIAP, Panama

N Fertilization for Upland Rice

Field trials comparing N responses of local rice varieties IDIAP 2503 and 3003 were continued for a second crop on Ultisols at Calabacito and Inceptisols at Trinchera. Upon completion of data analysis for

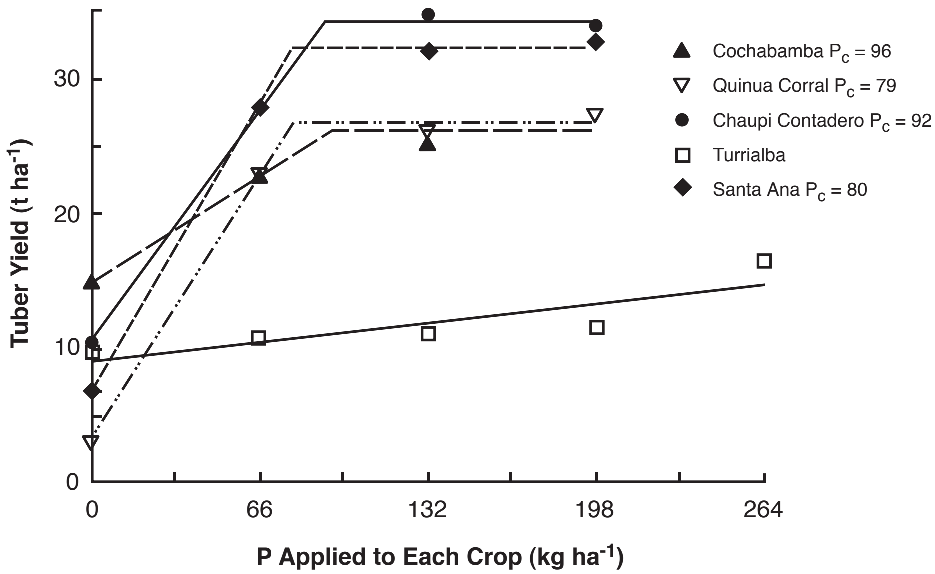


Figure 7. Potato tuber yield in Andisols of Ecuador and Costa Rica for the second crop as a function of fertilizer P applied to each crop.

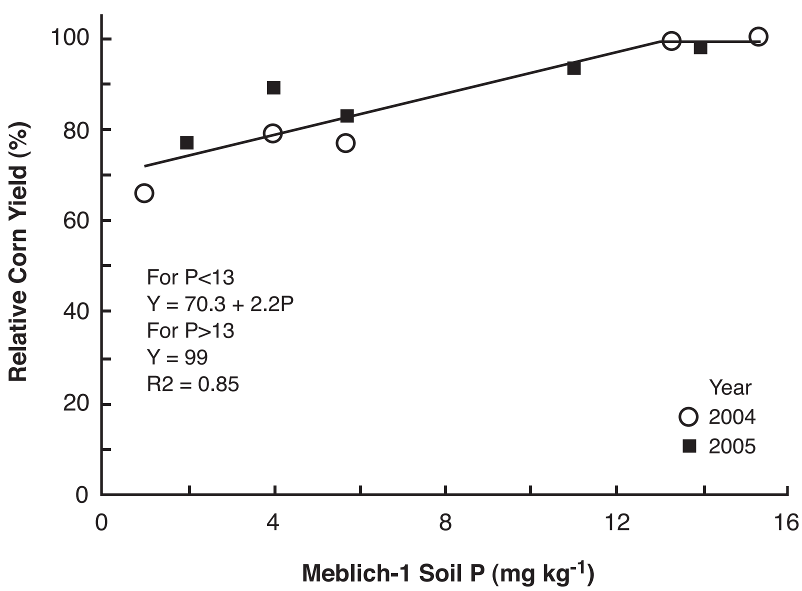


Figure 8. Relative yield of two consecutive corn crops in an Azuero Alfisol as a function of Mehlich-1 soil test P for five fertilizer P rates applied prior to the first crop.

the second crop means values across seasons of grain:stover ratios, grain and stover %N, soil N supply and % fertilizer N use efficiency will be added to the NuMaSS databases and used as default values for local N recommendations. Preliminary comparisons between NuMaSS recommendations, based on varietal coefficients derived from the first cropping season and local recommendations, indicate that software recommendations will decrease fertilizer N inputs for the widespread upland rice production in the region.

P Fertilization for Corn in an Azuero Alfisol

Corn yields for the second crop were higher than for the initial crop; mean experiment yields were 4.1 t/ha in crop 1 and 7.9 t/ha in crop 2. Residual effects of broadcast P, applied at planting of the first crop, increased yields in the second crop from 6.6 t/ha with 0 kg P/h to 8.4 t/ha with 100 kg P/ha. When averaged across residual broadcast P rates, fresh applications of banded P increase yields from 7.6 t/ha without band applied P to 8.2 t/ha with 30 kg of banded P/ha.

The combined data from both corn crops also indicated that the Mehlich-1 critical soil test P value for corn in this Alfisol was 13 mg/kg, whereas the value predicted by NuMaSS was 7.5 mg/kg (Figure 8). The Azuero region is a major corn production area, wherein fields are fertilized when cropped to corn and residual nutrient inputs benefit subsequent rotations into pastures. These locally derived soil P critical level and buffer coefficient will enhance the use of NuMaSS for fertilizer P recommendations to growers in the region.

EMBRAPA, Brazil—CPATU

N and P Fertilization for Grain Crops in Clayey Oxisols

Initial crops of corn, soybean and upland rice were harvested from N and P fertilization trials designed to test NuMaSS predictions and validate/refine soil and crop coefficients on Oxisols with 80 percent or more clay content. This is a region in the southeast portion of the State of Pará where extensive areas of rainforest were converted to pastures after clearing by slash-and-burn in the 1970s. Currently, degraded and unproductive pastures are being used in a 'ley cropping system'—land is fertilized and cropped with grain crops for several years, followed by re-seeding of pastures with improved varieties of *Brachiaria*. Initial soil tests of the degraded pastures show that P is limiting (2 mg/kg of Mehlich-1 P), but, surprisingly, there are no acidity constraints (pH 5.4 and <20% Al saturation) and soil K supply is adequate.

Yields of both soybean (first crop) and corn (second crop) increased significantly with P fertilization (Figures 9 and 10), achieving yields (dependant on variety or hybrid) of 8.8 t/ha for corn and 2.3 t/ha for soybean with a single application of 88 kg P/ha. Preliminary estimates of Mehlich-1 soil P critical levels were in the range of 6-8 mg/kg- for both crops, and the Mehlich-1 soil P buffer coefficient was estimated to have a value of 0.186. Both of these soil P coefficients are very similar to values predicted by NuMaSS for clayey Oxisols.

Yield response to fertilizer N differed among the corn hybrids, with no response by BR 106 and a yield optimum of 8.5 t/ha by Pioneer 30F80 with 84 kg N/ha (Figure 11). Yields between 5 and 7.5 t/ha without fertilizer N are indicative of good native N supply by these soils, once the degraded pastures are cleared and fertilizer P is added. Yield responses to fertilizer N were similar for upland rice varieties 'Aimoré' and 'Colosso', with mean yields increasing from 2.5 t/ha without applied N to an optimum of 4.0 t/ha with 60 kg N/ha.

Fertilizer and Lime Trials in Sandy Oxisols and Ultisols of Northeast Pará

Continuation of on-station and on-farm lime, P, K and N trials at Terra Alta and Tracuateua, with a corn-cowpea annual cropping cycle have begun to provide critical soil test indices for use in NuMaSS recommendations for cowpea. Approximately 20,000 ha are cultivated with this cash crop in the region, and there is limited information for cowpea in the software's database. In the third consecutive year of cropping, cowpea is beginning to show significant yield reductions in the absence of lime. Regression of relative cowpea yields on soil exchangeable acidity for five site-years indicates a critical % Al saturation value of 14 percent for this crop. This critical value is considerably lower than that reported for other sites, and may be associated with improved Ca and Mg supply with liming of these sandy, low cation exchange capacity soils. Similar regressions of cowpea yield over three years in a P experiment at Terra Alta indicated a

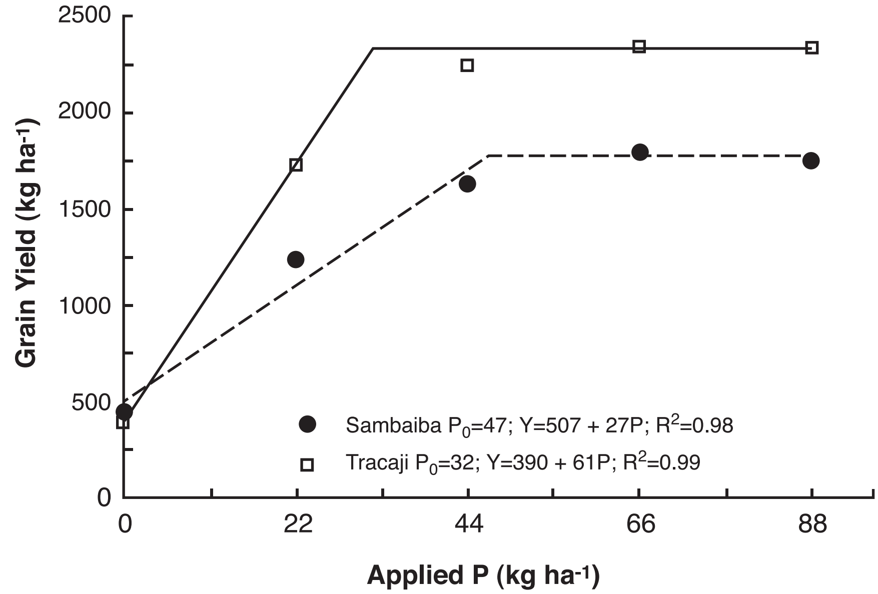


Figure 9. Grain yield of two soybean varieties as a function of fertilizer P applied broadcast at planting on a clayey Oxisol at Paragominas, Pará, Brazil.

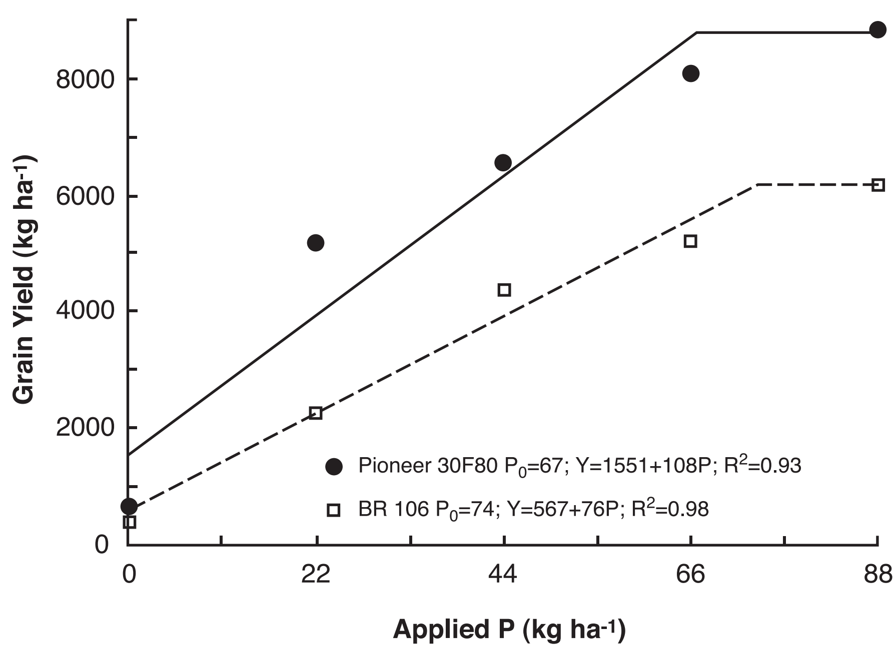


Figure 10. Grain yield for a corn hybrid and variety as a function of fertilizer P applied broadcast to a preceding crop on a clayey Oxisol at Paragominas, Pará, Brazil.

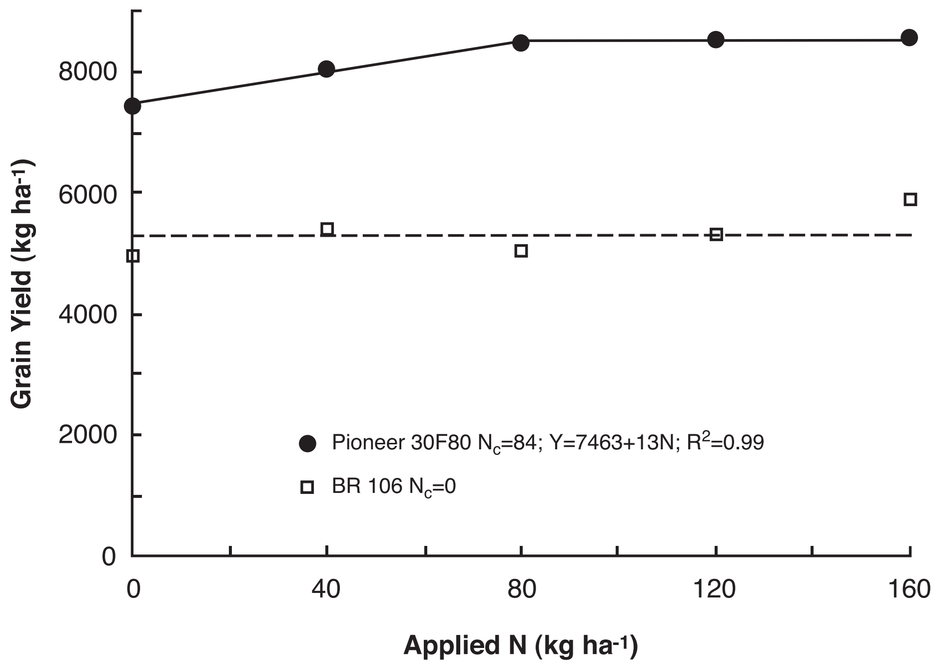


Figure 11. Grain yield for a corn hybrid and variety as a function of fertilizer N applied to a clayey Oxisol at Paragominas, Pará, Brazil.

Mehlich-1 soil P critical level of 13 mg/kg. The soil's Mehlich-1 P buffer coefficient was previously reported to have a value of 0.82.

Potassium deficiency occurs frequently on these sandy soils. The critical soil K level for cowpea, based on seven site-years of K fertilization trials, is 26 mg/kg. These field trials also suggest that K fertilization required for the preceding corn crop may not provide adequate K for the succeeding cowpea crop.

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

Field Testing the NuMaSS Data Base Editor Module

During visits to collaborator sites this past year, we have tested the Data Base Editor Module by adding to NuMaSS soils data for their trials sites, and soil and crop N coefficients which their trials have produced for locally-used crop varieties. In some cases we have also added new commercial fertilizer formulations and nutrient analysis for locally-available chicken litter and animal manures.

User reactions to this ability to customize the software's database with their local information have been very good. It minimizes their need to store region-specific information in separate documents, as well as the repetitive task of data input each time they run the software. Data customization and confidence in the software's recommendations for Diagnosis and Prediction has enable users to make better use of the powerful Economics module. Users are beginning to appreciate the importance of selecting appropriate mixtures or blends of fertilizers available in their local markets, as well as considerations of various "what if" scenarios in terms of constraints on available cash to purchase fertilizers or available sources of commercial and organic nutrients.

Based on user feedback, we have added additional soil and crop variables to the Data Base Editor Module and perfected steps to be taken for deletion of an undesirable data record. Several user-selectable options for software retrieval of data table values were added to ensure that software performance by users with crop variety-specific information did not compromise NuMaSS use by novice users who depend entirely on the default values originally present in the data tables.

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

Field Tests of NuMaSS Fertilizer Recommendations by NGOs in Honduras

Five of seven corn field trials comparing NuMaSS recommendations to local farmer practices were followed to completion this year. This outreach program involved the CIAT-MIS consortia providing technical assistance to seven different NGOs involved in an FAO-sponsored seed production project for subsistence agriculture. Each trial site was located in a different farm community throughout Honduras. NuMaSS recommendations were based on a preliminary soil analysis for each site and, when available, information from NGO collaborators on cropping history and targeted corn yield.

For the harvested sites, yields with NuMaSS recommendations were similar or superior to those with local farmer practices (Table 11). Results also show that fertilization, even among subsistence farmers, is a common practice. The two most frequently used fertilizers are 12-24-12 and 18-46-0. Native soil K levels, however, were adequate for all sites and NuMaSS recommendations for several of the sites indicate adequate P availability.

As noted in the report that follows on the workshop, NGO and FAO collaborators were pleased with the NuMaSS sensitivity to site-specific soil conditions and farmers' targeted yields. Consequently, they have decided to expand the field trials next year to a greater number of farming communities, with NGOs and farmers cost-sharing the initial soil test analyses of all sites.

NuMaSS Workshop in Honduras/ Nicaragua

The annual planning meeting with CIAT-MIS collaborators participating in the N fertilization trials for corn in Honduras and Nicaragua, held this year at Siguatepeque-Honduras, was expanded into a joint three-day workshop with NGO participants in the FAO project for subsistence farmers in Honduras. One full day was devoted to hands-on training with the NuMaSS software, wherein participants used soil tests, yields and economics data from field trials at each of their locations. A total of 23 participants attended the workshop: thirteen from the CIAT-MIS N trial network, nine from NGOs and one representative from the region's major fertilizer distribution company (FENORSA). The importance of repeated training events on NuMaSS, to overcome changes in collaborating personnel, can be illustrated by the fact that only one of the 20 CIAT-MIS participants trained in the initial workshop of 2002 attended this second workshop.

Table 11. Targeted and achieved corn yields with NuMaSS N and P recommendations and local farmer practices in NGO trials throughout Honduras in 2005.

NGO	Site	Department	Target Yield	NuMaSS N	NuMaSS P	NuMaSS Yield	Local Practice N	Local Practice P	Local Practice Yield
			kg/ha						
CISP	Tocoa	Colon	6490	220	13	[a]	97	7	[a]
V. Mund.	Cuchilla	S. Barbara	3894	56	15	1362	0	0	951
CCD	Flores	S. Barbara	4543	145	21	[b]	?	?	[b]
G. Guia	Guinope	El Paraiso	4543	136	4	577	0	0	495
MOVIMUNDO	Alauca	El Paraiso	3245	107	0	[b]	8	7	[b]
ICADE	Limones	El Paraiso	3894	113	0	4540	82	26	4824
MOVIMUNDO	Canciras	Ocotepeque	4543	175	0	3959	82	26	4543

[a] Damaged by Hurricane Wilma
[b] No crop harvest

The CIAT-MIS collaborators tested the outcomes of NuMaSS predictions and recommendations after entering their soil and maize varietal N coefficients to the software database via and interim version with the Data Base Editor Module. The NGO collaborators benefited from exposure to the field trials generating varietal N coefficients because they use the same varieties in their work with subsistence farmer communities.

Considerable discussion focused on the Economic evaluations of the fertilizer N and P recommendations. Several situations were encountered where fertilizers with K were being used on soils with ample native K or P fertilizers on soils with adequate P. Even under conditions where both N and P are needed, the use of locally available N-P-K mixtures often led to excess applications of fertilizer P when trying to meet the crops N requirements. In such cases, collaborators were enthused to learn that the NuMaSS Economics module adjusted recommendations to avoid excess P when fertilizers with only N were added to the pool of available nutrient sources.

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 Investigators:
John M. Antle, Montana State University
Jetse Stoorvogel, Wageningen University and Research Center

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 WUR and 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 (Landbouw Economisch Institute/Wageningen University Research Center).

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.

Project Year 9

- A one and a half day training workshop on carbon modeling and TOA was held in Accra, Ghana, in February 2006, in collaboration with the UF carbon project. An Excel-based minimum data carbon model and an Excel-based minimum-data economic model were developed and used in the workshop.
- Using the material from the Ghana workshop, a one-day workshop was held in May 2006 at ISRA in Senegal with the Bureau of Economic Analysis (BAME) and the National Laboratory for Agricultural Production (LNRPV).
- A one-day workshop on payments for ecosystem services was held in Pallisa, Uganda, as part of the collaborative project between Makerere University and the TOA project, funded by the Food and Agricultural Organization (FAO).
- A proposal was prepared in collaboration with Makerere University for funding by the Association for Strengthening Agricultural Research in Eastern and Central Africa. The title of the proposal is, "Adapting Payments for Environmental Services for Wetlands Management in Africa."

- A funding proposal is being prepared for FAO to support analysis of PES in the Panama canal zone watershed.
- Collaboration continued with the KARI and ICRAF to support their project on carbon sequestration in Western Kenya.

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 biophysical 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.

Project Year 9

- A preliminary version of the market equilibrium TOA software was developed.
- Minimum-data models were further refined and made available on the project web site.
- A version of the TOA software with feedbacks from economic decisions to soil productivity was implemented and tested.
- Climate change analysis was completed and is being written up.

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.

Project Year 9

A graduate course on TOA modeling was developed and presented Spring Quarter 2006 at UC Davis. The course materials are available on-line at www.tradeoffs.montana.edu/are290.htm.

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

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

Healthy Seedling Production for Rice and Vegetables

Partner Training and Technology Transfer

The Healthy Seedling Technology (HST) continues to be transferred for rice and vegetables through existing partnerships in Bangladesh with Rangpur-Dinajpur Rural Development Service (RDRS), East West Seeds, Inc. and Department of Agriculture Extension (DAE). Although we have tried not to take on new partners at this stage of the project, two small Bangladesh NGOs, DIPSHIKA and ZIBIKA, specifically requested training to address their clients' needs for improved seedling production and homestead gardening. In Nepal, training and technical support were expanded with current partners Educate the Children (ETC), CARE, Winrock SIMI and Morang District Agricultural Development Office (DADO). Overall during PY9, 350 farmers were trained directly by the project in farmers field schools (FFS) or small farmer groups, while 227 trainers, agricultural officers or farmer promoters working with NGO partners were educated about the Healthy Seedlings technology in hands on field trainings. Over half of the training participants (55 percent) were women.

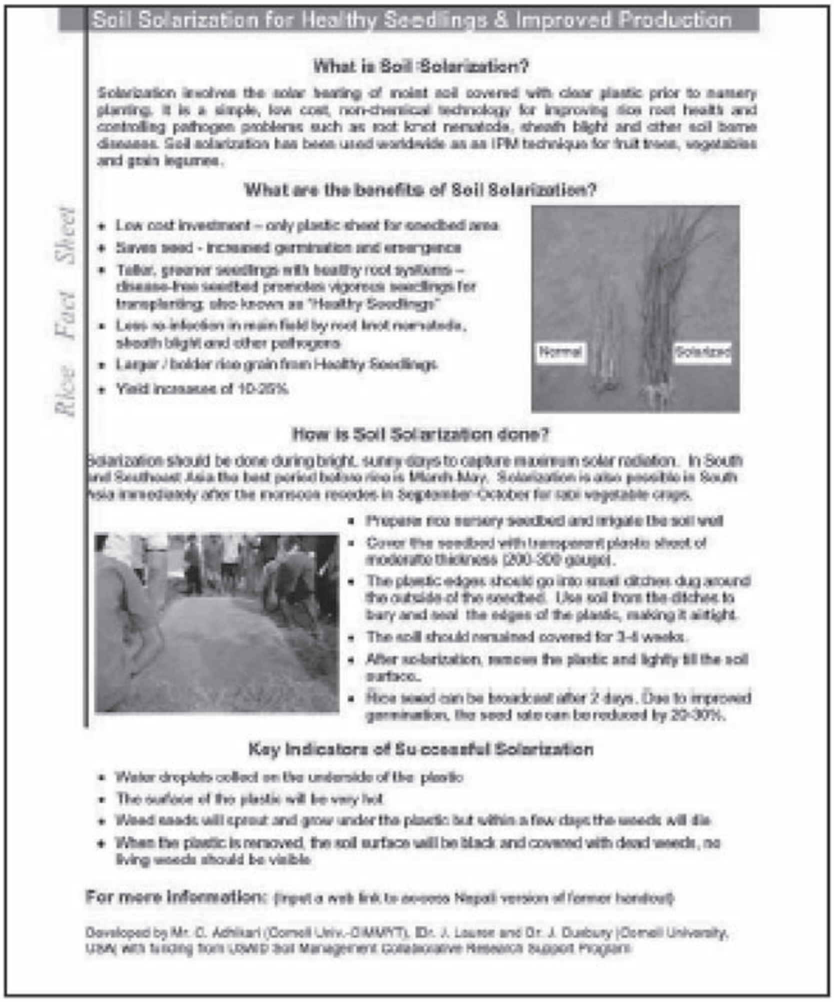
A fact sheet on HST was developed at the request of the IRRI Nepal representative to be included in the country section of the Rice Knowledge Bank (Figure 12). A similar fact sheet was also submitted for inclusion in the Bangladesh Rice Knowledge Bank. Fact sheets target extension workers and literate farmers, providing a brief description of the benefits, methods and indicators of a technology and are available on the Web. For the Healthy Seedling watermelons, Pazirul obtained 50 fruits/decimel but only 30 fruits/decimel from the normal seedlings. In addition fruit weights from Healthy Seedlings averaged 67 percent more than those from normal seedlings.

Impacts and Applications

The impacts of Healthy Seedlings for both rice and vegetables continue to be quite positive at our new sites. Data collected during 2005-06 in terms of seedling color, plant height, root health, numbers of nematode galls, yield and fruit production are consistent with what we have observed in previous years.

While HST is most commonly used for rice, tomato, eggplant, cabbage and cauliflower, chili, onion, bottle and bitter gourd; a few new applications have been observed:

- In Nepal, four of the farmers participating with the ETC group utilized Healthy Seedlings to produce flowers for the highly lucrative and growing Kathmandu city flower market. Several producers observed larger, healthier seedlings produced more flowers per plant. Impressive increases in sales were also noted. One farmer increased her income from Rs 8,000 last year to Rs 18,000 from the same area. Another ETC client increased his flower sales by 36 percent with HST.
- Bangladeshi farmers who learned about Healthy Seedlings through RDRS farmer field schools and DAE applied the technology to improve production of tobacco, garlic and hybrid boro rice. Assuring survival and early vigor of hybrid rice seedlings with solarization provides additional benefit given that the price of hybrid rice seed is roughly 8x normal rice seed. Likewise for garlic, high market prices and low production present an incentive to use HST for this crop.
- Pazirul, a RDRS farmer from Thakurgaon district in Bangladesh, solarized soil in September, put the solarized soil in plastic bags and grew hybrid watermelon (seed price Taka 180-220/10g). Healthy Seedlings exhibited 5 percent mortality versus 20-25 percent for normal seedlings, and a doubling of seedling height. Once transplanted



Soil Solarization for Healthy Seedlings & Improved Production

Rice Fact Sheet

What is Soil Solarization?

Solarization involves the solar heating of moist soil covered with clear plastic prior to nursery planting. It is a simple, low cost, non-chemical technology for improving rice root health and controlling pathogen problems such as root knot nematode, sheath blight and other soil borne diseases. Soil solarization has been used worldwide as an IPM technique for fruit trees, vegetables and grain legumes.

What are the benefits of Soil Solarization?

- Low cost investment – only plastic sheet for seedbed area
- Saves seed - increased germination and emergence
- Taller, greener seedlings with healthy root systems – disease-free seedbed promotes vigorous seedlings for transplanting; also known as "Healthy Seedlings"
- Less re-infection in main field by root knot nematode, sheath blight and other pathogens
- Larger / bolder rice grain from Healthy Seedlings
- Yield increases of 10-25%

How is Soil Solarization done?

Solarization should be done during bright, sunny days to capture maximum solar radiation. In South and Southeast Asia the best period before rice is March-May. Solarization is also possible in South Asia immediately after the monsoon recedes in September-October for rabi vegetable crops.

- Prepare rice nursery seedbed and irrigate the soil well
- Cover the seedbed with transparent plastic sheet of moderate thickness (200-300 gauge).
- The plastic edges should go into small ditches dug around the outside of the seedbed. Use soil from the ditches to bury and seal the edges of the plastic, making it airtight.
- The soil should remained covered for 3-6 weeks.
- After solarization, remove the plastic and lightly till the soil surface.
- Rice seed can be broadcast after 2 days. Due to improved germination, the seed rate can be reduced by 20-30%.

Key Indicators of Successful Solarization

- Water droplets collect on the underside of the plastic
- The surface of the plastic will be very hot
- Weed seeds will sprout and grow under the plastic but within a few days the weeds will die
- When the plastic is removed, the soil surface will be black and covered with dead weeds, no living weeds should be visible

For more information: (Input a web link to access Nepali version of farmer handout)

Developed by Mr. D. Adhikari (Cornell Univ.-CIMMYT), Dr. J. Lauren and Dr. J. Duxbury (Cornell University, USA) with funding from USAID Soil Management Collaborative Research Support Program

Figure 12. Healthy Seedlings fact sheet for Rice Knowledge Bank.

Healthy Seedling watermelon developed greater ground cover than normal seedlings along with larger fruit size and number. More culling of small fruit was necessary for the normal seedling watermelon (e.g., more labor). The cost of solarization for this farmer was only one percent of his total input costs—Taka 40 for 3 x 5 ft plastic versus Taka 40,000 for seed, fertilizer and irrigation. For the Healthy Seedling watermelons, Pazirul obtained 50 fruits/decimel but only 30 fruits/decimel from the normal seedlings. In addition fruit weights from Healthy Seedlings averaged 67 percent more than those from normal seedlings.

We have also worked to expand use of HST in the commercial sector:

- DAE personnel identified a group of commercial seedling farmers from Khansama, Bangladesh as a good target group for HST. They produce vegetable seedlings 10 months out of 12 for sale in weekly "haat bazaars" which serve rural communities in Dinajpur district. Twelve farmers out of a group of 20 who received hands-on-training utilized the technology on their land for tomato, eggplant, chili, cabbage and cauliflower seedlings. Farmers noticed increased germination, fewer weeds and greener/taller seedlings compared to normal seedlings. Differences in market prices are detailed in Table 12. With these initial benefits, producers predicted they could increase their incomes by 2-4 times and were willing to double solarized nursery areas.
- There are insufficient quantities of quality vegetable seed in Bangladesh to supply farmer needs. While solarization clearly has beneficial effects on vegetable fruit yields, we expect it also will be helpful for increasing vegetable seed production along with improved quality.

- Ten East-West Seed, Inc. contract seed growers were given Healthy Seedlings training to trial for seed production and quality in 2005-06 for eggplant, tomato, onion and chili. Results so far confirm our hypothesis. Tomato seed yields from HST averaged 552 g/decimal versus 422 g/decimal from normal seedlings. Mean eggplant seed yields were 735 g/decimal from Healthy Seedlings and 616 g/decimal from normal seedlings. Yield of onion bulbs, which will be planted next year for seed, also increased by 15 percent using HST. While seed extraction for chili is still ongoing, we expect a similar pattern to tomato, eggplant and onion in terms of seed yield. Dramatic differences in plant growth were evident for chili. Healthy Seedling chili plants were twice as big as normal plants and with considerable more branching and fruits per plant. Quality analyses between Healthy and normal seedlings will be compared once all the seeds are extracted.

Technology Adoption Studies

Three surveys were conducted during the project year to assess adoption of Healthy Seedlings for rice and vegetables by CARE client farmers. CARE has been a major technology transfer partner with us since 2003 teaching farmers about HST through farmer field schools (FFS) in Northwest Bangladesh and the eastern Terai of Nepal.

Survey 1

1) The CARE Nepal Churia Watershed Management Program (CWMP), which will end in June 2006, focuses in the Sarlahi and Mahottari districts. The project's goal is to improve livelihoods of 25,600 households in degraded forest-agricultural boundary areas through sustainable natural resource management and improved agricultural production. A survey of 91 FFS participants (63 percent women) and 60 non participants (32 percent women) was undertaken in 2005 to assess adoption and farmer-to-farmer transfer of HST for rice. From the participant group, 42 percent were still practicing HST one year after introduction. The dominant limitation to adoption amongst FFS participants was the unavailability of quality plastic in the input shops. While 40 percent of the respondents purchased more plastic, they found it to be too thin. Nevertheless yields from HST using the thinner plastic were on average 19 percent higher than yields from normal seedlings.

Farmer-to-farmer transfer of HST knowledge appeared positive, as 65 percent of the nonparticipant respondents were aware of HST. Of these, 26 percent adopted the technology using thinner plastic purchased at the local market. Of those who did not adopt, 44 percent were constrained by availability of quality plastic.

2) Two additional surveys were carried out within the CARE Bangladesh Rural Livelihoods Programme (RLP) command area where HST had been introduced. The RLP, which ended in March 2006, was composed of Go Interfish (GO-IF) and Shabge projects. GO-IF focused on rice-fish production with male and female farmers, while

Table 12. Comparison of market prices obtained by Khansama commercial vegetable seedling producers for Healthy and Normal seedlings.

Farmer	Vegetable	Healthy Seedling	Normal Seedling	Change
Khansama, Bangladesh		Taka/100 seedlings		
Mafiz	Tomato	12	8	50%
Mostofa		10	8	25%
Mobar Ali		15	12	25%
Vutto	Eggplant	6	4	50%
Faiz Uddin		8	5	60%
Latif		10	6	67%
Mokhter Ali		6	4	50%
Samsul Alam	Chili	6	4	50%
Joynal Abedin		5	4	25%
Samsul Islam		8	5	60%
Jalil	Cabbage	15	10	50%
Mojahar	Cauliflower	15	8	88%

Shabge worked primarily with women to increase homestead vegetable production. These projects had the goal of improving the livelihoods of men and women in 221,375 poor and vulnerable households in Bangladesh.

Survey 2

A combination of Focus Group Discussions (FGD) and individual interviews were used to obtain information on HST adoption and economic impact at 11 GO-IF and 9 Shabge FFS, which represent 10 percent and 14 percent, respectively, of the FFS where HST was initially introduced. A total of 267 people participated in FGD across five districts of Northwest Bangladesh. Semi-structured questionnaires were used by two facilitators to assess how many FFS members and non members had adopted HST in 2003, 2004 and 2005. Participants' perceptions by year were tallied according to well being status (extremely poor, poor, middle, non poor) and gender. A subset of FGD participants was selected for individual economic surveys to compare costs, production, income and net income from rice or vegetables produced by using HST versus conventional practice.

Averaged over the three years, adoption was higher in the Shabge FFS (34 percent) compared to GO-IF (13 percent). Overall adoption by both groups followed a similar pattern with maximum adoption in 2004 following introduction and then dropping off in 2005 (Figure 13).

While overall adoption of HST for rice by GO-IF FFS members was low, the adoption pattern by individual FFS over the three-year period was quite variable. Three FFS reported consistent and substantial adoption rates of 36 to 58 percent, 59 to 48 percent and 16 to 40 percent through 2005. The eight remaining FFS did not adopt the technology in 2005, but four FFS had adopted the technology in 2004 at levels of 10-40 percent.

The adoption pattern by individual Shabge FFS also was variable over the three-year period. Three of the nine Shabge FFS were still practicing HST in 2005 at high rates ranging from 45 to 80 percent while two schools reported adoption rates in 2005 at only 9-16 percent. Four of the nine Shabge FFS did not adopt HST in 2005, but in 2004 had adoption rates ranging from 16 to 63 percent of FFS members.

Thus we conclude that HST for rice was sustained in only 27 percent of the GO-IF FFS surveyed. On the other hand 55 percent of the surveyed Shabge FFS were continuing to practice HST for vegetables at moderate to high rates. Sustained adoption of HST for rice or vegetables did not appear to be restricted to specific districts but was found in all surveyed districts but one. Unfortunately specific causes for disadoption were not elucidated by the survey. A majority of the FGD responses mention no problems with the solarization technology. The cost of the plastic and fencing were reported as problems by 24 percent and 20 percent of FGD, respectively; while lack of knowledge about using HST with other crops was also mentioned (4 percent). Comments about the plastic and fencing costs were made by both adopters and non adopters, so it does not appear that these problems were critical determinants of disadoption.

Individual economic survey results revealed that the costs of HST for rice on average were 17 percent less than conventional practice. This unexpected difference was associated with pesticides, which is consistent with farmers telling us that they applied less pesticide with HST for rice. Survey respondents reported that mean yield increases with HST were 60 percent higher than conventional. As a result, net income (assuming all rice was sold) was on average 1.9 times greater with HST than normal practice. In fact, 77 percent of the surveyed farmers used their rice production for home consumption and only 23 percent was sold.

Mean costs associated with cole crop production were 3 percent higher with HST than normal practice, whereas tomato production costs with HST were on average 27 percent greater than conventional costs. The difference between the crops is primarily due to efficiencies associated with greater acreages in cole crops. These analyses did not consider seed savings associated with HST, which could be significant, especially with hybrids. Despite higher seedling production costs, the net income for HST tomato and cole crops was 1.7 and 2.1 times higher than normal seedlings, respectively. Unlike rice, vegetable farmers sold 89 percent of their cole crops and 73 percent of their tomatoes.

Survey 3

This survey was conducted in collaboration with RDRS and CARE Bangladesh. The RDRS Farmer-Student Participatory Research Program supported the thesis research of a MS student from Bangladesh Agricultural University to do a localized evaluation of farmer-to-farmer transfer of HST

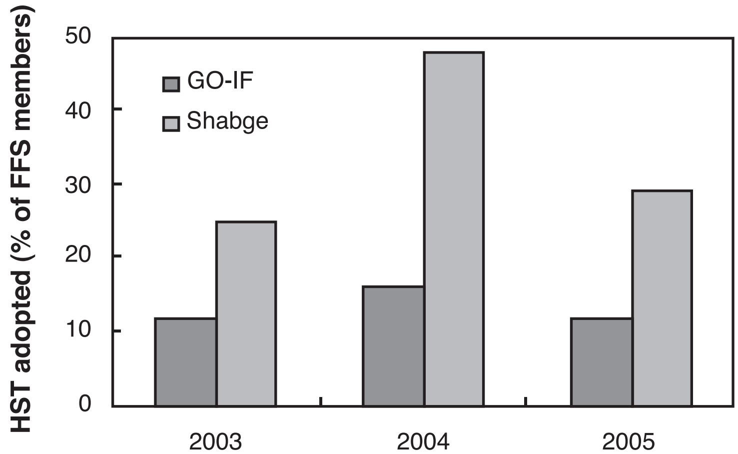


Figure 13. Comparison of HST adoption by participants in GO-IF and Shabge FFS, 2003-2005.

to non FFS participants in a CARE Bangladesh GO-IF command area. A structured instrument was utilized to survey 66 former FFS participants and 30 non participants in Taragonj upazilla, Rangpur and Chirirbandar upazilla, Dinajpur. FFS respondents to this survey represented 23 percent and 18 percent of the FFS participants in the Taragonj and Chirirbandar areas, respectively.

Farmer-to-farmer transfer from FFS participants to non participants (secondary extension) was also spatially variable. In Taragonj, 89 percent of FFS respondents extended the technology to others, but only 50 percent of FFS participants in the Chirirbandar area shared HST. HST sharing by non participants (tertiary extension) was also greater in Taragonj than Chirirbandar. Family gender distribution, respondent age or education do not explain these differences between Taragonj and Chirirbandar groups. However slightly higher wellbeing status, total income and farm sizes in Chirirbandar may have contributed to different farmer-to-farmer transfer patterns.

Extension of HST to Rice in NE Thailand

A collaboration was initiated in PY9 with Mahasarakham University and Thailand Ministry of Agriculture Rice Research Centers at Chum Phae and Ubon Ratchathani to assess the role of HST and micronutrient enriched seed for improving transplanted and directed seeded rice production in drought prone Northeast Thailand. In addition an assessment of the extent of rice root health problems in the Northeast region was also accomplished.

Field demonstrations comparing HST and normal nursery practice were set up on 10 farms across Khon Kaen, Mahasarakham and Ubon Ratchantani provinces. Responses to HST in terms of seedling growth, color and main field performance were similar to our results in Nepal and Bangladesh. Healthy seedling yields were generally higher than normal practice varying from 17-20 percent over conventional practice. At one site in Khon Kaen, yield with HST was 70 percent higher than normal.

Rice nurseries across Northeast Thailand were surveyed for root knot nematode galls and root disease. Ten seedling samples were collected from each of 120 sites. Seedbed type, rice variety, soil texture, shoot length, root length, seedling age, gall numbers and root ratings (according to 1-9 scale) were recorded. Site locations were geo-referenced for mapping purposes.

Nematode gall numbers were quite variable, ranging from 0 to 411 counts/10 seedlings. Figure 14 displays the distribution of gall counts across the survey area. As we observed in Bangladesh and Nepal (PY8), Thai locations with high gall counts were most often associated with sandy soils. The survey results also indicated that the rice variety RD6 (glutinous type) was more effected by root knot nematode than other varieties such as KDML (jasmine type). The spatial results from this survey will be used to target areas for further trials with HST and micronutrient enriched rice seed.

More Thai farmers are moving towards direct seeded rice to save on costs. Micronutrient enriched seed can be used to enhance seedling emergence and to increase resistance to root infections from soil-borne pathogens for direct seeded rice. Healthier root systems also increase the capacity of the plant to acquire nutrients and water from the soil. We worked with scientists at Khon Kaen to enrich rice with micronutrients Mn, Cu and Zn by soil and foliar spray as an alternative to HST for direct seeding. Unfortunately a blast infection affected yields and micronutrient contents in the grain with our first effort. A new trial was set up for the 2006 wet season.

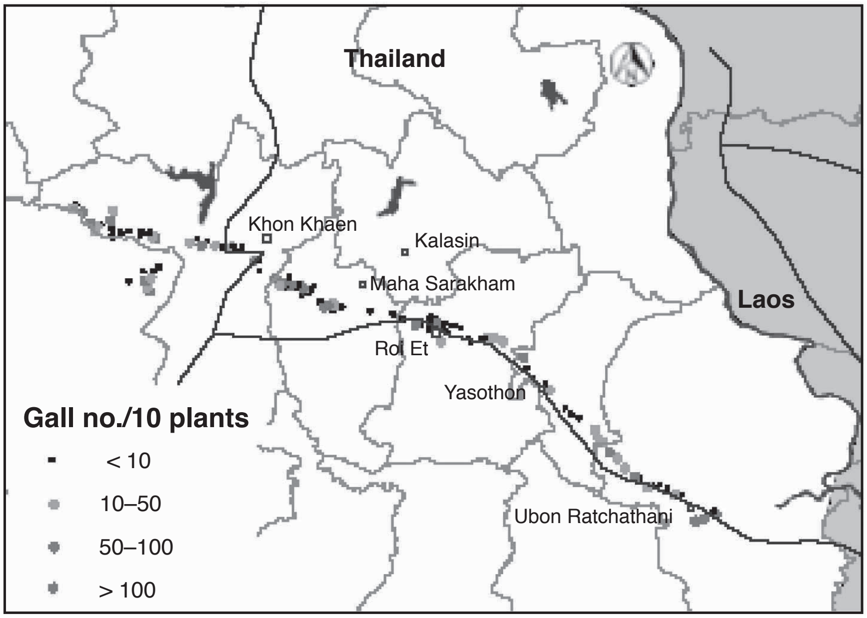


Figure 14. Nematode gall survey results from nursery rice seedlings in NE Thailand, wet season 2005.

Micronutrient Seed Enrichment

Farmer Micronutrient Trials

Farmer trials with micronutrient addition to soil for generation of micronutrient enriched seed of rice and wheat, and subsequent evaluation of micronutrient enriched seed performance, continued in PY9 (Table 13).

Table 13. Impact of micronutrient enriched seed on crop yields in farmer trials in 2005-06.

Crop (number of trials)	Crop Yield (t/ha) Control No MN[1]	MN to Soil	MN Enriched Seed
Wheat (10)	1.52	2.10	2.23
Rice			
All (14)	3.79	4.10	
Seed comparisons			
Fmr. seed (4)	3.55	3.78	3.70
WRC seed (4)	3.62	4.02	4.05

[1]Micronutrients added were Zn, Cu, Mo and B

Wheat yields were very low (0.2-0.3 t/ha) without micronutrients at two sites, most likely due to B deficiency. This was corrected either by soil application of B or with micronutrient enriched seed. Rice yields showed a small increase in yield (8 percent) with micronutrient additions to soil. Farmer generated enriched rice seed, which is only enriched in Mo and possibly B gave a very small yield benefit (4 percent), while that from the research station, which is enriched in all four elements showed a greater benefit (12 percent).

Seed Enrichment Methods for Zn

Zinc is the key micronutrient with which to enrich seed for both increased productivity (overcoming Zn deficiency and increasing resistance to biotic pressures) and human health. Soil application of Zn successfully increased Zn content of wheat but not rice in both research experiments and farmer trials. Multiple foliar applications of Zn can increase rice grain content 2.5X but are not practical for farmers. In PY 9 we evaluated different fertilization strategies to increase Zn in rice grain through both greenhouse (Ithaca) and field experiments (Bangladesh). So far we have not found a simple way to enrich Zn in rice grain, although several treatments enrich the straw of rice. Field and greenhouse results were similar. Field results were:

- Addition of 10 kg Zn/ha to soil (double the normal pre-plant soil application rate) gave mean grain Zn concentration of 25.1 and 24.1 mg/kg for plus Zn and no Zn treatments, respectively (n=14). However, straw Zn increased from a mean of 74 to 102 mg/kg
- Addition of Zn to floodwater in addition to soil (pre-plant) had only a small effect on grain Zn but increased straw Zn, with application at flowering

having the greatest effect (n=4) (Table 14).

- Addition of Zn to soil where rice was grown in a more aerobic environment on a raised bed also had little effect on Zn in rice grain but a large effect on straw Zn, especially when applied at flowering (n=1) (Table 15).

Ongoing experiments in the greenhouse are evaluating the effects of foliar application at flowering, foliar application to flag leaf during grain filling, growing rice aerobically and various drainage regimes.

Permanent Bed Planting

Initial Farmer Participatory Evaluation (2004-2005)

The study with 26-29 farmers in Durgapur, Santospur and Duary, Bangledesh villages was completed over two cycles of a rice-wheat-mungbean rotation. In the second year farmers were encouraged to change from mungbean if they wished, given the low yields achieved in 2004 (due to late germination caused by lack of rain). This technology adoption exercise introduced the permanent bed technology without altering any other farmer practice. The results were very encouraging with yields of all crops generally increasing when planted on the bed (Table 16), similar to results obtained in our research experiments.

Mungbean is a new, high value crop in the system so we surveyed farmers to determine how they used the 2005 mungbean crop. Averaged over the eight farmers, 89 percent of the crop was sold, 16 percent was consumed (average of 8.5 kg/family, range 6-12 kg/family), and 10 percent was given to relatives. The selling price of Tk 25-26/kg, would give an average gross income (sale of total crop) of Tk 30,750/ha for production on beds and Tk 24,500 for production on the flat.

Table 14. Effect of Zn addition to soil and floodwater on Zn concentration in rice grain and straw.

Treatment	Grain Zn mg/kg	Straw Zn mg/kg
No Zn	24.3	77
Zn to soil (10 kg/ha)	26.0	102
Zn to soil + floodwater at:		
Max tillering (5 kg/ha)	27.3	130
Flowering (5 kg/ha)	27.7	146

Table 15. Effect of Zn addition to soil of raised bed on Zn concentration in rice grain and straw.

Treatment	Grain Zn mg/kg	Straw Zn mg/kg
No Zn	19.1	35
Zn to soil at:		
Max tillering (5 kg/ha)	22.3	59
Flowering (5 kg/ha)	21.4	178

Farmer Assessment of the Permanent Bed Technology

Farmers generally liked the bed technology as it gave higher yields with less seed (~30 percent less) and required less irrigation water due to increased efficiency of moving water over the field. Farmer innovation included development of a simple mechanical weeding tool to facilitate weeding between the beds (Figure 16) and modification of the planter for more reliable seed drop.

Expansion of Technology Transfer

The transfer of bed planting technology was expanded in PY9 despite concerns that the technology is not mature (conclusion from workshop held last year) and that it requires new equipment. The main reasons for the expansion were:

- The Durgapur farmer group wanted to expand use of the technology.

Table 16. Yields of rice, wheat and mungbean in farmer permanent bed trials.

Year	n	Yield (t/ha) Bed	Flat	Increase with bed %	n	Yield (t/ha) Bed	Flat	Increase with bed %	n	Yield (t/ha) Bed	Flat	Increase with bed %
		Wheat				Mungbean				Rice		
2004	26	3.61	3.20	13	23	0.55	0.47	18	23	4.83	4.22	14
2005	29	3.51	3.06	15	8*	1.23	0.98	29	23	4.74	4.59	3

* Of the 26 farmers, 10 grew sesbania green manure; three grew jute (no yield data); one grew maize and had 30 percent yield increase on the bed; and four fallowed the land due to lack of water

Figure 16. Farmer-designed weeding tool for furrow area of beds.

- An organization of 22 farmer community groups exists in the area. The farmer groups are former CARE FFS (a goal of that program had been to make the FFS groups sustainable) and they meet monthly to share experiences and ideas.
- The expansion will allow us to evaluate farmer-to-farmer transfer of technology through the farmer community groups, which could potentially be scaled up across the country.

Results from Durgapur

A constraint to expansion within the original farmer groups was the lack of a suitable power tiller (Dongfeng) and their lack of access to a loan to finance the purchase of such equipment. Accordingly we agreed to provide an interest free loan to the Durgapur farmer group of ~$1,000 with repayment over one year. We used a contract format developed by CIMMYT for similar equipment purchase. The group purchased the equipment in October, 2005. The group expanded bed planting of wheat in their village from 24 farmers to 115 farmers on a total of 68.5 acres. An additional six farmers in Nandigram and six in Santospur villages also participated bringing the totals to 127 farmers and 74 acres.

The yield of wheat in 2006 averaged 3.44 t/ha for the 127 farms. Six of the farmers had a comparison with conventional practice where the average yield was 2.73 t/ha. Several farmers commented to us that yields with conventional practice would have been very low because of no rain during the entire crop period and limited access to irrigation water (many shallow tube wells went dry) in this season. The national average yield for wheat in Bangladesh over the last 5 years (2001-2005) was 2.15 t/ha (range 1.95-2.47 t/ha).

An economic survey of 30 farmers following wheat production in 2006 (Table 17) showed that while the cost for individual operations often shifted, total production costs were similar for bed and conventional practice in this initial crop. Notable changes were the higher land preparation and weeding costs but lower seed and irrigation costs with beds. Land preparation costs with permanent beds would be similar or less than conventional practice in subsequent crops. Irrigation cost is less with the beds because of higher irrigation efficiency (less time and water).

Except for the six farmers' wheat production mentioned above, yields were compared with farmer yields from the previous year because the farmers did not have conventional production for comparison. On this basis, yields were 60 percent higher on beds and all farmers commented that yields on the beds were better than they usually experienced. The disposition of wheat was 16 percent for home consumption; 21 percent sold; 39 percent for own seed use; and 16 percent to sell for seed. The expected price for seed was Tk 20-22kg/kg compared to Tk 15/kg obtained at harvest. The district extension officer told us that he planned to buy all of the seed from beds for use in his seed multiplication program. He felt that the seed from the beds was better than that from conventional production.

Transfer to Other Farmer Groups

The following activities were organized, mostly by the Durgapur farmer group, to promote technology transfer to other farmer community groups:

- Held a farmer rally on February 12 with the purpose of illustrating the bed planting technology to the twenty two other farmer community groups in the area and to bankers (who might be willing to provide equipment loans). The Janata, Sonali, NCC and Rajshahi Krishi Unoyan bank sent representatives. Several reporters attended the rally and television channel 'i' produced and later aired a 25 min. video of the technology (we later showed this in meetings with farmer groups).
- Organized hands-on trainings in the technology (April 12 and 13) for the farmer community groups who expressed interest in trying the technology (Table 18).
- Held individual meetings (April 23-26) with 10 farmer groups in Durgapur upazilla to assess their interest in and ability to use the bed planting technology (Table 18). The discussions with individual groups revealed that they had different levels of organization, leadership and participation. The need for power tiller and bed former equipment was the major constraint to adoption of the technology. Farmers in this area have the SaiFeng power tiller, which is a lighter version of the DongFeng tiller and cannot use the bed former/planter attachment. Of the ten groups, two indicated that they could/would purchase the equipment from their own funds, four would consider applying for a loan either as a group or individuals within the group, two were inclined to try and rent from the Durgapur group. The other two were probably not yet ready to try the technology. The equipment training and the lead role of the Durgapur farmers in transferring knowledge were observed to be key factors in the positive reception to the technology.
- Subsequent discussions with the bankers about their willingness to provide loans had mixed results. The banks do not usually grant loans to groups and they require land titles as collateral. However, farmers in the community groups are generally young, land titles are held by their parents and it is culturally unacceptable for the young farmers to ask their parents to provide land titles. Only the Rajshahi Krishi Unoyan bank agreed that it would consider loan requests from farmer community groups. Six of the farmer groups plan on making loan requests. We will also approach the Grameen Bank as their philosophy for giving loans seems to be a better fit with the situation.

Table 17. Economic survey for 2006 wheat crop.

Factor	Bed	Flat	Change
Cropped Area (bigha)[1]	54	16.4	
Land Prep. -Tillage (Tk/bigha) -	362	360	35%
Bed prep. (Tk/bigha)	123	0	
Seed Cost (Tk/bigha)	350	440	-20%
Fertilizer & Pesticides (Tk/bigha)	517	605	-15%
Irrigation No	2.1	2.2	
Irrigation Cost (Tk/bigha)	231	381	-39%
Weeding Cost (Tk/bigha)	98	9	
Harvest Cost (Tk/bigha)	259	259	
Threshing Cost (Tk/bigha)	129	94	
Total Costs	**2,070**	**2,148**	**-4%**
Yield (kg/bigha)	399	249	60%
Total Value @ Tk15/kg (kg/bigha)	**5,985**	**3,735**	**60%**
Net Return	**3,915**	**1,587**	**2.4X**

[1] 3 bigha = 1 acre; 7.41 bigha = 1 ha

In order to promote the granting of loans we analyzed the maximum possible use of the power tiller/bed former-planter combination over the course of a year for permanent beds and the income generating activities that enabled the Durgapur group to pay back the loan for the DongFeng power tiller.

Earned income from the power tiller after 6 or 7 months was ~ Tk 50,000 (70 percent from general tillage—40 percent wheat, 24 percent onion, 6 percent spring rice—and 30 percent from bed forming and planting for wheat on beds). The group was paying back the one-year loan on schedule.

Issues/Questions about Bed Planting Technology

Limited experience with permanent beds indicates that there are some issues that require continuing research. These issues are:

- Direct seeding of rice.
- Use of mulch to protect the soil surface and reduce evaporation of water.
- Nutrient management practices appropriate for a no-tillage system.
- Determination of whether soil texture is a determinant of successful application of the technology.
- Understanding of long-term impact on biotic pressures (weeds, diseases and insects).

In addition to the listed issues, it is clear that permanent beds represent a large management shift and as such the "system" will evolve over time and may do so in ways that are not entirely predictable. It is important, therefore, that research stays connected with and responds to farmer experience and observations for at least five more years. This is necessary if we expect widespread adoption of the technology to occur. Clearly the needs for research, both with regard to the technology and its adoption, will go well beyond the life of the current SM CRSP.

Surface Seeding of Wheat

The Rice-Wheat Consortium published, during PY9, the publication from our surface seeding adoption study in Nepal (*see* Publications in this report), concluding this activity.

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

As part of our collaboration with Doyel Agro Complex Ltd., a farmer field day was held in 2005 at Patgram where ~200 farmers viewed lime rate demonstrations and had discussions about the lime technology with WRC staff. All the participants were eager to use lime and a majority chose the 1 t/ha rate as the most economical. In PY9 a random sampling of 52 farmers who had attended the 2005 field day were surveyed to find out whether they had applied lime for maize and if so, at what rate. Eighty-eight percent of the respondents had applied lime on a total of 72 ha of maize; however, only 8 percent of the farmers applied lime at the 1 t/ha rate, while a majority (73 percent) applied 0.5 t/ha lime and 8 percent used lime at 0.25 t/ha. Doyel and DAE block supervisors had recommended the 0.5 t/ha rate, despite the observations of farmers

Table 18. Farmer groups participating in bed planting training and group discussions**.**

Group	April 12/13 Training Participants	April 23-26 Group Meetings Participants	April 23-26 Group Meetings Gender
Durgapur (3 groups)	71		
Durgapur Jobo Unayon		25	20:80 m/f
GamudorKhali	2		
Namodorkhali		25	male
Nandigram	5		
Nowpara	2		
Raturgram	2	30	male
Santospur	5		
Shabashpur (2 grps)	4	38	female
Shanpukuria	2	28	male
Shaphulgasi	1	25	70:30 m/f
Surzobhag	1	45	male
Tiorquri	3	37	50:50 m/f
Uzalkolshi	2	28	male

and recommendations by WRC soil scientist, Md. Bodruzzaman. Farmers, Doyel and DAE appear to have revised their opinions after subsequent discussions and viewing the substantial residual effect of the 1 t/ha rate relative to the 0.25 and 0.5 t/ha rates.

During PY9, further progress was made towards developing lime requirements for acid Bangladesh soils. This work forms the basis of Md. Bodruzzaman's PhD to be obtained through Bangladesh Agricultural University. Analyses were completed for initial pH, exchangeable bases, exchangeable aluminum, lime incubation pH and SMP buffer pH on soil samples collected from 36 representative sites across Bangladesh for both high and medium high land types.

The analytical results were used to determine lime requirements based on NuMaSS, soil-lime incubation and SMP buffer (van Lierop modification) approaches, using a target pH of 6 for the incubation and SMP approaches. Target aluminum saturation values were not known for Bangladesh maize and wheat varieties, so 10 and 15 percent were chosen for NuMaSS based on the lime responses seen to date in our field trials.

It was our intention to make countrywide maps of lime requirement (by NuMaSS, incubation or SMP) as associated with previously identified acid soil areas with similar pH, texture and mineralogy (*see* SM CRSP PY7 Annual Report). However major discrepancies between our soil sample pH data and SRDI's (Soil Resource Development Institute, Bangladesh) soil pH map were found. While there was good agreement between soil sample pH and soil map classes in the far east and western parts of Bangladesh, substantial areas were consistently lower (eastern northwest, central north) or higher (western central) than the map classes. We plan to resolve these inconsistencies in soil pH before mapping lime requirements according to our representative soil pH-texture-mineralogy areas.

Nevertheless a visual comparison of the three lime requirements for high lands plotted by location (Figure 17) indicates that lime rates of 2-4.5 t/ha were consistently predicted for the western portion of northwest Bangladesh. Similar lime levels were determined for eastern Bangladesh by the soil-lime incubation, but lesser amounts were predicted by SMP buffer and NuMaSS.

NuMaSS determinations of lime requirement for Bangladesh were quite low compared to the other lime requirement approaches at a TAS (crop critical acid saturation) of 10 percent and even less at 15 percent TAS.

Field trials to verify lime requirements for yield were continued across Bangladesh, including field experiments on both high and medium high land

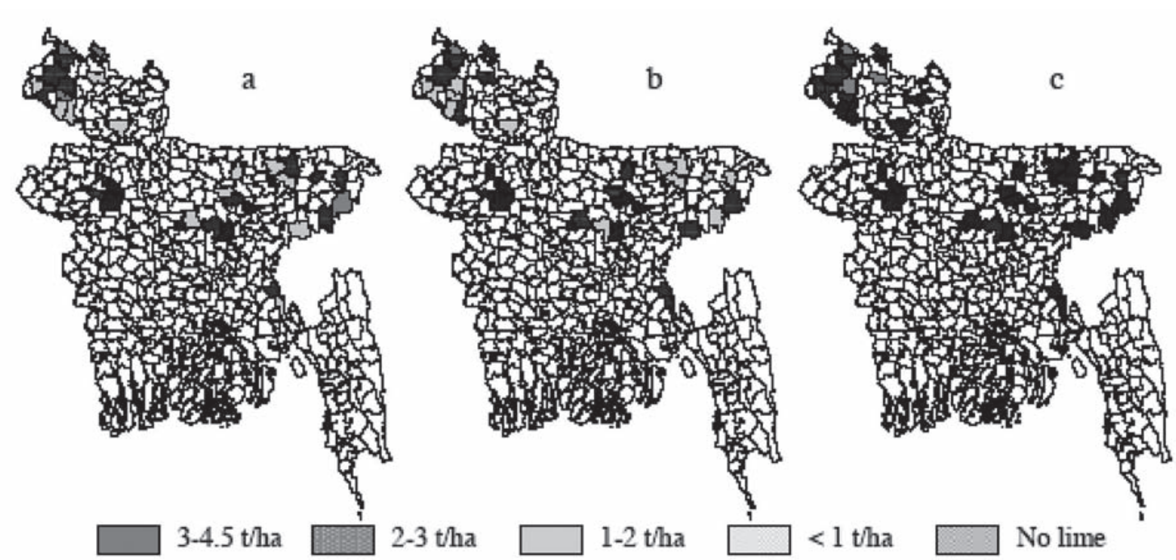


Figure 17. Lime requirement for high lands as determined by (a) soil-lime incubation; (b) SMP buffer and (c) NuMaSS (TAS 10 percent).

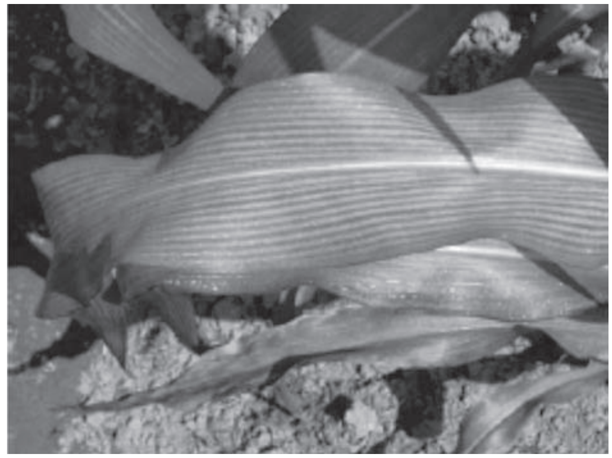


Figure 18. Magnesium (left) and magnesium plus phosphorus (right) deficiency on maize.

types in Panchagar, Lalmonirhat and Dinajpur districts to compare soil-lime incubation, SMP buffer and NuMaSS lime requirements at ten sites for maize and wheat production. In these plots, we found visual evidence of widespread Mg deficiency during flowering and even combined Mg and P deficiency (Figure 18). Yields from these plots are not yet available.

Trials to assess lime residual effects were continued on two farmers fields at Patgram for a third year after applying lime. No reduction in the impact of a single lime addition was evident. Optimum rice and maize yields were still found at the 2 t/ha lime rate on both farms.

Despite some problems with last year's lime trials with the WINROCK BREAD II project (farmers harvested maize and sites with pH.6), trials in Comilla district were continued in 2006 to evaluate residual effects from the applied lime. Relatively small yield responses of 6-13 percent over the unlimed control were found at the 2 t/ha lime rate. New WINROCK trials were also established at Khagrachari and Rangamati districts, where initial soil pH values ranged from 4.38 to 4.99. Maize yield responses to lime were found up to 4 t/ha and ranged from 31-62 percent in Khagrachari and 28-34 percent in Rangamati relative to unlimed controls.

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
John M. Duxbury and Julie G. Lauren, Cornell University

Overview

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.

This 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 achieving them is in the same general 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 in West Africa

Objective 1, Output 1: Integrated Protocol for Measuring the Gains and Losses of Soil C Under Agricultural Systems Incorporating Sampling, Prediction and Remote Sensing Technologies (UH)

Mali

Measuring Soil Organic C

This year, the University of Hawaii group collected a set of 23 samples representing a range of soils and soil environments in Mali for the dissertation study of H. Konaré. Initial studies on loss on ignition were carried out to explore a potential, low technology option of determining soil C in the Sahel. The Loss on Ignition procedure was proposed and a manuscript was prepared. Recently, spectroradiometers have become available that provide options for measuring soil organic C. Figure 19 illustrates an example of initial testing of the instrument on samples already prepared for the traditional analysis. While the instrument appears extremely promising, many details regarding its use remain to be determined. Currently, the LOI method proposed by Konaré appears the most cost-effective and available for developing nations.

Senegal

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 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.

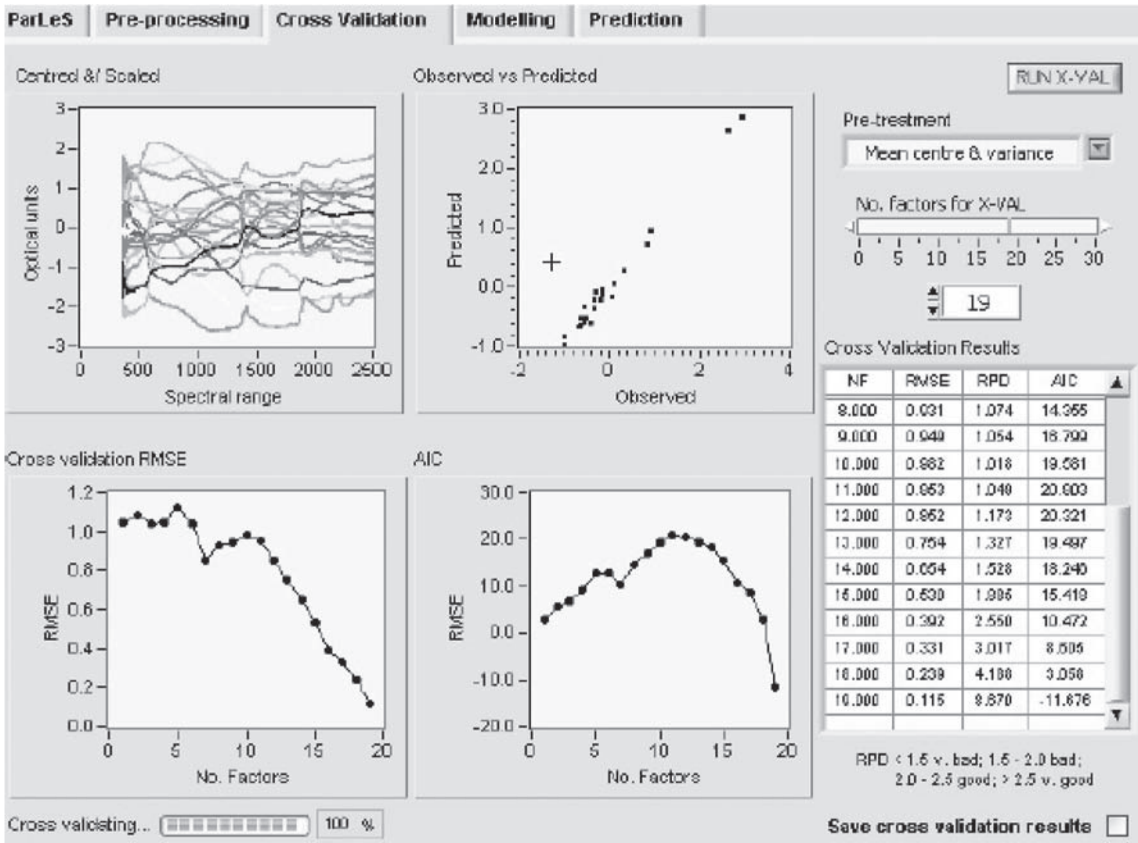


Figure 19. Initial results of use of a VNIR spectroradiometer to measure soil organic C.

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.

Soil Sampling

Table 19. Carbon sequestrated in the upper 20 cm in different types of land use (in t/ha).

Land use	Min. Carbon	Max. Carbon	Average
CCBF no fertilizer, no tillage	8.6	21.0	14.9
CCP organic input, no tillage	18.7	39.1	28.9
CRCPHI fertilizer input, tillage	11.7	17.2	14.9
CRCPLI no fertilizer, no tillage	8.6	23.1	13.7
PFBF undisturbed[1]	12.5	13.9	13.2
PFP undisturbed[2]	18.6	19.5	19.0
PFT undisturbed[3]	24.8	24.8	24.8

[1]hydromorphic soils seasonally water flooded, uncultivated
[2]rocky plateau, uncultivated
[3]terrace, uncultivated

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

The distribution of organic carbon in different land use shows a relatively large variation (Table 19). Highest C content (28.9 t/ha) occurs with organic matter amendment as opposed to lowest C (13.7 t/ha) content when continuous cropping with fertilizer application is practiced.

Objective 1, Output 1: Integrated Protocol for Measuring the Gains and Losses of Soil C Under Agricultural Systems Incorporating Sampling, Prediction and Remote Sensing Technologies (UF)

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. In PY8, we the UF group re-visited that goal and concluded that it was 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.

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.

Development of the EnKF Approach for Combining Measurements and Models

There could be several thousand fields in a carbon sequestration project. The ensemble approach reported later in this report requires many calculations to develop several hundred realizations of each field. These realizations are used 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.

A paper was published describing the use of the Burkina Faso data for modeling changes in soil C over time in the different experiments (Bostick *et al.*, 2006). Notably, we found that much of the soil C in the top 20 cm of soil is rather stable. An estimate of the stable pool of C was between 55 and 60 percent of the initial soil C and that most of the decomposition of soil C occurred in the first five or six years of the 11-year experiment in Burkina Faso. The simple model that was estimated using these data were incorporated into an Extended Kalman Filter (ExKF) and compared with the Ensemble Kalman Filter (EnKF). The ExKF requires mathematical manipulations to create a linear approximation of the non-linear model. The reason is that this produces an analytical solution to the soil C estimation process that requires much less computer time. Although we found that the ExKF is a good approximation to the non-linear estimation problem, the savings in computer time did not compensate for the additional time required by researchers to produce the linear approximation. Thus, we concluded that the EnKF is a more practical method for scaling up soil C estimates over space and time.

Because of the need to estimate soil C sequestration (i.e., the change in soil C during the course of a project), we revised the EnKF to directly estimate soil C sequestration. This approach allows one to incorporate the uncertainty in initial soil C in the filter. The simple model published by Bostick *et al*. (2006) was used to determine the capability of the approach to also include stable and labile pools of soil C that are characteristic of soil C. We showed that the formulation of the EnKF for soil C sequestration provides a more accurate approach than estimation of soil C alone, mainly due to the uncertainty in initial soil C and initial level of soil degradation at the start of a project. A paper is being written on this new work.

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 last year. Two of our cooperators in West Africa (Naab and Traore) attended the TOA workshop held last year in Senegal. We planned a DSSAT training course in Accra, Ghana for this October with a half day devoted to exposing DSSAT users to TOA and to data needed for TOA for linkage with DSSAT. The workshop in October was mostly supported by researchers in the region via the Water Challenge program (ICRISAT and CIAT/TSBF) and AfNet, a network of about 350 members in Sub Saharan Africa.

A simulation analysis of soil C sequestration in the Wa, Ghana area was completed to provide input to the TOA model. Two management options were compared with the traditional maize-peanut production system. The first analyzed changes in production and soil C over 20 years for small N fertilizer additions (20 kg/ha) and retaining about 50 percent of the maize residue in the field and the second option simulated 40 kg/ha of N fertilizer and retaining about 50 percent maize residue in the field. The TOA team analyzed how price of C would affect adoption of these two options, considering yield and price paid for C.

About 28 participants attended the training workshop held in Accra, Ghana in October. The focus of the project was on the DSSAT model that is being used in the project. The purpose of the workshop was to provide researchers in the African Network of Soil Scientists on the use of crop models in soil-related research, in particularly focusing on water and soil fertility. J. Jones and K. Boote from the SM CRSP soil C project were lecturers. J. Stoorvogel from the TOA project also presented the TOA approach for analyzing tradeoffs and potential adoption of practices, such as soil C sequestration practices.

The EEP Review of the TOA and the UF soil C projects were held together in Accra, Ghana in late February and early March, 2006. In addition to the review, the TOA and UF-Soil C projects jointly held a short training program focusing on TOA, DSSAT, and soil C sequestration. There were about 12 participants from Ghana in this workshop in addition to the EEP review panel.

Objective 1, Output 2: Predictive Tools for Evaluating Options for Soil C Sequestration at Both Farm and Cropping System Scales, Including the Role of Livestock on C and Nutrient Balances (UH)

Senegal

Soil and Biomass Carbon under Different Types of Land Use in the Peanut Basin of the Nioro Area in Senegal

The University of Hawaii group wanted to evaluate soil and biomass carbon as related to land use system at the scale of an administrative area using satellite images in the Nioro Department. To do this, the group surveyed and selected farmers' fields from several villages using baseline data (cropping systems, subsequent crops, soil management systems, etc.). This was a follow up from the work described earlier and was based on a sampling design that took into account both biophysical characteristics of the research area, the farming system (cropping system, livestock, etc.) and participation of local smallholders.

Landsat images from 1972, 1985 and 2000 were used to assess the land use/land cover changes. To assess the changes, land use units to be used for the LULC (Land Use Land Change) mapping were identified using the Landsat images. Then we used the main land use system to digitize the images. Finally, the different LUS (Land Use Systems) unit areas within the study zone were determined and soil and biomass sampling were done according to these units.

To determine biomass carbon measurements (tree, shrub, litter, root), trees were counted and measured (diameter breast height) on a 0.125 ha sampling area. Within each field, shrub biomass was evaluated within three replicates of a 3-m radius circle. Understorey and litter samples were taken respectively from two subquadrate replicates. Origin and direction of these subquadrates were established at random.

Allometric equations were used to quantify total biomass for trees, shrubs and roots (FAO), and then 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 subquadrates.

CENTURY model simulations for different scenarios were used to predict soil and biomass carbon content trends.

Results for Nioro Rainfall in 2005

At Nioro Agricultural Research Station for 2005, annual rainfall recorded was 780.5 mm. A fairly good rain distribution was observed. It was assumed that crop water needs were met.

Results for Land Use Land Change (LULC) Mapping

For the whole Nioro area, this task was undertaken in collaboration with Centre de Suivi Ecologique, which has provided Landsat Images and technical backstopping necessary for this output. LULC units are defined based on surveys on farmers' practices (Niang, 2004). Already available digitized maps are in a process of validation, using ground observations. The validated maps will be used to estimate the total C in the biomass and in the soil for each unit class.

A total of 69 representative sampling sites for both vegetation and soil were considered in the study area (15 in 2005 and 64 in 2006). The vegetation includes litter, root, herbaceous plant, shrubs and trees.

During the 2005 dry season, biomass and soil samples have been done for 15 sites, distributed throughout the Nioro Department. Site characteristics (location, UTM coordinates, land use system, etc.) are given in Table 20.

For the sites, total biomass carbon estimated is indicated. Among sites sampled in 2006, a large variation in total biomass C (0.24 to 31 t/ha) was found. Lowest biomass carbon values (0.24 to 3.8 t ha) were found on cultivated field, peanut fields in particular. Highest biomass carbon values (10 to 31 t/ha) were found in the forest, lowland or -champ de case with manure application. On the lateritic plateaus, biomass carbon contents ranging from 4 to 8 t/ha are found.

For the calculation of soil carbon content, only bulk density values are available. Soil samples for C analysis are sent to the CNRA laboratory.

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

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. Data from the first three years of the Kpeve experiment are being input to the DSSAT model to evaluate the

Table 20. Sampled sites for soil and biomass carbon during the 2005 dry seasons.

Sites	X coord.	Y coord.	C Understorey litter + herb. plant	Soil C (t/ha) 0-20	Soil C (t/ha) 20-40
Fass Nguéyène—lateritic plateau (LP)	419921	1518758	0.90	9.07	9.18
Fass Nguéyène—continuous field cropping (CC-millet)			0.76	9.29	9.61
Fass Nguéyène—continuous field cropping (CC-peanut)	418980	1517848	0.44	9.29	9.61
Forêt Pané	402149	1512105	0.93	10.91	9.55
Keur Moussa Poste Forest (F)	408100	1508576	0.91	10.58	10.01
Diamaguène-low land intermediate point	413970	1522225	0.79	9.13	8.73
Diamaguène-low land low point	413979	1522213	1.14	9.13	8.73
Low land low point high point	413956	1522214	1.61	9.13	8.73
Diamaguène-low land or bas-fond (LL)	413975	1522124	0.12	9.11	8.98
Diamaguène-millet field (CC)	414210	1521964	1.08	10.26	9.33
Diamaguène-peanut field (CC)	414234	1521903	0.00	9.37	9.42
New Ados field	435497	1507948	0.00	10.68	10.76
Ravine	435501	1507946	0.00	*	*
Boisement Ndiba Ndiayène-new tree plantation (P)	426782	1513337	3.22	6.32	4.07
Abdou Bouri (Lp)	424669	1515010	0.94	10.19	9.45
Dabaly-peanut (Cc)	433010	1521122	0.00	*	*
Bao Forêt A. seyal (F)	431709	1522717	1.53	*	*

* = Soil samples to be run at the laboratory.

ability of the model to simulate differences among treatments and years in biomass and grain yield as well as changes in soil C. Initial simulations have been made for three of the treatments.

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 soil C pool as 0.55 (fraction) of the total soil C in the top 20 cm and the decomposition rate parameter (k) as 0.40 (fraction per year). Standard errors of estimates were less than 0.02 and 0.04 for the estimates of stable pool and k, 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. A paper was published on this work by Bostick *et al*. (2006) in the *Soil and Tillage Research Journal*.

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. This work is continuing in 2006.

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 DSSAT. 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 20 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 obtained by J. Naab working in Wa, Ghana. Our next step is to compare the model with his data; this work is in progress.

A new graduate student (K. Dzotsi from Togo) joined the team in 2005. He is conducting an experiment in Kpeve, Ghana to evaluate the ability of the DSSAT-CENTURY model to simulate response to P in plots adjacent to those being used to evaluate rotation system effects on soil C changes over time. The student will also compare results using the data being collected by J. Naab in Wa, Ghana.

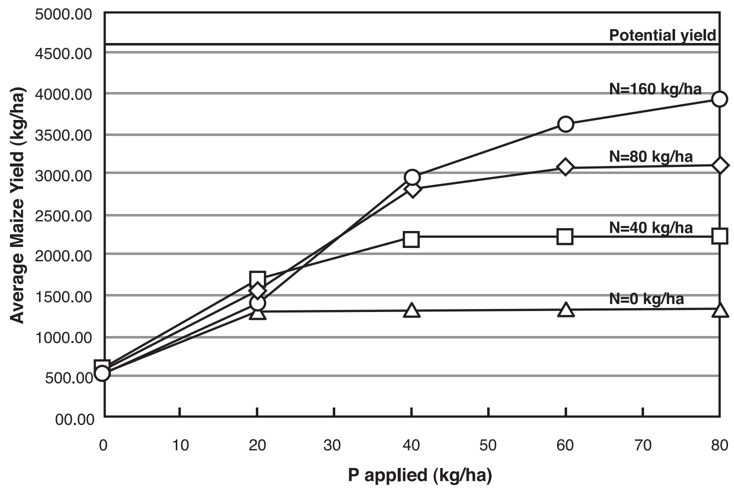


Figure 20. Simulated maize yields for different N and P levels in Omarobougou, Mali (20 years of weather data).

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. This was completed in 2005 and IMPACT is now being used to compare different soil C practices at a farm scale (*see later section in this report*).

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

Development of Soil C-Texture Relationships

Carbon Measurement Issues

Cornell's previous annual reports have noted that Graham's colorimetric procedure gives the best agreement with Cornell's combustion results. Our Nepali colleagues are now utilizing this method as a standard operating procedure in the NARC Soils Lab. A graduate student at IAAS is also using the colorimetric procedure for analyzing soil samples for his Master's thesis.

The loss on ignition (LOI) protocol was introduced last year as an easier and less expensive method than the colorimetric procedure for Nepali soils labs. However hands on experience with LOI in Nepal has been mixed. NARC Soils Lab used colorimetric TOC results to calibrate LOI for 195 soil samples from the Chitwan district (Figure 21). As expected the regression coefficients are different from those we developed using LOI and combustion data (TOC = 0.453(LOI)-0.095), but also the correlation between LOI and colorimetric values ($r^2 = 0.63$) was not as good as between LOI and combustion ($r^2 = 0.92$). It is possible that irregular power supply and humidity played a role in the observed variability.

The IAAS graduate student also used LOI on soils collected from the zero tillage experiment at Baireni, Chitwan. He calibrated LOI with combustion data from Cornell. In this case, there was excellent correlation between LOI and combustion data ($r^2 = 0.95$); however, the regression coefficients were substantially higher than we had found (TOC = 0.796 (LOI)-4.09). Losses after heating tended to be twice as high as our losses on similar soils, suggesting that the muffle furnace temperature was higher than thought. At IAAS it was impossible to check whether the actual oven temperature agreed with the dial setting. A muffle furnace with digital

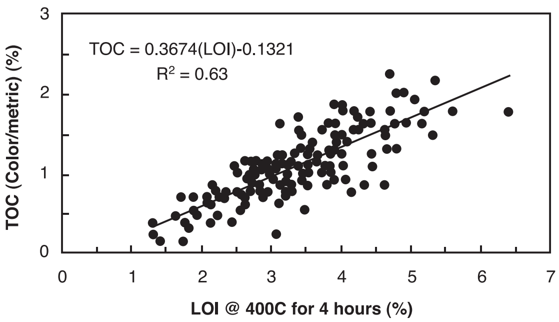


Figure 21. Loss on ignition calibration with TOC by the colorimetric procedure.

control is needed for LOI to be successful; otherwise, new calibrations are required for each lab oven.

Soil Carbon-Texture Relationships

Native and Rice-Wheat Sites. Additional data for native forest sites (Bangladesh and Nepal) and other no-tillage systems (tea garden and mango orchard in Nepal) were obtained in PY 9, mostly to a depth of 60 cm. We now have a total of 99 sites. The data for these sites showed considerable variation (Figure 22 upper panel) for 0-15 cm soil depth. Possible reasons for this variability are:

- Forest sites are disturbed in that they are used for harvesting wood and forage materials and may be grazed; consequently reducing C inputs and lowering SOC levels.
- Flooding and erosion are continually modifying forest sites in the Nepal terai.
- The land use history of the forest sites is not always well known so SOC levels may be lower than the equilibrium levels.

The data for both rice-wheat sites (Figure 22, lower panel) and the "native" ecosystem sites give an indication of the variability that exists in SOC content for surface soils and highlight the difficulty of finding sites that are truly representative of a long-term natural forest. We believe that it is justifiable to take an empirical approach to establishing relationships between SOC and silt + clay content to define maximum and minimum SOC levels from the SOC survey data and to use these to help interpret results from the modeling work described under Objective 2. Accordingly, regressions for maximum and minimum values, as appropriate, are shown in Figure 22.

Characterization of Organic Carbon Gains from Sequestration Practices

Long-term Soil Fertility Experiments in Nepal Terai

Carbon stocks in three long-term soil fertility experiments at Bhairahawa, Parwanipur and Tarahara and at adjacent grassland sites (except Tarahara) were measured 25 years after their start. The cropping systems were triple crop rice-rice-wheat at Bhairahawa and double crop rice-wheat at the other sites. All experiments were started in 1978 with similar core treatments (Table 21). There was no return of straw residues to the experiments, except for one treatment at Parwanipur where wheat straw (10 t/ha) plus 50 kg N/ha was added to rice. An additional treatment where NPK was added to the wheat crop and FYM + 50 kg N/ha to the rice crop was also included at Parwanipur.

At Bhairahawa and Parwanipur, areas directly adjacent to the experiment were maintained as unfertilized grassland since the inception of the experiment. This grassland had been part of the field where the experiment was placed and it represents a conversion

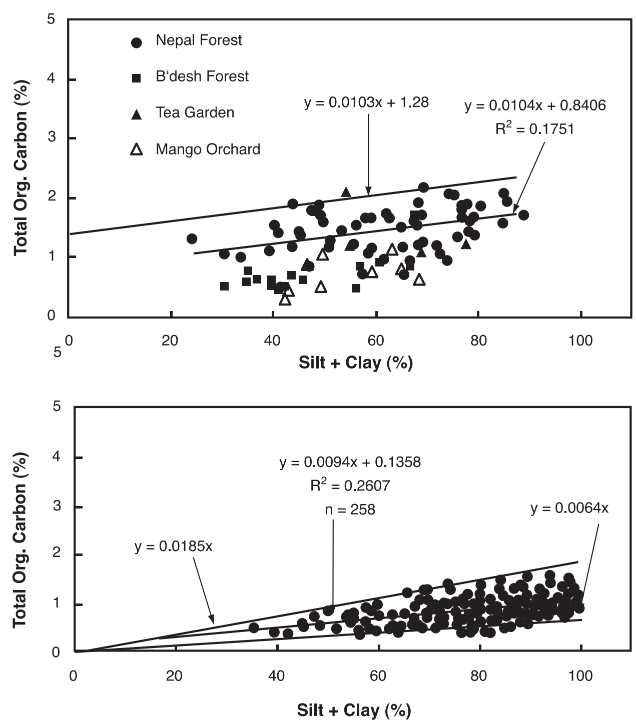


Figure 22. Soil organic C and texture relationship for the 0-15 cm depth for native forest and managed tree sites (upper) and rice-wheat sites (lower)

to no-tillage. The grass was more or less continuously harvested for animal feed so residue inputs were largely through the root system.

Mean crop yield data for the three experiments are shown in Table 22. Yields of all crops for the FYM and NPK treatments were generally similar at Bhairahawa and Tarahara. Lower crop yields for the FYM treatment compared to the NPK treatment at Parwanipur suggest an N limitation with the FYM treatment, which is supported by the higher crop yields in the FYM/NPK treatment. However, yield differences, unless extreme, are unlikely to lead to differences in root inputs of C to soil. Root inputs are most relevant to soil C stocks since aboveground biomass was removed from the fields (except for one treatment at Parwanipur). The removal of straw is similar to farmer practice.

Soils were sampled in 15 cm increments to a depth of 60 cm and bulk density of each depth increment was determined. Organic C and N were determined by dry combustion using a Europa Roboprep C and N analyzer. Pre-weighed samples of soils from Bhairahawa were treated with acid to remove $CaCO_3$ prior to analysis; this was not necessary at the other two sites. As expected, carbon stocks (Table 23) were highest in the FYM treatment and lowest in the unfertilized treatment. Some observations from the carbon stocks data are:

- Soil carbon stocks in the unfertilized and NPK treatments were similar at Parwanipur and Tarahara despite large differences in above ground biomass production (Table 23). This indicates that residue inputs (almost all through roots) were the same in the two treatments. At Bhairahawa, a strong P deficiency developed in the unfertilized treatment after six years, which in combination with N deficiency, severely limited plant growth and clearly reduced root growth and residue inputs compared to the NPK treatment.
- Soil carbon stocks increased substantially in the FYM treatment at all three sites.
- Soil C stock increases in the FYM treatment were essentially equaled by the unfertilized grassland at both Bhairahawa and Parwanipur indicating that changing to no-tillage was equivalent to adding 10t/ha fresh manure (estimated to contain 1.8 t C/ha) per crop.
- Between 43-60 percent of the soil C stock (0-60

Table 21. Treatments and nutrient inputs (kg/ha) in the long-term rice-rice-wheat experiment at Bhairahawa, and rice-wheat experiments at Parwanipur and Tarahara.

Treatment	Rice[1]			Wheat		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Unfertilized	0	0	0	0	0	0
NPK	100	30	30	100	40[2]	30
FYM	10 t/ha (wet wt)			10 t/ha (wet wt)		
FYM/NPK[3]	10 t/ha FYM + 50-0-0			100	30	30
Straw/NPK[3]	10 t/ha straw + 50-0-0			100	30	30

[1] for both rice crops at Bhairahawa
[2] 30 at Parwanipur
[3] only at Parwanipur

Table 22. Mean grain and straw yields for long-term soil fertility experiments.

Site/Treatment	Early Rice Yield (t/ha)		Main Rice Yield (t/ha)		Wheat Yield (t/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
Bhairahawa						
Unfertilized	0.40	NM[1]	1.07	1.67	0.53	NM
NPK	2.76		3.08		2.30	
FYM	2.80		3.14		2.20	
Tarahara						
Unfertilized	3.02	4.48	NA	NA	1.28	1.88
NPK	3.84	7.07			3.31	3.84
FYM	4.03	7.01			2.23	2.75
Parwanipur						
Unfertilized	1.96	3.08	NA	NA	0.64	0.76
NPK	3.16	5.46			2.04	2.52
FYM	2.67	4.37			1.14	1.52
FYM/NPK	3.32	5.72			2.15	2.63
Straw/NPK	3.00	5.32			2.03	2.66

[1]NM = not measured

Table 23. Carbon stocks (0-60 cm) in long-term soil fertility experiments.

Treatment	Total Organic C in 0-60 cm (t C/ha)		
	Bhairhawa	Parwanipur	Tarahara
Unfertilized	31.9	23.1	37.3
NPK	37.5	24.8	37.5
NPK (wht), 0.5N + Straw (rice)	-	28.4	-
NPK (wht), FYM + 0.5N (rice)	-	27.7	-
FYM	53.1	33.4	48.3
Unfert. Grassland	52.6	31.3	

cm) was found in the top 15 cm of soil.

- Treatment effects were restricted to the 30 cm depth at Bhairahawa and to the 15cm depth at the other sites.
- The pattern of the results is strikingly similar to those from the Broadbalk long-term small grain (wheat and barley) experiments at Rothamsted, England, which have run for 160 years with a single crop per year. Time is effectively accelerated in the Nepal terai with the double or triple cropping systems, a much warmer climate and irrigation of crops.

Permanent Bed Experiments

Our research has shown that permanent raised beds are a viable option for rice-wheat systems, leading to both increased crop yields and increased use efficiency of inputs (water and N). They also are close to a zero tillage option and so should increase soil C stocks. Carbon stocks were measured in two experiments, one at Nasipur in Bangladesh and the other at Ranighat in Nepal, after they had been in place for four years. Details of the experiments, which also include conventional practice treatments for comparison, can be found in our earlier reports.

Measurement of soil C stocks in the beds is complicated by the land surface structure created by the beds. We sampled both bed and furrow regions of the beds. We used a strategy that should collect samples to the same soil depth. Samples were collected in 5 cm increments to a depth of 15 cm, then from 15-35 cm on the bed, 15-25 cm in the furrow and 15-30 cm in the conventional, flat treatment. Sampling was by a Giddings soil corer (5 cm diameter) in Bangladesh and by hand in Nepal (2.5 cm diameter). Care was taken not to compact soil so that each sample also provided a bulk density value. The cumulative mass of soil and soil C collected in the whole column was determined. A weighted average was obtained for the permanent bed based on the dimensions of the bed and the furrow; 66.7 percent of the plot area was assigned to the bed and 33 percent to the furrow. The values for total soil mass were very close (< 10%) with slightly more soil being collected from the permanent beds. Soil carbon stocks were equalized to the same mass of soil by adding increments to the conventional treatments; these were calculated from the difference in soil mass and the C content of the lowest depth increment collected. The same approach was used at the Nepal site, except that sampling was to 50 cm. The sampling strategy, together with % soil C values in the different depth increments is shown for the Bangladesh experiment in Figure 23.

The total organic C stock for the nominal 0-30 cm

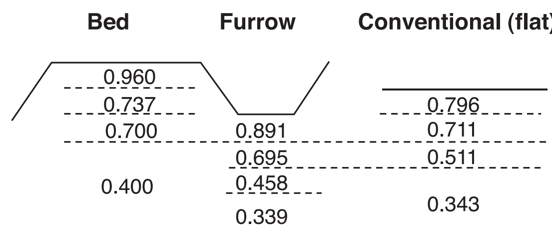


Figure 23. Schematic of physical arrangement and sampling scheme for permanent bed and conventional (flat) management at Nashipur Bangladesh, showing measured % OC values.

depth was 26.88 and 23.78 t C/ha for the permanent beds and conventional practice, respectively, with the values significantly different at $p < 0.001$. The annual rate of soil carbon accumulation in this experiment is 0.78 t C/ha, which is at the high end of the range reported for no-tillage soils. Data from the Ranighat, Nepal experiment show the opposite trend and we are working to resolve some potential problems with the data set.

Continuing Tillage Experiments

Tillage experiments continuing for sampling in the last year of the project are:

- Tillage and crop establishment at Bhairahawa, Nepal.
- Crop residue management at Bhairahawa, Nepal.

Surface seeding no-till and conventional till experiments at:

- IAAS, Rampur, Nepal and
- Baireni, Nepal.

Permanent bed experiments at:
- Nashipur, Bangladesh and
- Ranighat, Nepal.

Except for the crop residue experiment, all of these experiments have combinations of mulch and tillage treatments.

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 (UH)

Water and Soil Conservation

The UH group used the Ados techniques ("courbes de niveau") at the farmers' fields to gain a sustainable improvement of the water supply for sorghum, millet and peanut water supply

In the Senegal peanut basin, fallowing as a common soil fertility maintenance strategy has given way to continuous cropping because of increasing population pressure. The population pressure coupled with the breakdown in traditional systems of land management has caused per capita grain yields to diminish by over 40 percent since 1960 (Matlon, 1990). In fact, the current farmers' practices of intensive cropping with such a low input agricultural system are by no means alternative techniques for land management that protect soils from erosion and soil fertility depletion. On the other hand, this high cropping intensity on the naturally fragile soils combined with the recurrent droughts has been detrimental to ecological stability of the region.

Methods of reversing the vicious downward spiral of decreasing crop yields that threatens the very livelihoods and food security of the rural poor must be environmentally sustainable and yet enable an annual growth of three percent per annum in food, fuel, fiber and fodder production, just to keep pace with population growth. Experience has shown that solutions to the agricultural crisis in the Sahel are not to be found in high input, highly technological approaches that have worked elsewhere in the world, in different cultural, social and economic settings. Rather, integrated systems of natural resource management are required which do not rely on technologies imposed from outside; these systems must utilize technologies requiring low external inputs to provide locally-based solutions to local problems.

A number of soil conservation and water-use management practices (e.g., mulching, water harvesting, zaï pits, live fences, rock or grass bunds, ridge tillage, pre-emergence bedding, improved fallows and cover crops) have been scientifically documented as being beneficial to crop production in the Sahel. Application of a combination of some of these management practices at the watershed level is one effective way of controlling runoff and soil loss on these fragile soils. The improved crop water availability, as well as the reduced nutrient loss (through runoff reduction) provided by these management techniques allow for efficient use of applied fertilizer and therefore improved crop growth. This approach, however, is tedious to implement and requires a collaborative effort by all the farmers within a given watershed, which is always not feasible. This calls for soil and water conservation techniques that can be applied in individual farmer fields at the plot level. Mechanical techniques like *ados en courbes de niveau* (ACN) combined with ridge tillage have produced good results at plot level in the sorghum based cropping systems of Mali (Gigou *et al.,* 2000). In these ferruginous soils with high clay content, the observed sorghum yield increment resulted from increased water infiltration into the soil profile. In the sandy and erosion-prone soils of Senegalese Peanut basin, ACN can be an alternative to the watershed approach for peanut-sorghum crop rotation system because its easy implementation on an individual basis.

The "ados" technique (ridge tillage or "courbes de niveau") was evaluated by the UH group 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, natural regeneration (annual and perennial species), groundwater recharge and natural vegetation.

Materials and Methods

The 2005 rainy season is the third year since these trials have been installed in farmer's fields. One peanut field was added to the eight fields that were selected during the last two years (2003, 2004), giving four millet fields, four peanut fields and one sorghum field. However, two millet fields (Babou Toure and Tamsir Sene) were eliminated in 2005, as the farmers failed to respect the contract agreement. The seven farmer's fields that were retained are indicated in Table 24.

Table 24. On-farm fields for the 2005 rainy season.

Site location	Farmer's name	Crop	Variety
Djiguimar	Aly Coumba TOURE	Millet	Souna 3
K. M. Dramé	Chérif BA	Millet	Souna 3
Paoskoto	Omar KANE	Peanut	73-33
Djiguimar	Malick DIABO	Peanut	73-33
Djiguimar	Amath NDIAYE	Peanut	73-33
Djiguimar	Ismaila DIANE	Peanut	73-33
Prokhane	Cheikh WILANE	Sorghum	F2-20

Using GPS equipment, the fields were topographically mapped, waterways and roads delineated and the location of trees taken. Site characteristics include initial soil physical and chemical properties (mean soil C content, soil texture), slope, ados spacings, soil profile depth, etc. (Sene *et al*. 2004). One of the three fields millet fields was eliminated, as the farmer (Tamsir Sene) was not able to perform in due time the weeding operations on his field.

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 position 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 fertilizer applied after sowing; and millet and sorghum: F2-20, 150 kg/ha of 15-10-10 fertilizer added at thinning plus 100 kg/ha urea applied at early tasselling). Accordingly, four rates (0, 1/2 of recommended rate, recommended rate and 1 1/2 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 ran parallel to slope orientation. The timing of cropping operations from sowing to harvest were 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 have been analyzed in Hawaii for the following parameters: pH, C, P, exchange cations, (Ca, Mg, K, Al), etc. In analyzing these data, an attempt was made to determine the effect of the previous crop (peanut or millet) and soil texture (sandy vs. sandy clay) on the relationship between soil pH and exchange cations.

As for the natural regeneration, ados and fertilizer effects on post harvest weeds were studied in for biodiversity and dry matter production. One field for each crop was selected for this study. Three plot replicates (3 x 2 m) were chosen for the three inter-ados within a farm field, and their symmetrical counterpart located in the control plot.

Results

Correlations between soil pH and exchange cations as affected by previous crop and soil surface texture were found as indicated.

Millet as Previous Crop

Regardless of the previous crop, correlations between soil pH and exchange cations were affected by soil texture. Stronger correlations were found for sandy clay soil than for sandy soils.

Millet Yield

Grain and straw yields for the control treatment are also comparable to farmers yield in the area (0. 3 to 0.5 t ha).

Ados Effect

A negative ados effect was obtained on grain yields at 20 m-distance from the ados (33 to 52 percent yield decrease). At five metres from the ados, no ados effect was found.

Fertilizer Effect

Fertilizer effect is positive and significant, except for straw yield at 5m at the K. M. Ba village. The ISRA recommended rate seems to be optimal. Two- to three-fold yield increase resulted from fertilizer application, even at 1/2 rate.

Sorghum Yields

No ados effect was found. Fertilizer application, however, allows a two-fold increase when applied at a rate higher than 1/2 rate.

Identified Weed Species

The survey revealed 18 species, among which 14 are clearly identified. For the remaining four weed species, only local names are known for the moment. A list of the weeds encountered in the three selected fields is given as follows:
Tacca involucrata, Spermacoce sp, Eragrostis tremula, hibiscus, Polycarpaea linearifolia, Ipomea muricata, Cassia tora, Cucumis melo, Cenchrus biflorus, Commelina forskalei, Cyperus sp, Eragrostis ciliaris, Striga sp.

Neither ACN, nor the fertilizer application, had a significant effect on the weed species biodiversity.

Dry Matter Production

Post harvest biomass yield was higher for millet crop than for peanut or sorghum. This is in line with the weeding operation practices for these crops. In fact, millet cropping allows more weeds to develop than the other two crops, in part due to shorter cropping cycle. For peanut and sorghum no fertilizer or ados effects were found, as opposed to what was observed for millet crop.

Conclusions

For the two objectives defined for the SM CRSP Carbon Sequestration project, data collection according to the different protocols is well underway. These two activities are the main components of a PhD thesis by Roger Bayala.

In collaboration with CSE (Centre de Suivi Ecologique), a practical method for assessing carbon loss and gain in the cropping system under different types of land use was developed for the Peanut Basin of the Nioro area in Senegal. Upon completion of the mapping of different LUS units, the data already obtained, along with the additional data to be collected during the next few months, will allow a fairly good description of carbon changes in the ecosystem.

The impact of ados on crop yield, when significant, tends to be depressive; meaning that better water conservation resulting from ados construction does not necessarily result in yield increase. More investigation is needed to explain the findings, in addition to the following aspects:

- The ados effect on carbon sequestration. Baseline data is already collected and the soil sampling is done for spatial variability analyses (Prof Yost).
- The ados effect on groundwater recharge. As of this coming rainy season (June), a total of 21 access tubes for neutron tubes reading (seven tubes per field, three fields) are have been installed at a depth at least two metres. The water balance allows the quantification of drainage water to contribute to the groundwater recharge.
- The ados effects on natural regeneration. This includes both annual and perennial plants.

Objective 2, Output 1: A Demonstrated Capacity of Land Use Cropping Systems for Sequestering C in Soils in West Africa under Different Rainfall Regimes (UF)

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. Traore (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.

Two years after the initial soil C survey data collection, a second set of soil samples were taken from Wa and Kpeve. Fields that had been sampled during the first sampling mission were visited using GPS to locate them. However, the number of fields sampled in early 2006 was fewer than those sampled during the first trip. The samples are being analyzed by investigators in Ghana who worked with a PhD graduate student from UF (Koo) to collect the samples in 2006.

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

In PY8, 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 carbon maintenance, nitrogen fixation, weed control and seeds that could bring additional income to farmers.

The experiment was repeated during PY8. After only three years, major differences were found among treatments relative to soil C and crop production. Soil C in the maize-bare plot dropped almost one percent and appears to be at such a low level that additional decomposition of organic matter will not release sufficient nutrients to support maize production. The difference in appearance of the soil in that plot vs. other plots that have vegetation grown and incorporated into the soil is striking. In late 2005, a decision was made to divide this degraded soil treatment into four parts, keeping 1/4 of the plots as maize followed by bare fallow and planting mucuna and pigeon pea to assess how long it takes to recover the soil. Initial observations indicate that the mucuna and pigeon pea do not grow well, meaning that it is likely to take several years to recover the soil sufficiently for production.

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 described in AR8, 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 superphosphate 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. These experiments were repeated in PY8. Results indicate potential for soil C sequestration, depending on practices. In particular, plots that were not tilled had higher levels of C gain than tilled soil. A decision was made to assess no-tillage as part of the experiments during the next year.

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

As described in AR8, 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

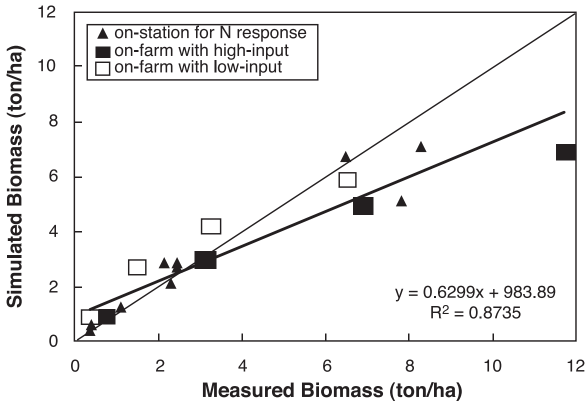


Figure 24. Measured vs. simulated total dry matter of maize from two on-farm and one on-station experiments conducted in Wa, Ghana 2004.

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 24 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. These on-farm experiments were repeated in 2005 and results are being analyzed. We found considerable variability in biomass and yield produced in the on-farm studies.

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

In PY9, the DSSAT-CENTURY model was used to simulate 50 different cropping systems for analysis of soil C sequestration using the Impact model. These simulation runs provided the needed yield and soil C changes for candidate cropping systems for soil C sequestration. Model runs showed that soil C increases are feasible using the different rotations, N fertilizer levels, and residue management studied; increases ranged between about 50 to 500 kg/ha per year. High rates of soil C sequestration were found under practices that are likely not possible for mixed livestock-farming systems. When 90 percent of maize residue was returned to the field and fertilizer levels were high (80 kg/ha) and crops were rotated with fallow, yields and soil C were highest. However, there is a strong tradeoff between livestock units that can be supported and residue kept in the field vs. feeding to livestock. For Maize-peanut-fallow, the cost per ton of C sequestered was low, mainly due to the increased yield for maize in this rotation and income derived from it (in contrast to additional income computed for soil C sequestration at $10 per ton of C).

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 (UH)

Extending ACNs

Efforts have been conducted to extend ACN, at least the survey and staking, free of charge to farmers. These efforts were conducted primarily in our pilot sites (Table 25).

Table 25. Sites, farms and areas surveyed for installing ‘ados’ (for ACN implementation).

Sites	Farms	Total areas (ha)
Fansirakoro	3	7
Oumarbougou	6	26.5
Sotuba (Bamako)	2	2
Konobougou	9	18.5
Bamako	3	7
Koniobla	2	6
Yayadiassa	1	5
Zignasso	3	8
Total	29	79

Impact of C-4-T on Cotton Yields and Soil Carbon

The UH group designed and implemented an experiment to evaluate the impact of selected management practices on soil organic carbon and crop yields. These management practices, referred to as C-4-technologies (C-4-T), include: ACN, fertilizer, reduced tillage and residues management. This experiment is being implemented in Fansirakoro, Sotuba, Konobougou, Cinzana, Niessoumana, Oumarbougou and Diou. The data collected are those for the fourth year of implementation on the same plots. The crop was cotton, in rotation with millet last year.

Plant growth and yield, soil and plant samples collected are still under analysis (laboratory and statistics). For previous growing seasons, there were significant effects of ACN and fertilizer application through recommendations made by NuMaSS. As expected, ACN found grain yield increase by 43 percent, while NuMaSS recommendations provided 70 percent more millet grain yield. These yield increases are particularly high due to the fact that last year (2005) was a very dry year. Leaving crop residues on the field (left over after free grazing by livestock) has not yet built up cumulative effects to positively impact millet growth and yield. In fact, free grazing has become a critical factor in inhibiting the build-up necessary for a significant impact of crop residues on yields.

Assessment of Soil C Related to ACN

The sampling plan began in 2000 was continued in early 2006 with the 2006 sampling of fields of Yaya Diassa, Sikasso; André Dembele, Oumarbougou; Mory Konaté; Zan Diarra, Siguidolo; Drissa Traoré, Fansirakouro; and Bacorro Ballo, Fansirakouro. The previously sampled field of Bouba Togola, Siguidolo, was turned into a vegetable garden with the digging of an irrigation well. While the data remain to be tabulated and analyzed, over 1200 trees were measured for allometric estimates of biomass and over 600 soil samples were collected for the two-year update (2000, 2002, 2004, and now 2006) sampling of soil C. Analysis will be carried out with the assistance of agroforesters at IER.

Impacts of ACN

Increased Biodiversity

One of the surprising occurrences was the number of new specimens of various trees in the field of Zan Diarra, Siguidolo (Figure 25). Especially impressive were the *Adansonia digitata*, some of the new plants (since ACN was implemented 12 years ago) which are now 60 cm in diameter.

Availability of Irrigation Water for Home Gardens

A brief survey of the village of Siguidolo indicated that approximately 80 percent of the households are now producing vegetables in the dry season ("hungry season"). Indications are that the widespread adoption of ACN by the village for now 10 years may be a factor in making this possible.

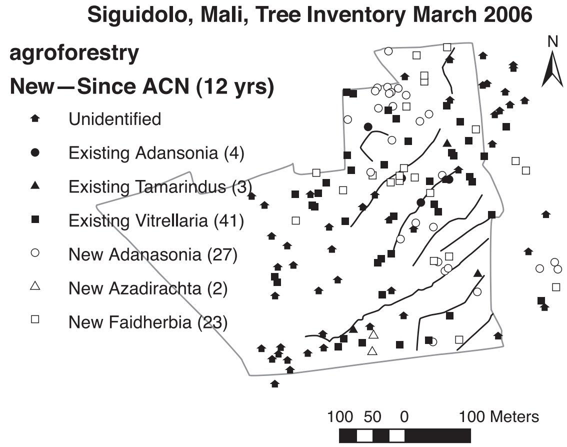


Figure 25. Spontaneous regeneration of trees—12 years after ACN (ridge-tillage) was introduced.

Cost-benefit Analysis and Impacts of the Adoption of Level Bund Contour Ridging in Southern Mali

(The following material is abstracted from a manuscript in preparation by A. Berthé, IER)

The decline of crop yields is one constraint to agricultural intensification in dry savannah rainfed agriculture. Soil and water management activities in general and particularly ACN or Level Bund Contour Ridging (LBCR) reduce the negative impact of declining crop yields on rural population welfare and preserve the natural resource basis.

Results show that the adoption of ACN, a soil and water conservation technology, on rural productivity in cotton based rural livelihoods in Southern Mali, is positively affected by the level of information on the head of households, the land tenure and some household socio-economic factors. The estimation of soil and water conservation benefits was done through methods of improving income and productivity. A probit model is used to understand factors determining the adoption of technologies.

Implementing soil and water management technologies increases crop production. It increases also the efficiency of available labour and fertilizers inputs. Finally, it increases income, which increased 44.62, 7.81 and 59.44 percent, respectively, for cotton, maize and millet-sorghum in the first year of adoption.

These factors call for a generalization of the adoption of ACN technology in the CMDT zone. The cost/benefits approach of Soil and Water Conservation used in this study could be used at regional and national level for estimating profits from environmental actions.

Determinants of the Adoption of ACN

Factors affecting the adoption of ACN, based on the estimation of the Logit regression, included the age of the head of households, the level of information about ACN, the number of cattle, the low level of soil fertility, the land security and the land use type. The duration of farming the field crop was correlated negatively with the probability of adopting ACN.

Based on the coefficients related to the variable "information" on ACN technology, it appeared that the awareness of farmers affected positively the probability of adopting ACN. Farmers who have more information tend to implement ACN. On average, improving farmers' awareness through extension activities increases the probability of implementing ACN by farmers by 0.05 points. The know-how required for implementing ACN may explain why farmers most informed are those implementing the technology.

The age of the head of the household is correlated positively with the probability of adopting ACN, although the correlation is low. But, if we related the age of the head of the household with his experience in farming, we can assume that older farmers who are more experienced and aware of soil degradation and water runoff problems, may adopt ACN technology because of it advantages.

The large number of cattle owned by farmers is associated with a higher probability of adopting ACN. Assuming that the size of a livestock herd is an indicator of the wealth, it can be concluded that wealthier farmers are the more apt to adopt ACN. Small farm households will be less inclined to adopt new technologies because climate hazards and other shocks affecting their production may impact negatively impact their livelihoods. Their strategies are mostly based, not on increasing the level of production, but on securing and or maintaining a level of yearly production.

ACN was also more often adopted for newly farmed fields crops rather than for old fields (variable presence with a coefficient of –0.054). Those having smaller fields are also more frequently concerned with the adoption of ACN (coefficient related to land area of –0.102).

The implementation and the maintenance of ACN requires a sizeable labour input. This may be an incentive to implement ACN on small areas for an optimum management, where less labour is required. Shively (1997) supported also a higher probability of adopting soil conservation technologies on small plots. The profitability of investments in soil conservation may be lower on large fields because of mismanagement and low soil quality as a result of nutrient depletion. Farmers, therefore, may be more willing to invest in soil conservation on smaller plots.

The fertility of the soil of fields was included in the regression based on the assumption that low levels of soil fertility positively affect the probability of adopting ACN. The probability of adopting ACN on less fertile soil was 0.54 against 0.35 for a more fertile soil.

The direct use of land appears as an important factor affecting the adoption of soil conservation technologies. It seems that location of land and or contracting land use do not encourage farmers to make long term investments in land resources and may reduce their planning horizon to the short term. In this study, the direct use of land is one of the main determinants of the adoption of ACN.

The question of land security based on legal systems (ownership title and other land tenure regulations) may also affect farmers' decision-making process for investing in land rehabilitation and or restoration. The lack of a clear definition of users' right is a constraint and farmers need to be assured that they may benefits benefit from future outcomes of soil conservation investments. Although, land tenure security is a determinant factor for the adoption of ACN, it is not a sufficient condition for its amplification. Of the 72 sample fields where ACN was adopted, only 25 percent had been used on a very long term basis.

Conclusion

Strategies used by farmers for adopting ACN vary according to their resources endowments and potentials profits. Among the factors affecting the adoption of ACN are the level of information about the technology, the age of the farmer and the size of the livestock herd (a wealth indicator). Various characteristics of field crops favor the adoption of ACN – land tenure security, the direct use of land and the low level of soil fertility. ACN adoption occurs mostly on small plots of two to three hectares.

The ACN technology offers opportunities for the intensification of rainfed farming systems in the Sahelian drylands, the conservation of biodiversity and the rehabilitation of degraded lands. However, the adoption of the technology has been limited by the lack of an incentives policy. Additional studies may be required to assess the impact of a national incentives policy of and any off-site effects of the technology.

ACN in The Gambia

The fundamental assumption of the integrated approach in enhancing soil organic C sequestration is that neither organic amendments nor inorganic fertilizers may be secured in adequate quantities to sustain high crop yields so as to conserve soil organic C in traditional cropping systems (TropSoils, 1987; Bationo *et al*., 1993).

The key variables for soil organic C sequestration are soil type, especially texture and acidity; climate, notably rainfall and temperature; crop type, whether cereals or legumes; and cropping systems and management factors, such as whether crop residues are buried vs. surface applied as mulch, and watershed system.

Gigou *et al*. (2000) created the ridge-tillage technology for the Sahelian countries in recognition of the importance of the interaction between soil moisture and a mixture of soil amendments for crop yield improvement. Prior to that, numerous water harvesting techniques had been tested in the region with inconsistent results, including tied ridges, no-till, zai, terracing, contour planting, small dams and their effects on farm fields and suitable crops and cropping systems.

It may be appropriate, therefore, to conclude that soil characteristics, moisture conditions, fertilization, crop varieties and management, together and separately, influence carbon conservation and crop yield after cultivation. The objective of this study was to provide empirical evidence of potential advantages of ridge-tillage over conventional watershed or farmers' current practices on crop yields and soil carbon conservation. Returns over variable cost of fertilizer were also estimated.

Materials and Methods

The study was initiated in 2002 at the National Agricultural Research Institute (NARI) experiment site at Yundum in the Western Gambia. The experimental design was a split-plot with three replications; two main plots and four sub-plots. The main plots were 1) Ridge Tillage (RT) and 2) Conventional Watershed Management (CT). Sub-plots were four fertilizer treatments applied in two splits. The first split was two thirds of total fertilizer for the experiment applied three weeks after emergence. These consisted of: 1) check (with no fertilizer), 2) 200 kg/ha NPK fertilizer + 16 kg/ ha of urea, i.e., half the national recommended rate, 3) 200 kg/ha NPK fertilizer + 43 kg ha of urea, i.e., the national recommended rate, and 4) 200 kg/ha NPK fertilizer + 150 kg/ ha of urea, i.e., double the national recommended rate.

The remaining one third fertilizer was applied six weeks later to the respective plot as: nil for treatment one, 26.6 kg/ ha of urea for treatment two, 43 kg/ha of urea for the third treatment and 108 kg/ha of urea for the last treatment.

The test crop was maize (variety *Jeka*), planted at a spacing of 0.25 m by 0.75 m, which gave 53,000 plants/ha. Conventional watershed management plots were disc-ploughed and harrowed using a tractor. Construction of the ridge-tillage system was delayed by few weeks due to poor weather and ill-health of one of the oxen. Accordingly, adjustments were made in data collection. Ridge-tillage plots consisted of a series of small ridges (~0.3 m wide) between large ridges, known as "ADOs" (~1.5 m wide) spaced about 20 m along the contours. A leguminous weed, *Icacina senegalensis*, common to the site, was incorporated into the soil before planting. Main plot (watershed treatments) size was 40m by 60m while sub-plots were 10m by 60m. Harvest plot size for grain yields and yield component harvest was 5m by 5m.

Baseline top (0-15 cm) soil was sampled for pH, extractable P, organic C and electrical conductivity using standard analytical methods compiled by Ceesay and Njie (1992) at the National Agricultural Research Institute (NARI).

Results and Discussion

Maize Yields

The results of the first two years indicated no significant impact of the ridge-tillage treatments as shown in Tables 26. The results from the 2004 harvest year, however, indicate that ridge-tillage out-performed the conventional watershed management in terms of maize grain yields (Table 27) and percent soil organic C (Table 28). Maize yields in the ridge-tillage plots increased 23 percent over conventional watershed treatments. Furthermore, the highest yields in both ridge and conventional plots were obtained with the low fertilizer rate, i.e., half the national recommended rate.

Table 26. Effect of ridge tillage, conventional tillage systems, and fertilizer on maize yields (kg/ha) in Western Gambia, 2003.

Fertilizer (kg/ha)	Tillage systems Ridge-tillage	Conventional watershed
	(yield kg/ha)	
Check (no fertilizer)	423	520
200 NPK + 42 urea	1140	1040
200 NPK + 86 urea	1125	930
200 NPK + 258 urea	1090	1180
Source	F-value	Analysis of variance P-value
Watershed system (T)	0.15	0.737
Fertilizer (F)	51.69	0.001
T*F	2.79	0.085

As expected, maize significantly responded to fertilizer (P<0.001). Half the national recommended rate in ridge-tillage yielded 2690 kg/ha and the control plot without fertilizer in -1 the same watershed management system produced 620 kg/ha, showing a 300 percent increase in maize yields. Similarly, in the conventional watershed system, the respective yields were 2120 kg/ha for the fertilized plots and 570 kg/ha for the control plots, equivalent to an increase of about 270 percent over the control plots.

A positive and significant interaction exists between watershed treatments and fertilizer as shown in Table 27. Results of 2005 and combined analysis were largely similar to results of 2004. These results demonstrate the superiority of ridge-tillage with respect to gradual improvement in yields and carbon conservation over the years.

The potential of ridge-tillage over conventional watershed treatment system for improving crops' yields encouraged Gigou *et al*. (2000) to design and promote the technology among farmers. The technology was intended to conserve excess rainwater for crop use during drought in the Sahelian region of Mali. Arising from the generally poor soil fertility in the Sahel (Bationo, 1991), ridge-tillage is used in combination with modest amounts of fertilizer or manure to revamp degraded soil and enhance crops' yields.

Table 27. Effects of ridge tillage, conventional watershed systems, and fertilizer on maize yields (kg/ha) in Western Gambia, 2004.

Fertilizer (kg/ha)	Tillage systems Ridge-tillage	Conventional watershed
	(yield kg/ha)	
Check (no fertilizer)	620	570
200 NPK + 42 urea	2690	2120
200 NPK + 86 urea	2210	1690
200 NPK + 258 urea	2120	1830
Source	F-value	Analysis of variance P-value
Watershed system (T)	31.29	0.03
Fertilizer (F)	280.867	<0.001
T*F	6.588	0.007

Results of a two-year study in Mali indicated that rainfall capture was significantly greater with ridge-tillage systems, especially in the 80-160 cm depth of the soil profile (Kablan *et al*., 2006). Field water balance estimates from the Mali study also indicate much greater groundwater recharge where ridge-tillage management was applied (Brannan *et al*., 2006). The technology is being adopted in Mali to the extent that many farmers are willing to pay a fee to the extension specialist for installation of ridge-tillage on their farms (Gigou *et al*., 2000).

Percent Soil Organic C

On average, ridge-tillage has greater soil organic C, 0.87 percent, than conventional watershed treatment, 0.73 percent (P<0.022). Soil organic C was greatest in the low fertilizer rate in the ridge-tillage, 1.06 percent and conventional watershed treatment: 0.76 percent (P<0.004). Fertilizer had a significant influence on soil organic C (P<0.0001). The result is also portrayed graphically in Figure 19 showing a correlation between soil organic C with maize yields (r=0.81**) in the two watershed management systems (Table 28).

Experts determined that it is particularly difficult to increase soil organic C in traditional cropping systems in the Sahel. They attributed this to high temperature at most times of the year and the competition for alternative uses of crop residues such as firewood, poles for construction and staking of yams or climbing beans and fodder for livestock.

Our results are, therefore, somewhat surprising and encouraging. We believe that the enhanced growth and seasonal incorporation of the shrub *Icarina senegalensis*, with its relatively recalcitrant biomass, may be a factor in the soil organic C increases observed.

Table 28. Effects of ridge-tillage, conventional watershed systems, and fertilizer on % soil C concentration in Western Gambia, 2004.

Fertilizer (kg/ha)	Tillage systems Ridge-tillage	Conventional watershed
	Percent soil C (%)	
Check (no fertilizer)	0.61	0.56
200 NPK + 42 urea	1.06	0.76
200 NPK + 86 urea	0.92	0.82
200 NPK + 258 urea	0.9	0.79
Source	F-value	Analysis of variance P-value
Watershed system (T)	43.52	0.022
Fertilizer (F)	54.49	<0.001
T*F	7.47	0.004

Maize Carbon Stock

Maize carbon stocks in 2005 as influenced by watershed treatments and fertilizer are shown in Table 29. Carbon stocks in ridge-tillage plots were greater than that of conventional watershed management (P<0.030). The range for ridge-tillage was 1120 to 4880 kg/ha and 1040 to 3840 kg/ha for conventional watershed. The greatest values were recorded in plots with low fertilizer treatments. As well, application of fertilizer significantly affected carbon stocks (P=0.001). This may imply that fertilizer use causes sustainability in that fertilization resulted in improved grain and stover biomass, i.e., carbon in the cropping system. In the absence of fertilization, the yields and stover biomass were quite low.

Table 29. Effects of ridge-tillage, conventional watershed systems, and fertilizer on maize carbon stocks in Western Gambia, 2004.

Fertilizer (kg/ha)	Tillage systems Ridge-tillage	Conventional watershed
	Carbon stocks (t/ha)	
Check (no fertilizer)	1.1	1
200 NPK + 42 urea	4.9	3.8
200 NPK + 86 urea	4	3
200 NPK + 258 urea	3.8	3.3
Source	F-value	Analysis of variance P-value
Watershed system (T)	31.247	0.031
Fertilizer (F)	280.939	<0.001
T*F	6.584	0.007

The interaction between watershed and fertilizer treatments was significant (P=0.007), signifying that watershed treatments combine with fertilizer to give greater yields in the ridge tillage plots. Fertilizer and soil moisture are often synergistic (Bationo *et al*., 1993). Water and wind erosion are rampant in Sahel. Their actions similarly scrape the thin organic layer on the soil surface leaving the acid infertile subsoil, which can hardly support good crop growth. Restoration of the degraded soil is complex and often requires expert systems or modeling effort to achieve the desired results. It is costly and generally involves large tonnage of animal and green manure, fertilizer and lime.

Cost-Benefit Analysis

Result of the cost-benefit analysis, that is, total revenue from maize minus total costs of fertilizer, is presented in Table 30. The cost of NPK fertilizer is 400 Dalasis per 50 kg bag; cost of one 50 kg bag of urea is 350 Dalasis and the selling price of 100 kg maize is 440 Dalasis. Watershed treatment costs for both the ridges using animal traction and conventional watershed treatments using a tractor and plough are assumed to be about equal. It is also assumed that the same quantity of seed maize was used for planting. Labor cost for weeding between the watershed systems is equally insignificant. Therefore, the analysis focused mainly on variable cost of fertilizer only.

Table 30. Returns over variable cost of fertilizer on maize in ridge and conventional watershed systems in Western Gambia (mean=4), 2005.

Fertilizer (kg/ha)	Tillage systems Ridge-tillage	Conventional watershed
	(Delasis/ha)	
Check (no fertilizer)	2728	2508
200 NPK + 42 urea	9820	7312
200 NPK + 86 urea	7520	5234
200 NPK + 258 urea	5922	4646
	Statistics	
Mean	6497	4925
Standard deviation	2979	1925
Coefficient of variation	0.458	0.401
Paired t-test	P<0.057	

Fertilizer costs of the various treatments are: Check (with no fertilizer) = zero Delasis, 2) 200 kg/ha NPK fertilizer + 16 kg/ha of N in the form of urea, (i.e., half the national recommended rate) = 2016 Delasis, 3) 200 kg/ha NPK fertilizer + 43 kg/ha of urea (i.e., 100 percent the national recommended rate) = 2202 Dalasis, 4) 200 kg/ ha NPK fertilizer + 150 kg/ha of urea (i.e., double the national recommended rate) = 3406 Delasis.

In 2004, returns from ridge-tillage that averaged 6497 Dalasis outweighed conventional with an average of 4975 Delasis. The probability of paired t-test (P<0.057) between the two systems implies an approximately 94 percent chance that ridge-tillage and conventional watershed do not have equal revenues. Given the increased yields in 2005 (Table 31), the returns are likely to be greater in the long-term, if the ridge-tillage technology is sustained.

Table 31. Effects of ridge tillage, conventional watershed systems, and fertilizer on maize yields (kg /ha) in Western Gambia, 2005.

Fertilizer (kg/ha)	**Tillage systems**	
	Ridge-tillage	**Conventional watershed**
	(yield kg/ha)	
Check (no fertilizer)	1840	1410
200 NPK + 42 urea	3080	2760
200 NPK + 86 urea	2170	2790
200 NPK + 258 urea	2670	2620
Source	F-value	Analysis of variance P-value
Watershed system (T)	0.54	0.538
Fertilizer (F)	28.13	0.001
T*F	4.9	0.019

Over 150 producers that participated farmer-to-farmer visit in 2003 and 2004 cropping seasons unanimously selected maize in plots with the lowest rate of fertilizer as best-performing principally due to big cob sizes, vigor and healthy growth as expressed in green leaf color and large maize stems.

The study suggests that ridged-tillage may be more appealing than conventional watershed management to Gambian farmers, because it addresses their long-term concerns with regard to stability of crops' yields, income, improvement in soil organic C status, and soil productivity.

Assessment of the Impact of ACN on Shrubs

Icarina senegalensis is a shrubby weed that is found in The Gambia and southern Senegal that borders the North Bank of Gambia. This shrub was present in the experimental area prior to the installation of the experiment. After the installation of the experiment, however, the population and growth of the species increased noticeably in the ACN plots. The growth was particularly noticeable in the plots after maize harvest around November and continues until the next cropping season began in June. A preliminary assessment of the shrub is shown in Table 32. The study revealed that mean population/plot was 1450 on the ridge-tillage plots versus 1280 plants on the conventional tillage plots (p=0.0695). Not only was a higher population of plants noticed, but also the mean dry weight was even larger, i.e. the mean dry weights were approximately 100 kg/ha on the ridge-tillage compared to 70 kg/ha on the conventional plots (p=0.0023). Presumably, *Icarina senegalensis* biomass alone might add as much as 50 kg C/ha/yr to the soil under the ridge-tillage system.

Average height of five plants selected at random was 54.1 cm on the ridge-tillage and 38.3 on the conventional tillage plots (p=0.0487), which is another indication that the shrubs responded to ACN by substantial increases in growth just before the cropping seasons. Even though these are preliminary results, the above information suggests that *Icarina senegalensis* and perhaps other plants that grow after the cropping seasons such as the weedy legumes *Cassia tora* may be contributing plant biomass to the soil organic C pool in ACN treatments. The shrubs, which grow during the dry season, should be beneficial to farmers because they likely reduce soil erosion losses and soil degradation.

Table 32. Preliminary assessment of *Icarina senegalensis* as influenced by tillage systems.

Parameter	**Tillage systems**	
	Ridge	**Conventional**
No. of plant stand (ha^{-1})	1450	1280
Dry weight (kg/ha)	100	70
Height (cm)	54	38
Variable	F-value	Probability
Plant stand	12.9	0.0695
Dry weight	432.0	0.0023
Plant height	19.05	0.0487

Modeling of Factors Affecting Soil C (Sub-contract, Virginia Tech, Saied Mostaghimi and Kevin Brannan, Biological Systems Engineering Department)

The main objectives of this research were to:

1. 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.

2. Adapt and implement the KINEROS model of soil moisture runoff and erosion for ridge-tillage systems in order to improve the technology and adapt it to different conditions of soil, topography, and rainfall.
3. Process Diviner data for in situ, field scale, water balance calculation and modeling in Mali and other devices in Senegal and elsewhere.
4. Sample and process elevation data for improved prediction of soil C sequestration.
5. Train and support other team members in hydrologic calculations, modeling and publications.

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 was collected in Mali, Senegal, and The Gambia. We have developed soil parameter files for fields in Senegal and Mali and are in the process of developing soil parameter data sets for The Gambia. Also, the soil moisture data collected in Mali will be used to calibrate PARCHED-THIRST. The climate and soils data will be used in applications of the PARCHED-THIRST model in the coming year.

After reviewing the current state of KINEROS model, it was concluded that the model was not the best-suited tool for investigating ridge-tillage. This decision was reported in detail in the *Project Year 8 Annual Report*.

The soil moisture monitoring experiment implemented in two fields in Mali is continuing and has been expanded to a fourth 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. The transfer of the data analysis procedures to IER/Mali is still underway. 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 international journal, *Agriculture, Ecosystems & Environment*.

A ground water monitoring component was implemented this year. Observation wells were installed in the fields in Fransirakoro Mali where soil moisture measurements have been taken (Figure 26). Richard Kablan (University of Hawaii) was involved in getting the wells installed. IER/Mali personnel have begun water surface measurements in the observation wells and in other wells located in and around the village. After an initial surprise at finding no water at a depth of 20m the 12-well design was modified to four wells – two in ACN and two outside of the ACN (Figure 26). The wells have now accumulated about 13m of water – about 7 meters from the well surface. The elevations of all the wells will be determined this coming rainy season in order to standardize the measurements and to attempt to quantify the effect of ACN on groundwater recharge. The surface measurements will be used to estimate recharge form the fields with and without ridge-tillage for the fields in Fransirakoro, Mali.

The DEMs (Digital Elevation Maps) developed in 2004-2005 will be used in the analysis of the soil

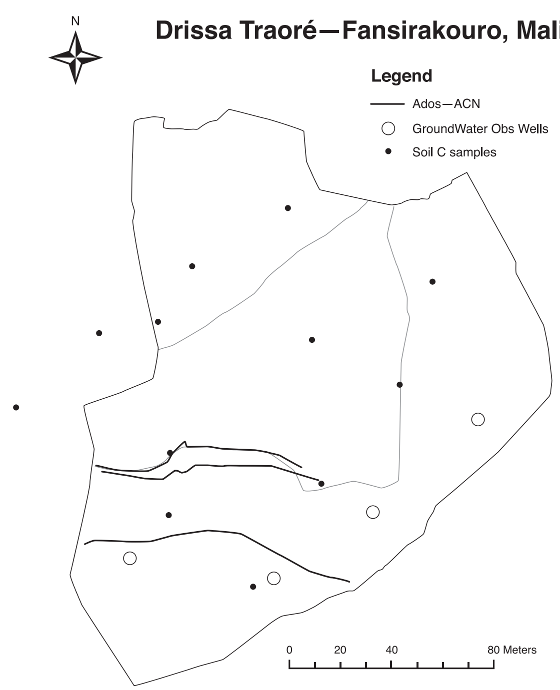


Figure 26. ACN impact on groundwater recharge, location of groundwater observation wells, Drissa Traoré, Fansirakouro, Mali.

moisture data along with in the application of the PARCHED-THIRST model.

IER/Mali personnel were trained in 2006 to measure water surface levels in the groundwater observation wells. Data sheets were created by Kevin Brannan and Richard Kablan for recording and archiving of water surface data.

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 (UF)

Scaling Up Estimates of Soil C

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 plan and progress for scaling up estimates of soil C from point samples to fields and to large areas.

Three sites were selected for scaling up purposes. 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 UF component of the SM CRSP. Three high resolution images (Quickbird) were obtained for Omarobougou, Mali and one for Wa, Ghana. Due to consistent cloud cover, we were unable to obtain an image in Kpeve, Ghana until 2005. 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. Sampling 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 2006. 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 Monte Carlo simulation approach will be used with the DSSAT model. A number of different practice 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.

This work is continuing. The DSSAT-CENTURY model will be used this year to simulate soil C changes in all of the fields surveyed in each region.

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 Traore, 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.

Most of the fields that were sampled in 2003 in the two Ghana sites were sampled again in early 2006. The changes in soil C over the areas will be estimated using geo-statistical methods. And, the data will be used for analyzing the Kalman Filter approach for scaling up estimates of soil C in these two areas.

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

A paper published on implementation of the EnKF for multiple fields, taking into account correlations of soil C and decomposition rate parameters among fields (Jones *et al*., 2006, 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 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

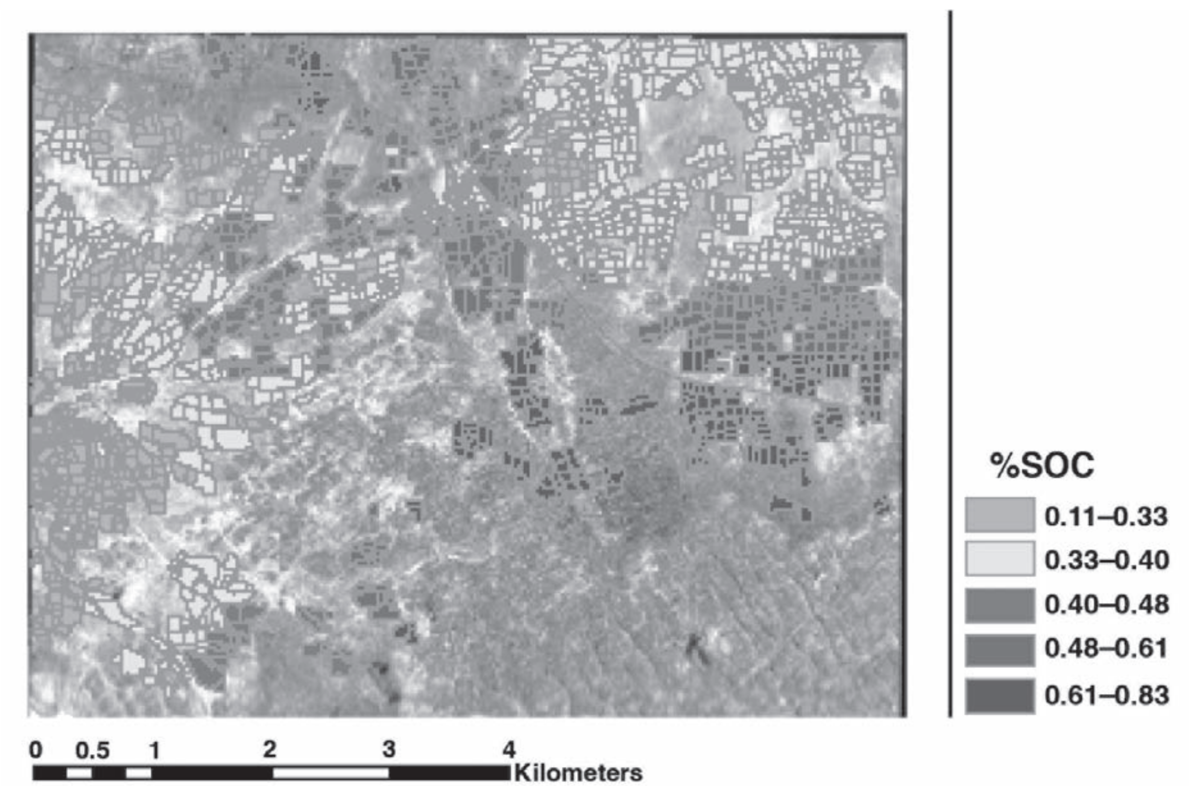


Figure 27. Map of SOC % used to initialize the EnKF simulations. Values were generated by block kriging point measurements of soil carbon in an area near Omarobougou, Mali collected by P. S. C. Traore and M. Bostick.

27 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. This work is being continued and will be completed this year.

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

Modeling of Carbon Dynamics in Long-term Soil Fertility Experiments

The ultimate goal of the Cornell group is to use models to project the impact of management changes in the rice—wheat system on soil carbon stocks. In PY 9, modeling of the long-term soil fertility experiments was undertaken with both the CENTURY and RothC soil carbon models. Neither model has been used for rice-wheat systems, except for a preliminary study by the Colorado State NREL Century modeling group. CENTURY has provision for anaerobic environments and tillage variables but Roth C does not.

Reliable soil OC data at the beginning of these experiments in 1978 is not available. Consequently we modeled the carbon dynamics from the time the land was cleared from forest (1900 for Bhairahawa and Parwaninpur, and 1950 for Tarahara) to the beginning of the experiments. We used the regression for the maximum soil OC value obtained from our forest site survey (see Figure 22 under South Asia Objective 1) to determine the initial starting point for each site. Land use, crop yield and crop harvest index history in the region were used to develop mean values for estimated root C inputs (Table 33). Root C input values were estimated as 25 percent of total above ground biomass C. Individual site climate data were used.

Modeling for the experimental period onwards to 2080 with the RothC model was based on mean crop data for the 25 year experimental period. However, with CENTURY it was based on predicted yield trends to 2030.

Table 33. Parameters used to derive root residue inputs prior to start of long-term fertility experiments.

Time Period	Cropping System	Mean Yield (t/ha)	Harvest Index	Estimated Root C Input (t/ha)
1900-1960[1]	R	0.95	0.3	0.317
1960-1978	RW	R 1.95	0.35	0.557
	W 1.5	0.44	0.340	

[1]1950-1960 at Tarahara

RothC Results

For this model we estimated that the inert SOM pool was 75 percent of the minimum value calculated for rice-wheat systems from the regression equation established for data from our survey of rice-wheat sites (Figure 22). The model provide a fairly good fit to the single data points for the Bhairahawa and Parwanipur experiments but overestimated soil OC content at Tarahara, especially for the FYM treatment (Figure 28). Derived values for the maximum and minimum soil OC values observed for rice-wheat farms (Figure 22) are shown to provide a perspective. The rice-wheat minimum value was being approached at Bhairahawa and Parwanipur. None of the NPK treatments approached the rice-wheat maximum value, suggesting that the latter is associated with sites that have received FYM.

The grassland data point was fitted by finding the appropriate residue input value rather than being empirically derived; the residue input values were 5 and 2.5 t C/ha, respectively for Bhairahawa and Parwanipur. These values seem unreasonably large and we conclude that rate constants in RothC will likely need to be modified by a tillage factor.

CENTURY Results

We have only use CENTURY to model the results at Bhairahawa. For this site, the model predicted the soil C content for the NPK treatment, but underestimated soil C content for the FYM and unfertilized treatments and for the grassland (Figure 29). CENTURY differs from RothC in that it predicts C inputs from a crop growth model, whereas RothC requires that all C inputs are specified. The crop growth model is unnecessary for most agricultural situations because root inputs of C vary little with crop yield and residue inputs from plant tops are generally known. So far, we have not been able to get CENTURY to accurately predict crop yields in the Bhairahawa long-term experiment. This may be

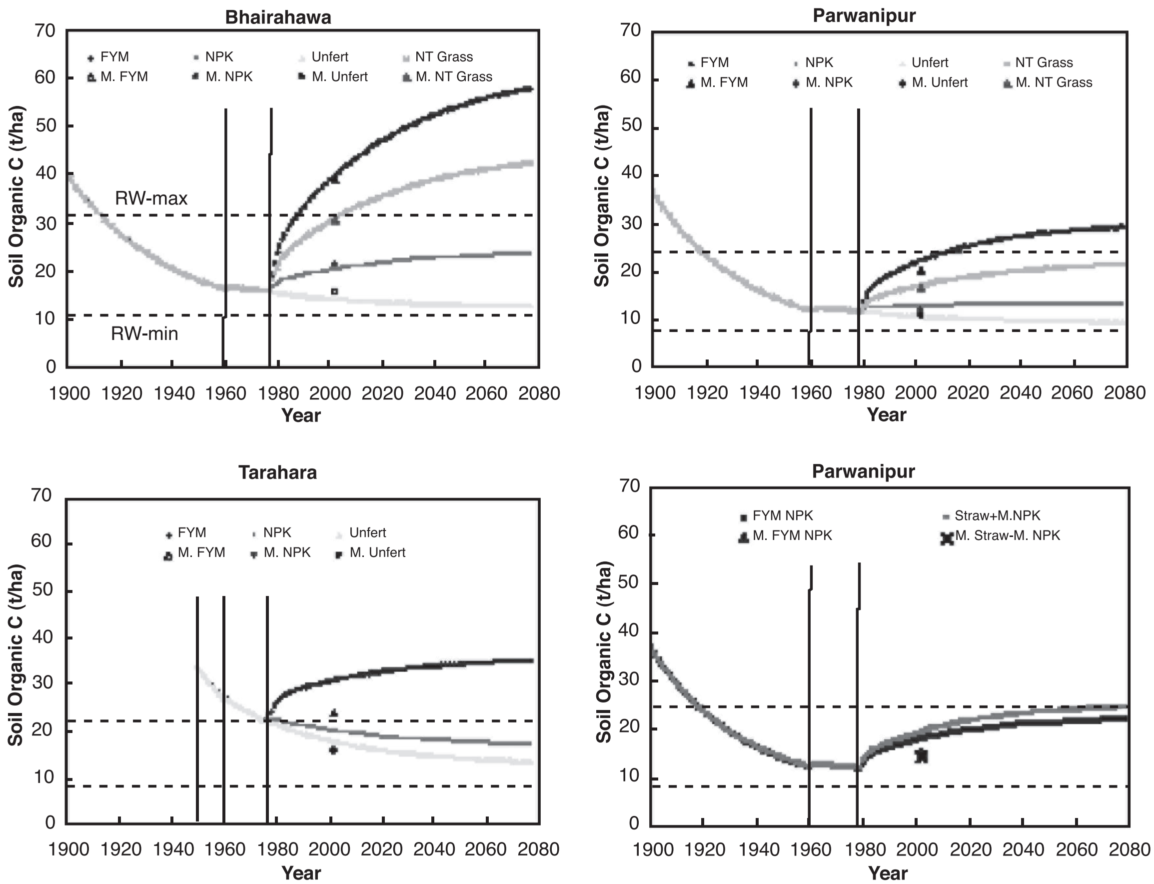


Figure 28. RothC modeled soil C dynamics for long-term soil fertility experiments.

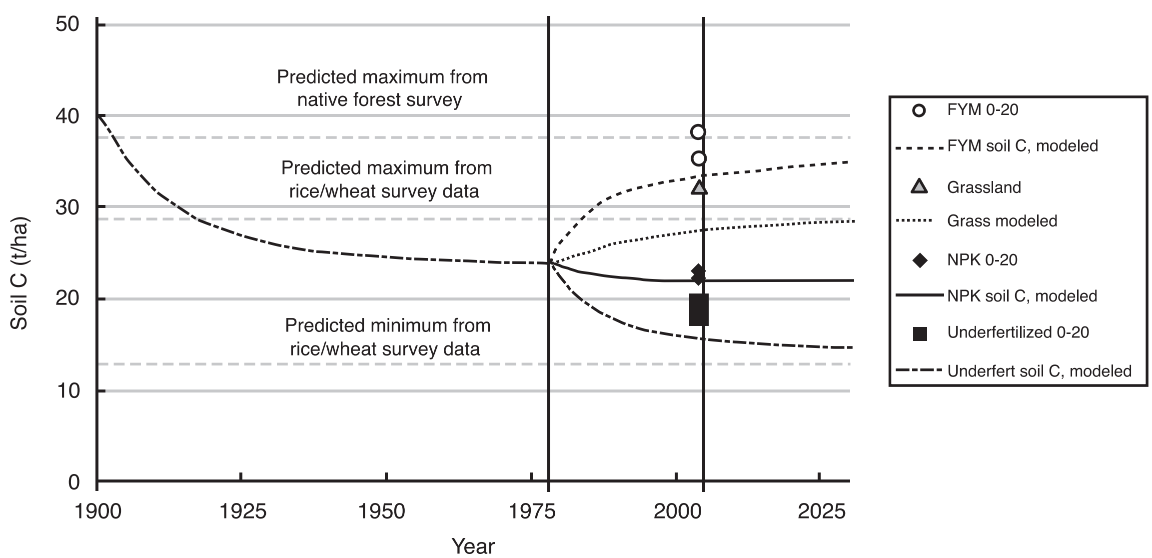


Figure 29. CENTURY-modeled soil C dynamics for Bhairahawa long-term soil fertility experiment.

because the factors causing the observed yield decline with time are not captured by the crop growth model.

Modeling Issues

- An important aspect of the models for our purposes is their ability to accurately predict the future. Currently, CENTURY and RothC predict very different scenarios for the future of the Bhairahawa experiment. Reasons for this are being investigated. The RothC model predicts that C stocks will change a lot over the next 75 years, especially for the FYM treatment and the grassland. This pattern seems unreasonable for this environment. In contrast, CENTURY suggests that soil C stocks will essentially reach equilibrium values within 50 years of the start of the experiment, which seems more plausible.
- RothC does not seem to be limited by a lack of rate constant adjustment for anaerobic conditions but may well need a tillage parameter.
- Neither of the models has adjustments for soil bulk density, so the data points shown in the RothC model (Figure 28) are adjusted to a constant soil mass based on the NPK treatment.

BIOTECHNOLOGY

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

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

Overview

Field studies have been carried out for three consecutive years in New York (corn) and China (rice), and two consecutive years in Colombia (cotton). Soil samples have been collected at planting, anthesis and harvest in the corn trial; at the seedling, heading and physiological maturity stages 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 was excavated at physiological maturity for each crop in the past year, with future excavations scheduled at the same phenological point in subsequent years of the study. DNA has been extracted from the corn litterbag samples and bacterial and fungal residue colonizers analyzed by T-RFLP fingerprinting. A molecular method developed to determine community structure of arbuscular mycorrhizal fungi (AMF) was found to be unreliable. A number of primers and protocols were tested over the past year and one primer set found to be sufficiently robust for use in the AMF biodiversity studies. All collaborators will use this protocol to assess AMF community structure in soil samples collected to date in the coming year. The Cornell team has tested a protocol for measuring glomalin as an indicator of the abundance of AMF with soil samples from the 2004 and 2005 seasons. Chambers for $^{13}CO_2$ pulse-labeling of corn were constructed and a greenhouse trial conducted in which Bt and non-Bt corn were grown with and without corn rootworm pressure and labeled with ^{13}C at various phenological stages. 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. Graduate student and technical officer Luz Marina Londoño is conducting research on AMF abundance and community structure.

Field Trials and Objectives

Corn – M. Devare, J. Thies, J. Duxbury, L. Allee, and J. Losey (Cornell Univ., NY)
Field trials were established at the Musgrave Experimental Farm in Aurora, NY, in May 2004, 2005 and 2006. The trials consist 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 treatments were established in two fields with varying field histories: one was previously in continuous corn and the other in alfalfa. The former had preexisting root worm pressure and the latter did not. Two composite soil samples consisting of 10 sub-samples across a transect of each plot were collected at planting in 2004, 2005 and 2006, and at anthesis and harvest in 2004 and 2005 to a depth of about 15 cm using soil corers. Root samples were collected at anthesis and harvest to identify AMF colonizers.

Rice – W. Wu (Zhejiang University, Hangzhou, China)
Three replicates of Cry1Ab Bt rice (KMD1) and two NonBt 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, 2005 and 2006. 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. Roots were retained for analysis of AMF colonization.

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 and 2005 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.

NOTE: The cotton experiment at CIAT was terminated in May, 2006, due to program cuts at CIAT that included the program of Dr. Barrios. All litterbags were recovered from the field in May, 2006. Arthropods colonizing cotton residues from sampled litterbags will be analyzed at CIAT in the coming months. DNA from soils sampled to date is being shipped to Cornell University in order to complete T-RFLP analysis of AMF fungal communities.

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

Overview

Soils were sampled at least three times over the annual growing season for each crop to assess components of their symbiosis with arbuscular mycorrhizal fungi (AMF). Abundance (spore counts and glomalin), infectivity (root length colonized) and diversity (genotypes colonizing roots and persisting in soil) of arbuscular mycorrhizal fungi are being assessed in sampled soils. Data from all trials indicate no adverse affects of the Bt genotype on any components of the AMF symbiosis in either of the two years for which complete datasets are available or in any of the crops tested.

Abundance of AMF – Spores and Hyphal Lengths

Spores were enumerated microscopically after separating them from 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) (Figure 30).

Spore counts in sampled soils varied by stage of plant development and by year in all trials, but not by genotype or insecticide applied in any of the trials.

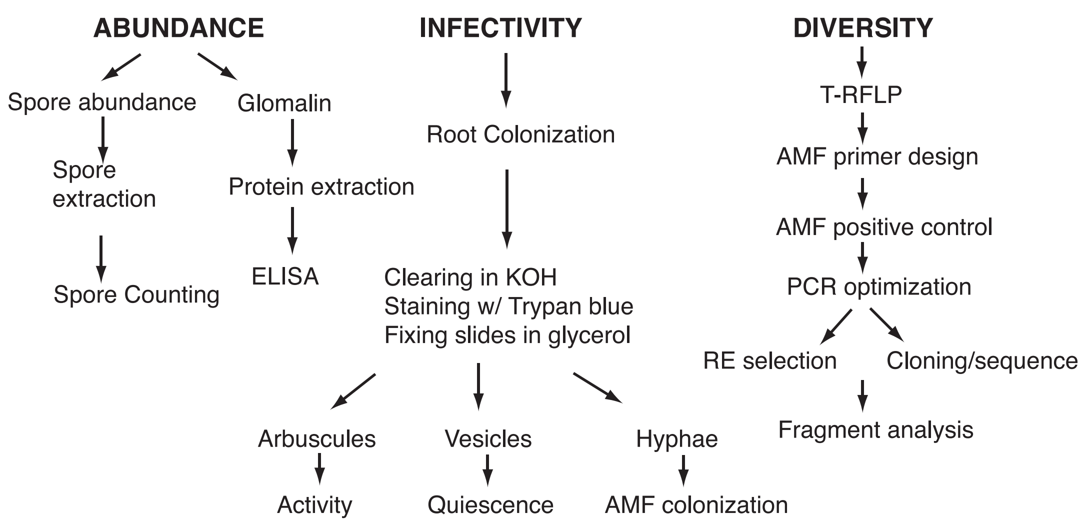


Figure 30. Flow chart of analyses used to assess AMF in field trials.

Results from corn plots in NY indicate that there was no significant effect of corn genotype on counts of AMF spores in soil. There was a highly significant effect of sampling time (p=<.0001) and a significant effect of field history (p= 0.006).

The number of spores in rhizosphere soil varied over the course of rice development in 2005 in China (Figure 31, Bars=SD). However, there were no significant differences between rice genotypes in the number of spores per gram of rice soil.

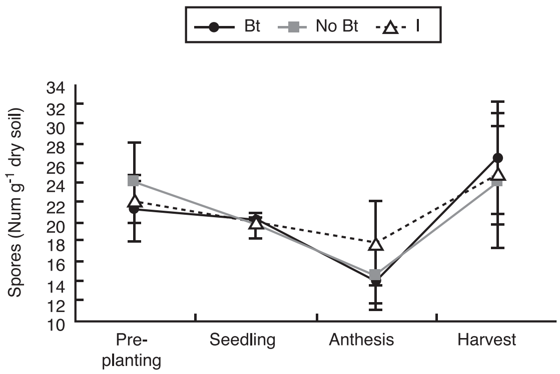


Figure 31. AMF spores/g soil in rice plots in China.

There were no significant effects on spore numbers due to the cotton genotype. There were, however, significant differences between years (Figure 32).

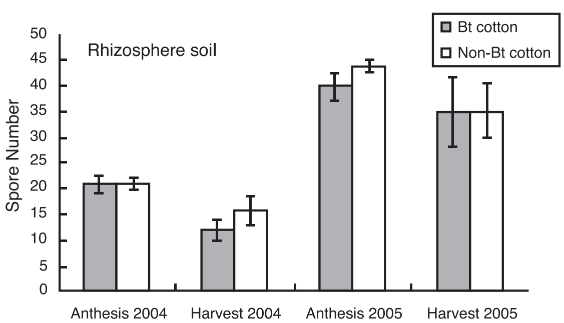


Figure 32. AMF spores/g soil in cotton plots in Columbia.

In Colombia, AMF hyphae were extracted from six soil subsamples of 5 g 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 gridline-intersect method (Tennant, 1975) from 70 visual fields on each filter.

Table 34. AMF hyphal lengths in Bt and Non-Bt cotton plots in Colombia.

Sampling	Soil	Hyphal length (m g-1 dry soil)
Anthesis 2004	Rhizosphere	23.2a
	Bulk	14.5b
Harvest 2004	Rhizosphere	17.6a
	Bulk	8.0b
Anthesis 2005	Rhizosphere	14.8a
	Bulk	8.0b
Harvest 2005	Rhizosphere	14.9a
	Bulk	9.2b

Means followed by different letters are significantly different at the P<0.05 level (Tukey's test)

Results comparing AMF hyphal lengths in soils collected from Bt and Non-Bt cotton plots in Colombia showed no significant differences during two seasons of cotton cultivation (Table 34), suggesting that there was no adverse impact of cotton plants expressing the cry1Ac gene and containing the Cry1Ac protein on this measure of AMF abundance in the field.

Abundance of AMF – Glomalin

A protocol to estimate abundance of AMF by extracting and measuring glomalin ("easily extractable glomalin", EEG), using the Bradford total protein assay by Bradford (1976) as adapted by Wright *et al*. (1996), was tested and applied to all 2005 soil samples from the New York and China trials (Figure 33).

Glomalin (a purported biochemical surrogate for AMF abundance) varied by crop growth stage in corn and rice, and was significantly reduced by insecticide application in corn, but not affected by genotype in either 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 NonBt and NonBt+Insecticide plots in fields with a history of corn cropping, 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

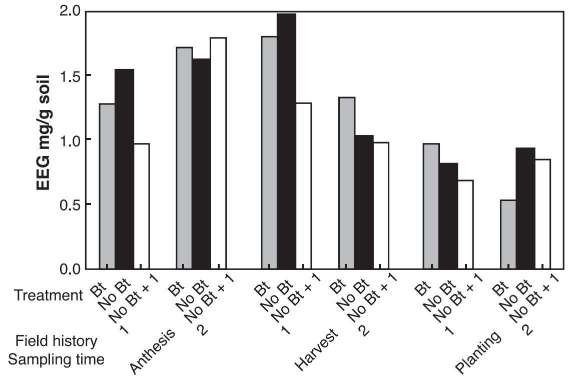


Figure 33. Easily extractable glomalin (mg/g) in soil from corn plots in New York.

the opposite held true at harvest. There was also a significant effect of sampling time ($p < 0.0001$).

The variability in glomalin measurements made by the published method is high, and recent findings in the Thies Laboratory suggest that the method may not be specific for glomalin, but it may be extracting other proteins from the soil as well. We have been working to develop an ELISA protocol, which would allow a quantitative and less variable means to determine glomalin concentrations in soil.

There were no significant differences due to rice genotype in glomalin extracted from rice soils in China (Figure 34). However, glomalin content varied significantly between sampling times.

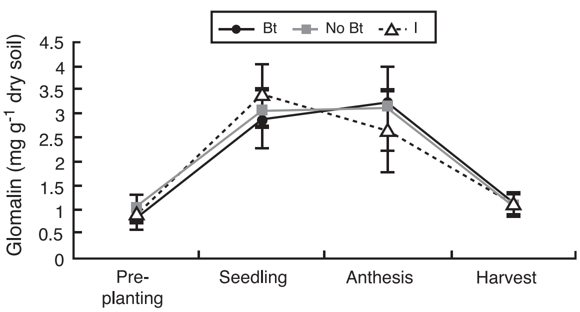


Figure 34. Glomalin extracted from rice soils in China in 2005.

Activity of AMF – Root Length Colonized

Root length colonized (presence of arbuscules, vesicles and hyphae) differed by growth stage in corn and by year in cotton, but not in relation to genotype or insecticide application in either trial.

There was no significant effect of corn genotype on percent root length colonized by AMF. However, there was a significant effect of growth stage on the different components of the symbiosis.

There was no significant effect of rice genotype on percent root length colonized by AMF. AMF colonization was only observed at harvest, but the extent was low.

There were no significant differences between cotton genotypes in the percent root length colonized. There was a significant difference between the years 2004 and 2005.

AMF Community Structure

A large number of AM fungal primers were tested by Luz Marina Londoño-R in the Thies laboratory at Cornell University for use in evaluating AMF diversity in these trials. Almost all primers tested lacked specificity and/or excluded important AM fungal genera from the analysis. One set of primers, coupled with a nested PCR protocol, gave good results and was used to analyze soils sampled from corn trials and DNA extracted from spores. Cloning and sequencing of DNA from soils and roots yielded sequences mostly confined to the genera *Glomus* and *Paraglomus* in the phylum Glomeromycota. No selection for particular genera was observed between the corn genotypes. Problems with the specificity of primers for use in molecular analyses of AMF diversity were summarized in last year's report and some are detailed in Table 35.

Of the other published primers considered, the VANS1 primer was found to exclude many Glomeromycota (Clapp *et al.*, 1995; Sanders *et al.*, 1996) and the AM1 primer was shown to fail to amplify the deeply-branching Glomeromycota (Helgason *et al.*, 1999; Daniell *et al.*, 2001). Hence, these could not be used in our studies. Two new primers (111F-851R; and 851F-ITS2R) were designed by downloading 18S rDNA sequences from Genbank, 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. Unfortunately, the specificity

Table 35. Summary of primers tested and their resultant specificity and utility for characterizing AMF populations in our studies.

	NCBI BLAST		Experimental Observations		
PRIMER	**COVERAGE**	**SPECIFICITY**	**Primer Pair**	**Specificity**	**Reference**
851	Good	Good	851F-ITS2	questionable	Thies lab, Cornell
851	Good	Good	111f-851r	Ascomycetes	"
851	Good	Good	851F-ITS4r	questionable	"
111	Good	Good	111F-nnSSU-1536R	Ascomycetes	Buckley lab, Cornell
LSU-Glom	Good	some Basidiomycetes	SSU-LSU-Glom	questionable	Renker *et al.*, 2003
AM1	Leaves 3 groups out	Good	AM1f-NS31r	questionable	Helgason, 1998; Ma *et al.*,2005
FLR3	Good?	some Basidiomycetes	FLR3-FLR4	Good	van Tuinen *et al.*, 1998, Gollotte *et al.*, 2004

of these primer pairs was not adequate for use in our studies (Table 35). The primer pair developed by van Tuinen *et al*. (1998), FLR3-FLR4, proved to be the most specific and to have the best coverage (Table 25). These primers will be used for all further diversity analyses of the AMF in our studies.

DNA from soil samples collected in the China rice and Colombia cotton experiments has been extracted and stored at -20ºC 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 was finalized in the Thies Laboratory. Now that a reliable PCR protocol has been established, DNA from the Colombia and China trials will be analyzed in the Thies laboratory at Cornell University in the coming year.

Objective 2. Assess the Abundance and Community Structure of Soil Detritivore Arthropods and the Community Structure of Bacteria and Fungi Colonizing Field Litterbag Residues of Bt Corn, Cotton and Rice

Litterbag Study Overview

Corn cobs, shoots and roots of plants were collected separately after harvest in 2005 from Bt, NonBt and NonBt+I plots in New York and stored at 4ºC. Residues were oven-dried at 65ºC until the weight of sub-samples was constant. Polyethylene mesh litterbags (12.5 x 12.5 cm; 2 x 3mm mesh size) were filled with 7 g of cobs, 10 g of shoots and 5 g of roots with two replicates for each sampling timepoint. 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.

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 were used rather than leaf blades as farmers return only the sheaths to the field. The mesh size of bags containing the fine rice roots was 0.5 x 0.5 mm, while that of bags containing the straw sheaths was 1.0 x 1.0 mm. Replicate root and straw bags were placed at the surface or at 10 cm depth in each plot.

In Colombia, litterbags consisted of aboveground biomass (shoots= stems + leaves + sexual structures) and belowground biomass (roots), all of which were initially air-dried followed by gentle drying at 40°C until constant weight. Plant material was cut into 10 cm pieces. Twenty grams of aboveground (tops) or belowground (roots) plant material were placed in 25 x 25 cm litterbags with a mesh size of 1 mm. Litterbags were placed in the field just prior to planting soybean on 12/02/04. Litterbags were sampled periodically for 26 weeks. All remaining surface and buried litterbags were removed from the field when the study was terminated in May 2006.

Detritivore Arthropod Abundance and Community Structure

Corn, rice and cotton litterbag residues were retrieved from the field at harvest in 2005 to determine the abundance and community structure of detritivore arthropods colonizing the residues. Enumerating and identifying detritivore arthropods on corn and cotton residues is ongoing, but initial data from rice residues.

These preliminary data suggest that the detritivore arthropod community is both less abundant and less diverse on rice residue samples placed at depth in the field compared to those that were placed on the soil surface. Neither abundance nor community structure of detritivore arthropods colonizing the residues differed between the straw and root residues.

Community Structure of Bacteria and Fungi Colonizing Corn Residues

T-RFLP DNA fingerprinting analysis was employed to assess the community structure of bacteria and fungi on corn cobs, roots and stalks in litterbags placed on the soil surface or at 10 cm depth in field plots. The litterbags were collected at harvest in 2005, bacterial and fungal DNA was extracted from residues, amplified, and digested using the restriction enzymes *Hha*1 and *Sau*96I for bacteria and *Hha*1 and *Msp*1 for fungi. Terminal restriction fragments (TRFs) were sized on an ABI 3730 at the Cornell Biotechnology Resource Center, Ithaca, NY, and resulting data analyzed by multivariate statistical approaches. Principal components analyses of the TRFs from bacterial and fungal communities colonizing corn residues are shown in Figures 35A and B and Figures 36A and B, respectively.

The bacterial community T-RFLP analysis is presented in Figures 35A (*Hha*I TRFs) and 35B (*Sau*96I TRFs), each of which consists of four panels. In each of the four panels, TRFs from samples representing the main effect treatments are highlighted. These are the effects of genotype (Treatment: Bt, NonBt, and NonBt+I -upper left); plant part (cobs, roots or stalks -upper right); residue placement (surface or buried -lower left); and field history (with or without corn root worm pressure, lower right). TRF fingerprints were unrelated to either genotype or plant part (upper left and right, respectively). However, clear separation of TRF fingerprints was observed for the effects of residue placement (lower left) and field history (lower right). These results indicate that while distinctly different bacterial communities colonized residue samples in litterbags placed on the soil surface vs. at 10 cm depth, and were different in plots with pest pressure vs. those without, neither crop treatment (genotype) nor plant part strongly influenced bacterial community composition as analyzed by T-RFLP using two restriction endonucleases.

The fungal community T-RFLP analysis is presented in Figures 36A (*Hha*I TRFs) and 36B (*Msp*I TRFs). In each of the four panels, TRFs from samples representing the main effect treatments are highlighted. These are the effects of genotype (Treatment: Bt, NonBt, and NonBt+I -upper left); plant part (cobs, roots or stalks -upper right); residue placement (surface or buried -lower left); and field history (with or without corn root worm pressure, lower right). As seen with residue-colonizing bacteria, TRF fingerprints for the residue-colonizing fungal community were unrelated to either genotype or plant part (upper left and right panels, respectively). However, clear separation of TRF fingerprints was observed for the effects of residue placement (lower left panel) and field history (lower right panel). These results indicate that distinctly different fungal communities colonized residue samples in litterbags placed on the soil surface vs. at 10 cm depth, and were different in plots with pest pressure vs. those without. However, neither crop treatment (genotype) nor plant part strongly influenced fungal community composition as analyzed by T-RFLP using two restriction endonucleases.

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

Carbon Allocation in Corn

$^{13}CO_2$ pulse-labeling of corn: In a glasshouse at Cornell University, Bt and NonBt corn seeds were planted in 96, 2 gallon 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 with $^{13}CO_2$ and un-labeled controls). Three corn seeds were planted and then thinned to one plant per pot containing peat, vermiculite, and perlite (1:1:1 by vol.) with 6 g pulverized limestone, 35 g $CaSO_4$, 42 g $FeSO_4$, 1 g fritted trace elements

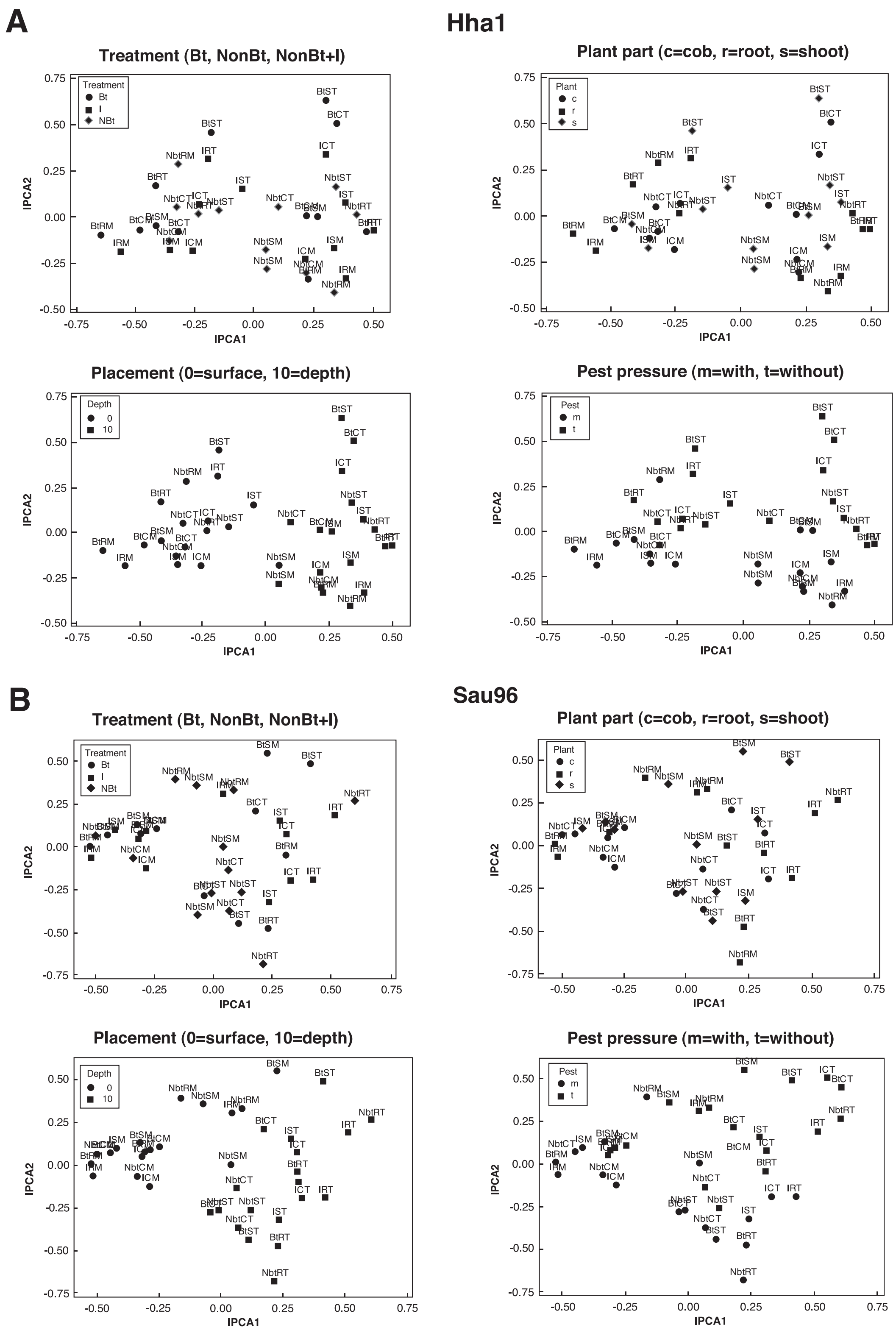


Figure 35. Principal components analysis of terminal restriction fragments obtained by [A] Hha1 and [B] Sau96I digestion of Bacterial 16S rRNA genes amplified from DNA extracted from Bt corn residue and non-Bt residue with and without insecticide applied. Variables examined include crop treatment, plant part, placement of litterbags and pest pressure.

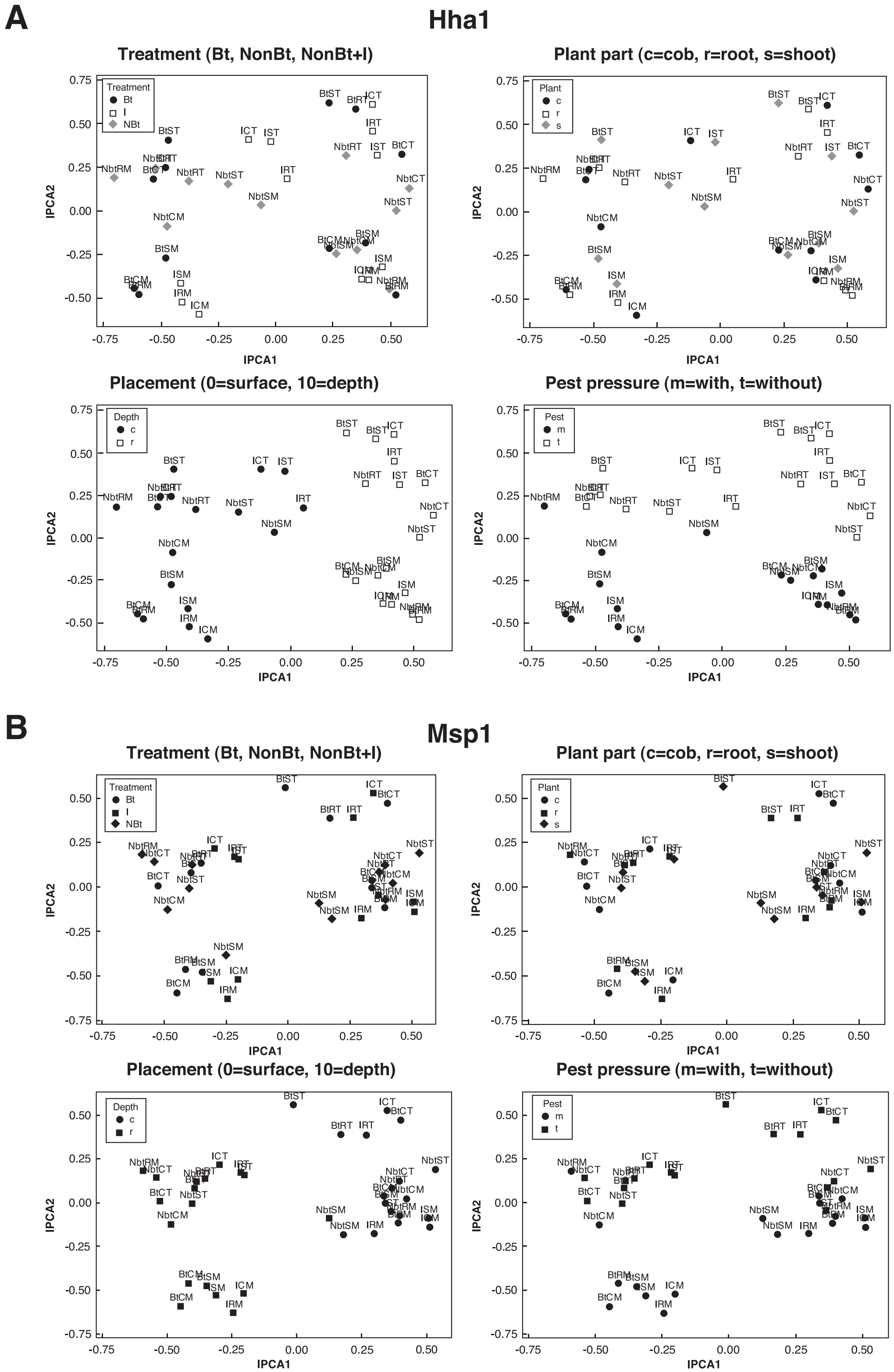


Figure 36. Principal components analysis of terminal restriction fragments obtained by [A] Hha1 and [B] Msp1 digestion of fungal ITS regions amplified from DNA extracted from Bt corn residue and non-Bt residue with and without insecticide applied. Variables examined include crop treatment (genotype), plant part, placement of litterbags and pest pressure.

(Peters FTE 555, Scotts Co., Marysville, OH), and 3 g 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., Berkley, CA) to prevent larval escape. Pots were irrigated daily, fertilized with nutrient solution weekly and the plants subjected to ambient light for 14 h. All pots were allowed to drain after each watering. Western corn rootworm eggs (*Diabrotica virgifera virgifera*) procured from USDA's Northern Grain Insects Research Lab (Brookings, SD) were 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.

Plants to be labeled with $^{13}CO_2$ were place into saran bags that were sealed around the stem of each plant to prevent labeling of the soil or roots. Replicate plants were labeled at the V6 growth stage with 99.99% atom $^{13}CO_2$ to achieve 1.029 g ^{13}C/plant. These plants were harvested at V7 (two days after labeling) and at R5 and ^{13}C content measured by mass spectrometry for different plant tissues. Additional plants were labeled with (2) 50 atom% $^{13}CO_2$ to achieve ~ 0.25 g ^{13}C/plant and harvested at V7 and R5 and ^{13}C content measured by mass spectrometry for different plant tissues.

The amount of ^{13}C in different plant parts in plants from the second labeling was measured at the V7 and R5 (reproductive stage 5; all or nearly all kernels are dented or denting) growth stage with and without insect pressure (Figure 37), along with plant height at V7, R5, and R7 (senescence), which is shown in Figure 38A, B and C. Dry weight of plant parts was measured at R5 and R7. Total C content in plant parts at R5 and acid detergent lignin concentration and content within plant parts were

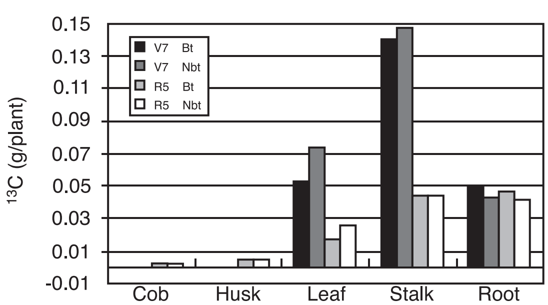


Figure 37. Amount of ^{13}C (g) in corn cobs, husks, leaves, stalks, and roots of Bt and Non-Bt corn at the V7 and R5 growth stages.

also determined in an effort to assess whether the form and or amount of carbon allocated to different plant structures varied with genotype.

Our data show that at V7, NonBt corn allocated more ^{13}C into leaves and stalks than Bt corn (Figure 37). Although this was true for leaves at R5, carbon allocation to stalks at this stage was about 53 percent for both genotypes. In contrast, ^{13}C allocated to roots was slightly higher in Bt as compared to NonBt plants.

NonBt plants grew taller than Bt plants (Figure 38). Rootworm pressure had an effect on both genotypes, causing an increase in plant height compared to control plants without rootworms.

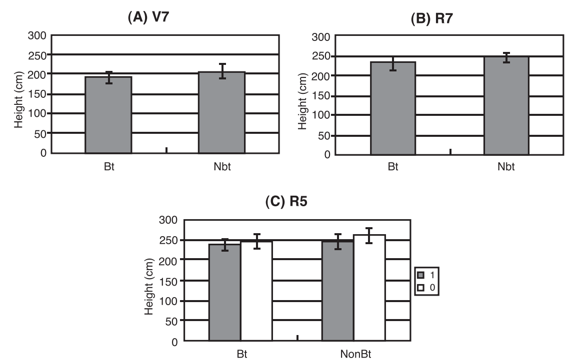


Figure 38. Height (cm) of the Bt and NonBt corn genotypes at (A) V7, (B) R7 and (C) R5 growth stages with (I) and without (0) insect pressure ($p < 0.05$).

In keeping with our findings on height differences between corn genotypes, the dry weight of NonBt plant parts was, in general, higher than that of Bt plant. Significant differences in dry weight were noted among plant parts, along with a significant interaction between dry weight and insect pressure at both growth stages. The pattern of total C content in Bt and NonBt genotypes was similar, except that Bt cobs accumulated more C than leaves, while the reverse was true for NonBt corn. The findings on total C content may be summarized as follows:

Bt: Roots > Stalks > Cobs > Leaves > Husks

NonBt: Roots > Stalks > Leaves > Cobs > Husks

Lignin concentration and content of Bt and NonBt corn plant parts as measured by the acid detergent lignin method did not vary significantly although lignin content in the plant parts was significantly

different as follows:
Root Lignin > Cob > Stalk > Leaf > Husk Lignin.

Residue Decomposition Rates for Bt Corn, Bt Cotton, and Bt Rice

Decomposition rates were assessed for residue in litterbags placed on the soil surface or at 10cm depth in the field for 14 weeks (corn), 39 weeks (cotton) and 52 weeks (rice) as described in the section on Objective 2. Baseline values for acid detergent lignin measured in the residues before placing them in litterbags are shown in Figure 39.

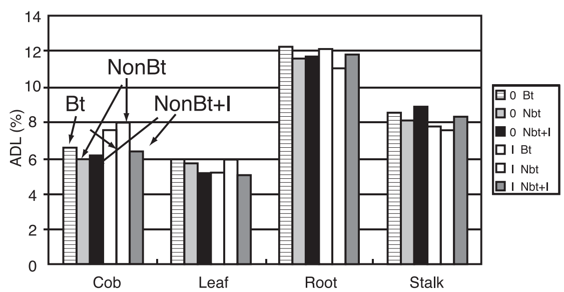


Figure 39. Acid detergent lignin content of cobs, leaves, roots, and stalks from Bt, NonBt, and NonBt+I field plots with (I) and without (0) rootworm pressure prior to placement of litterbags in the field.

Total C, N, and C:N ratio in Bt and NonBt rice residues before and after decomposition are given in Table 36, while C:N is graphically depicted in Figure 40.

There was no significant effect of genotype on corn shoot and cob decomposition after 14 weeks in the field in NY; however, shoot and cob material in litterbags buried at 10 cm depth decomposed faster than residues placed on the soil surface. Significantly more shoot and cob material was left after 14 weeks in plots where corn had been grown continuously for several years (rootworm present, I) compared to those that had a prior history of cropping to alfalfa (low or no rootworm pressure, 0). These results are consistent with data on the community composition of residue-colonizing bacteria and fungi (Figures 35 and 36), which also differed according to residue placement and field history. Combined, these results suggest that environmental factors associated with the placement location of residues (moisture, temperature, UV, etc.) were the dominant factors controlling both the composition of decomposer communities and the resulting rate of mass loss of the residues in the field.

Lignin content of the residues prior to placing them in litter bags in the field did not differ significantly with crop genotype for any plant part, but there was a significant effect of field history (with and without rootworm pressure) on the acid detergent lignin content of the cobs ($p<0.05$). There was also a significant difference in lignin content between different plant parts and a significant interaction between plant parts and field history ($p<0.05$) (Figure 39).

Bt cotton residues showed small but significantly lower mass losses (i.e., less decomposition) than non-Bt cotton residues only at the 8 and 12 week samplings. However, these initial differences were transient, and disappeared in subsequent samplings, suggesting that Bt and NonBt tops and roots decompose at similar rates in the field. As was observed for corn in NY, there was a significant effect of plant part and placement in the field for cotton residues in Colombia, with tops decomposing faster than roots, and soil incorporated roots and tops decomposing faster than those placed on the soil surface. These data again suggest that environmental factors (moisture, temperature and UV) were the stronger controls on residue decomposition rates than genotype.

Decomposition of Bt and NonBt rice straw and roots did not differ significantly. Although weight loss was greater for straw than for roots, this difference was not significant. In contrast with the results for corn and cotton, weight loss was significantly greater for residue samples at the soil surface, compared with those at depth. This result is not surprising considering that the field plots were water-saturated for much of the growing season. The resulting anaerobic conditions may be expected to depress the activity of decomposers.

The data presented in Table 36 and Figure 40 show that there were no significant differences between Bt and NonBt residues for total C, N, or C:N, and although some differences existed between residues at the soil surface vs. at depth for these variables, and between straw and roots, these differences were not consistent.

Table 36. Total C, N and C:N in rice residue before and after decomposing in field soils for 52 weeks.

	Status*	C %	N %	C:N
Bt straw	Control	34.4±0.47a	1.13±0.09a	30.7±1.42a
Ck straw	Control	35.4±0.19a	1.13±0.03a	31.3±0.45a
Bt straw	Surface sample	28.5±6.36a	1.63±0.21ab	17.3±2.34bc
Ck straw	Surface sample	28.1±5.21a	1.82±0.26ab	15.3±0.96b
Bt straw	Underground sample	32.9±2.97a	1.63±0.19b	20.3±1.80c
Ck straw	Underground sample	29.2±6.51a	1.63±0.23ab	17.7±2.05bc
Bt root	Control	38.6±0.14a	1.25±0.09a	30.8±1.55a
Ck root	Control	37.9±0.16ab	1.30±0.05ab	29.2±0.95a
Bt root	Surface sample	21.3±4.60d	1.47±0.20ab	14.3±1.48b
Ck root	Surface sample	24.4±4.81bc	1.66±0.20bc	14.6±2.02b
Bt root	Underground sample	29.4±3.90d	1.57±0.14c	18.6±1.45c
Ck root	Underground sample	19.6±1.93bc	1.55±0.19bc	19.2±0.95c

* Control refers to the original residue; sample refers to the sample decomposed for 52 weeks. Values within a column followed by the same letter are not significantly different (P<0.05).

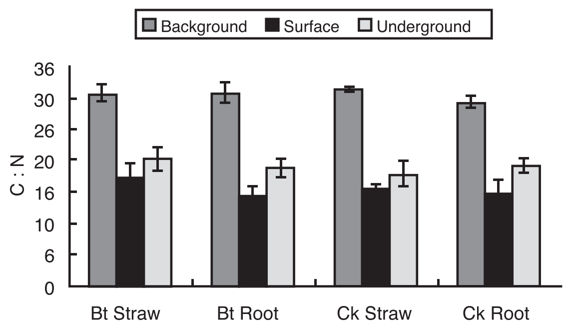


Figure 40. C:N during in Bt and NonBt rice straw and root residue in litterbags placed at the soil surface or at 10 cm depth in the field.

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

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

Summary

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 4.7 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.

Introduction

Accessibility to water and phosphorus has been identified as some of the major constraints in agricultural settings around the world. It has been estimated that phosphorus deficiency can limit yields in about 90 percent of cultivated soils. In addition, water deficits during critical developmental stages can have significant detrimental effects on productivity. Suitable fertilization practices as well as technologically advanced irrigation systems can be used to ameliorate these problems, but their implementation is not always economically feasible, especially in low input agricultural systems. Developing cultivars adapted to marginal edaphic conditions can reduce the complexities and challenges of soil management strategies and practices.

The first step in the development of such cultivars is the identification of adaptive root traits that can change the outcome of plant-soil interactions under sub-optimal conditions, and of the genes that control these traits. Genetic variation for phenotypic plasticity in root growth patterns has been observed in the common bean. Some accessions can alter the root growth pattern in response to phosphorous levels in the soil in a way that increases the efficiency of P-uptake. Genetic manipulation of this trait can lead to the development of cultivars that are highly efficient in P uptake. Unfortunately, there is a paucity of information on the genetics of root characters in the scientific literature. This is mainly due to the intrinsic technical difficulties of obtaining reliable root measurements.

Root size and morphology have been determined using several indirect methods. However, these methods are laborious, destructive and not necessarily accurate. In contrast to these methods, magnetic resonance imaging (MRI) is a technique that offers a great number of advantages for measuring several root characteristics in a non-destructive manner. MRI of biological specimens is based primarily on the nuclear magnetic resonance (NMR) properties of water hydrogen. MRI yields a set of tomographic images that can be integrated into a volumetric image.

The Advanced Magnetic Resonance Imaging and Spectroscopy Facility (AMRIS) is an integral part of the Center for Structural Biology located at the University of Florida McKnight Brain Institute. AMRIS has several spectrometers available for the UF research community. Although this facility has been primarily used for medical research, it is also accessible for plant research and roots in particular.

The objectives of this project are to implement MRI technology for studying the genetics of root characters and to use molecular marker technology to identify and map genes that control these characters. This information can lead to development of cultivars possessing root traits adaptive to low input agriculture, and to the addition of the genetic information to the existing Crop-Soil model to predict the impact of using genetically improved cultivars in specific soil environments.

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*

Objective 1, 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.

We have screened several soils 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% and Hectorite clay 20%.
- Mineral sandy soil (local).

Objective 1, 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 B0 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 1, Output 3: Development of a Probability Function for Roots

Although we have the ability to obtain intact root images from seedlings at different stages of development (Figure 41), we have not been able to perform a quantitative analysis of the imaged roots. To overcome this problem we have established a collaborative arrangement with Professor Baba Vemuri from the Computer and Information Sciences and Engineering Department at the University of Florida. A tensor model is being used to develop a set of algorithms that will be used to trace the roots in a 3-D space (Figure 42). These root traces will then be used to derive a probability function that will describe root volume, root density and branching patterns.

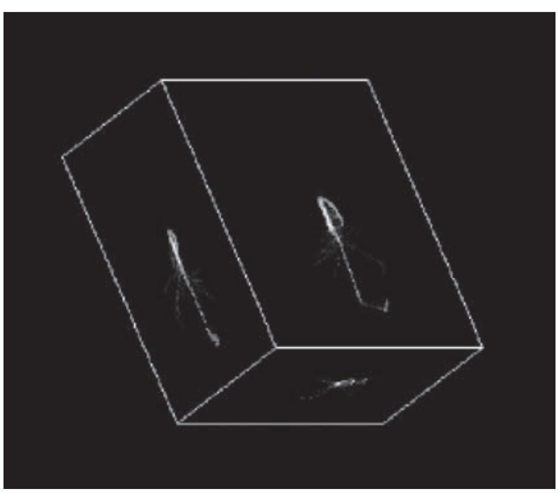


Figure 41. Image of a seven day old Calima seedling.

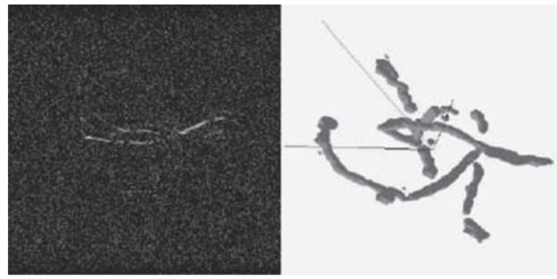


Figure 42. MRI data from Calima. Eight day old seedling (slice 119). A) MRI image, B) Digitized trace.

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

Objective 2, 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 (F_{10}) 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. F_2 progenies among these lines have been generated for future genetic analysis if needed.

Rhizotrons have been built to study root growth, and pre-screen and select phenotypes for MRI analysis. These rhizotrons encase a 3 mm layer of soil between black and clear Plexiglas sheets; 3 mm spacers are placed at the lateral edges. A soil bed is attached to the top of the rhizotron to accommodate the large bean seed. The rhizotron is tilted back at a slight angle with the clear Plexiglas sheet facing down to facilitate viewing of the roots by forcing them to grow against it. Roots were analyzed using Image Pro Plus, a software package commonly used in medical studies. Initial quantitative analysis of roots with this system has revealed drastic differences between the Mesoamerican cultivar Jamapa and the Andean landrace G19833 (Figures 43 & 44). The rate of tap root elongation is seven times greater in G19833 than in Jamapa, while the addition of new branches is 10 times greater in G19833 than in Jamapa.

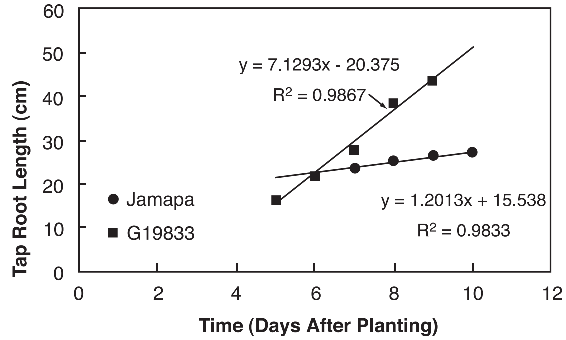


Figure 43. Growth analysis of tap root lengths in seedlings of Jamapa and G19833.

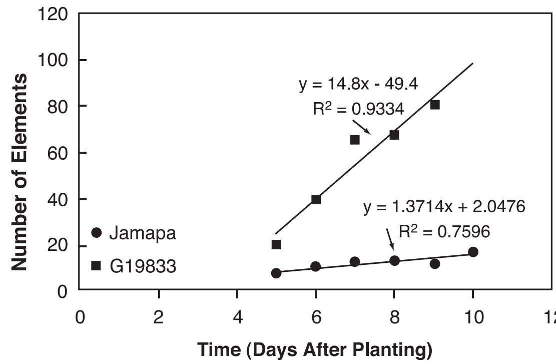


Figure 44. Analysis of the branching patterns of Jamapa and G19833 seedlings.

Objective 3: To Identify and Map, via QTL Analysis with Molecular Markers, Genes that Control Root Characteristics in the Common Bean

No progress was made on Objective 3 in PY9.

Objective 4: To Add the Genetic Information to the Existing Crop-Soil Model to Predict the Impact of Using Genetically Improved Cultivars in Specific Soil Environments

Objective 4, Output 1: A Genetic-based Crop-Soil Model Receptive to Molecular Marker Inputs

The parental genotypes and their recombinant inbred family have been grown at the University of Puerto Rico by Dr. James Beaver. Phenological and yield data for these genotypes have been made available to us for analysis. Computer simulations of root responses to irrigation have been generated for the parental genotypes using climate data from the Mayaguez Station in Puerto Rico. Figure 45 shows no significant root responses to irrigation treatments during the first 50 to 60 days after planting, and a significant effect was detected afterwards. What is interesting to note is the difference in root mass accumulation that appear between the parental genotypes following the first 50 days after planting. This observation raises the question of whether Jamapa has genes encoding greater root

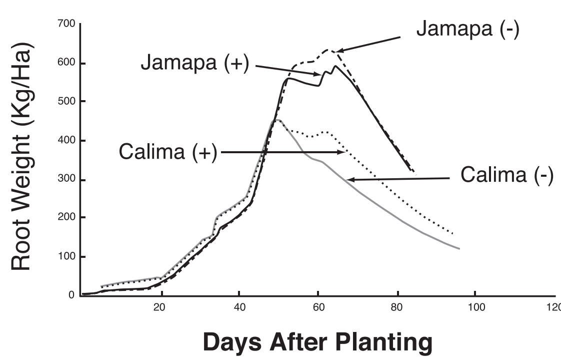


Figure 45. Computer simulations of root mass accumulation in the presence (+) or absence (-) of irrigation.

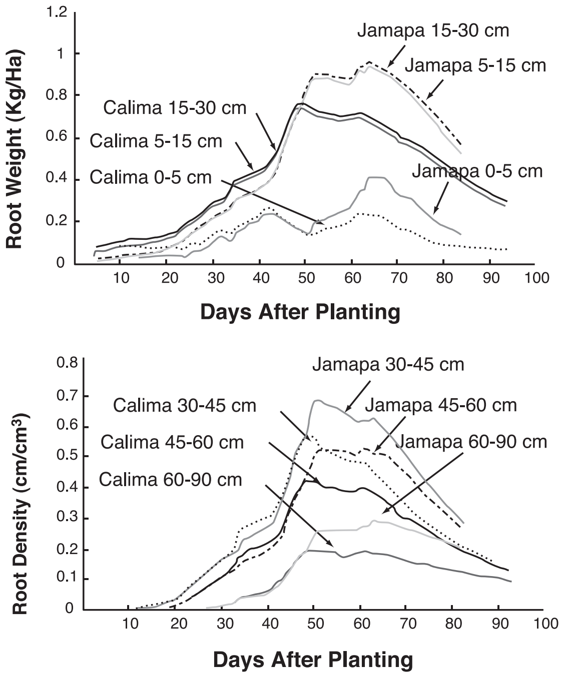


Figure 46. Computer simulations of root densities at different soil depths.

mass accumulation than Calima, or that the difference in growth habit is related to the difference in root growth. This issue will be addressed with the recombinant inbred family. Genetic analysis of this family will permit us to determine whether genes controlling root growth segregate independently of the gene that controls shoot growth habit. Simulation of root densities also showed (Figure 46) that significant differences between Jamapa and Calima can be detected more easily approximately 50 days after planting. At all depths Jamapa has greater root density than Calima. It will be interesting to determine the genetic complexity of this trait and its relationship to root branching.

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

A final activity of the SM CRSP in Timor-Leste was a workshop involving staff members of MAFF and the National University of Timor-Leste (UNTL) on the application of NuMaSS with field observations of soil properties. While this approach has proved successful in both Thailand and the Philippines, where soil surveys at regional levels were complete, this workshop was conducted at the request of the director of the MAFF Crops Division. The director, Deolindo da Silva, had participated in a SM CRSP workshop in Bangkok on NuMaSS in 2003 and requested our assistance in implementing this training activity as a follow up to previous sessions on the use of soil test kits, even though comparable soils information were not readily available for almost all regions in the country.

Samples from three locations in Baucau were used in the workshop to provide participants with hands-on experience to distinguish between soil color and texture. Soils from these three locations were previously studied by USDA/NRCS soil scientist, Patrick Niemeyer. His findings corroborated the geomorphic delineations proposed in the 1978 soil survey report of Timor-Leste (J.S. Garcia and J.C. Cardosa. 1978. Os Solos de Timor. Junta de Investigações Científicas do Ultramar, No. 64, Lisboa).

The all-day workshop also included a session on the use of handheld computers to assist MAFF officers in entering input soil and plant data and information to diagnose soil nutrient status and to allow them to enter economic values and costs that would allow them to provide options to farmers based on personal discussions with them. They were reminded that outputs from the computers were limited to the Baucau area where soil information could be corroborated with existing soil maps. Inputs and outputs from the handheld computers were programmed in the national language, Tetun. Richard Ogoshi of UH with translation provided by Michael Jones of GTZ organized and implemented the training.

The candlenut oil enterprise initiated during the sub grant period and supported through the USAID small grants program involving the University of Hawaii's College of Business Administration, Acelda (a small Timor-Leste enterprise in Baucau), and Oils of Aloha (a small U.S. enterprise in Waialua, Hawaii) was successfully established. The first shipment of candlenut oil was shipped to the U.S. in April 2006. Further information is available at the project URL, http://tpss.hawaii.edu/tl.

PARTICIPATING AND COLLABORATING SCIENTISTS AND INSTITUTIONS/ ORGANIZATIONS

National Agricultural Research Systems

Angola
Faculdade de Univ. Agostinho Neto
D. Kiala

Instituto de Investigacão
F. Almeida

USAID
G. Cambuta

World Vision
C. Asanzi

Bangladesh
Bangladesh Agricultural Research Institute (BARI)
M.E. Baksh
M. Bodruzzaman
M.I. Hossain
P.K. Malaker
A.E. Rahman
M.A. Sufian
A.M.H.S. Talukdhar

Bangladesh Agricultural University (BAU)
M. Jahiruddin
M.A. Kashem

Bangladesh Rice Research Institute (BRRI)
M.A. Mazid
D.N.S. Paul

Bangladesh Rural Advancement Committee (BRAC)
S. Ch. Nath

Cooperative for American Relief Everywhere (CARE)
Md. G. Talukder
N.D. Tex

Rangpur-Dinajpur Rural Service – Bangladesh NGO (RDRS)
M.E. Neogi
S. Samsuzzaman

Winrock Intnl.-BREAD II
S.M.S. Anwar

Bolivia
Foundation for Andean Products Research and Promotion, Bolivia (PROINPA)
Antonio Gandarillas
Pablo Mamani

Instituto Boliviano Technologia Agropecuaria (IBTA-Chapare)
Armando Ferrufino

Brazil
Brazilian Agricultural Research Enterprise-National Beef Cattle Research Center (EMBRAPA-CNPGC)
Manuel Macedo

Brazilian Agricultural Research Enterprise-Humid Tropics Research Center (EMBRAPA-CPATU)
Edilson Brasil
Manoel S. Cravo
Oscar Lameira
Austrelino Silveira Filho

China
Zhejiang University
Weixiang Wu

Colombia
International Center for Tropical Agriculture (CIAT)
Edmundo Barrios

Costa Rica
University of Costa Rica
Alfredo Alvarado
Gloria Melendez

Ecuador
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Potash & Phosphate Institute (INPOFOS)
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Gambia

National Agricultural Research Institute (NARI)
F. Fatajo
A. Jarju

Ghana

Savanna Agricultural Research Institute (SARI)
L. Abatania
J. Naab

University of Ghana
Samuel Adiku
Gabriel Dowuona

Honduras

Candelaria Community Technical Institute (ITC)
Juan López

Food and Agriculture Organization (FAO)
Edgardo Navarro

International Tropical Agriculture Center (CIAT)
Miguel Ayarza
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Oscar Mejia (MOVIMONDO)
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Elvis Murillo (CISP)
Santiago Pineda ((Vecinos Mundiales)

Regional University Center for the Atlantic Coast (CURLA)
Manuel López

Kenya

Kenya Agricultural Research Institute (KARI)
P. Gicheru
F. Maina

World Agroforestry Center (ICRAF)
K. Shepherd
L. Verchot

Laos

National Agricultural and Forestry Research Institute (NAFRI)
Kouang Doungsila

Mali

Institut d'Economie Rural (IER)
A. Ballo
A. Berthé
M. Doumbia
H. Konaré
S. Sissoko
Y. Toloba
M. Vaksman (CIRAD)
A. Yoroté

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Pierre C. Sibiry Traore

Institut de I'Environnement et de Recherches Agricoles (INEAR), Burkina Faso
Boubié Vincent Bado

Mexico

National Forestry and Agricultural Research Institute, Mexico (INIFAP)
Jaime Salinas-Garcia

Mozambique

Instituto de Investigacões Agrárias de Mozambique (IIAM)
Ricardo Maria
Candida Xavier
S. Xerinda

Nepal

District Agricultural Development Office (DADO)
R. Upreti

Educate the Children – Nepal NGO (ETC)
M.M.S. Rana (Mrs.)

Institute for Agriculture and Animal Science (IAAS) Rampur
K. Basnet
K. Dahal
S.C. Sah
S.M. Shrestha

Intermediate Technology development Group (IDTG)
S. Justice

International NGO – Cooperative for American Relief Everywhere (CARE)
R. Khanal
B.K. Pokharel
B. Thapa

Nepal Agricultural Research Council (NARC)
G.S. Giri
S.M. Maskey (Dr./Mrs.)
S. Rai
G. Sah
K. Scherchand
J. Tripathi
J. Tuladhar (Dr./Mrs.)

Univ. Wales/Dept. for International Development-UK (DFID)
K.D. Joshi

Winrock International-Nepal
L.A. Colavito

Winrock-SIMI
B. Bhatta
B.K. Gurung

Netherlands
Wageningen University and Research Center (WUR) and
Institute of Agricultural Economics (LEI)
A. de Jager (WUR/LEI)
A. Kuyvenhoven (WUR)
G. Meierink (WUR/LEI)
Jetse Stoorvogel (WUR)

Nicaragua
International Center for Tropical Agriculture Center (CIAT)
Edwin Garcia

National Institute for Agricultural Technology (INTA)
Luis Urbina
Reinaldo Navarrete
Jorge Olivares

Panama
Panama Agricultural Research Institute (IDIAP)
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Adeflor Garcia

University of the Philippines Los Banos (UPLB)
Rodrigo Badayos

Senegal
Ecole National d'Economie Applique (ENEA)
B. Faye
I. Diop Gaye
I. Hathie
A. Thiam

Institut Sénégalais de Recherches Agricoles (ISRA)
A. Dieng
P.N. Diéye
A. Fall
M.D. Faye
M. Khouma
C.M. Ndione
Modou Sene
M. Ndiaye

Thailand
Kasetsart University
Tasnee Attanandana

Eco-community Vigor Foundation
P. Verapattananirund

Department of Land Development (DLD)
B. Boonsompopphan

Ministry of Agriculture (MOA)
D. Harnpichitvitaya
S. Jearakongman

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P. Khangkhun
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N. Uphoff
S. Williams (Natl. Research Ecol. Lab, Colorado State Univ.)
P. Woodbury

Montana State University
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USDA Plant Physiology/Nutrition
R. Welch (Cornell)

Virginia Tech University
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International Agricultural Research Centers (IARC)

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N.E. Elahi (Bangladesh)
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Bangladesh Agricultural Univ.			
Md Bodruzzaman	Bangladesh	M	PhD
Md. Etear Uddin	Bangladesh	M	MSc
Tribhuvan University (Nepal)			
J.B. Adhikari	Nepal	M	MSc
Mahendra Aryal	Nepal	M	MSc
Nabin Dangel	Nepal	M	MSc
Rajendra Gautam	Nepal	M	MSc
R. Ghimire	Nepal	M	MSc
Shyam Kandel	Nepal	M	MSc
Arati Nepal	Nepal	F	MSc
Puspa Poudel	Nepal	M	MSc
Deepak Sapkota	Nepal	M	MSc
Florida			
Florida University			
Carrie Alberts	USA	F	MSc
Welch M. Bostick	USA	M	PhD
Kofikuma Dzotsi	Togo	M	MSc
Yibing Fu	China	M	PhD
Jawoo Koo	S.Korea	M	PhD
Ozlem Subakan	Turkey	F	PhD
Valerie K. Walen	USA	F	MSc
Sherbrooke University (Canada)			
Pierre C. Sibiry Traoré	Mali	M	PhD
University of Ghana			
N.K. Amon	Ghana	F	MSc
Stephen Narh	Ghana	M	MSc
Montana			
Montana State University			
Kara Gray	USA	F	MS
Roberto Valdivia	Peru	M	PhD
National Agrarian University (Peru)			
Denis Arica	Peru	M	MS
Renzo Barron	Peru	M	MS

Wageningen University (Netherlands)			
Guillermo Baigorria	Peru	M	PhD
Reinier Ellenkamp	Netherlands	M	MS
Abibou Niang	Senegal	M	MS
Cecilia Romero	Peru	F	PhD
Alejandra Mora Vallejo	Chile	F	PhD

Hawaii

University of Hawaii			
Hamidou Konare	Mali	M	PhD
A. Sidibe-Diarra	Mali	F	PhD
Antonio Querido	Cabo Verde	M	PhD
Kasesart University (Thailand)			
K. Dounphady	Laos	M	MSc
P. Limpatganangkul	Thailand	F	MSc
W. Nilawonk	Thailand	F	PhD
N. Sipaseuth	Laos	M	PhD
V. Souvana	Laos	M	MSc
S. Yampracha	Thailand	F	PhD
Université Cheikh Anta Diop de Dakar (Senegal)			
Roger Bayala	Ivory Coast	M	PhD
Abibou Niang	Senegal	M	MS
University of Bamako			
Souleymane Kanta Kiari	Mali	M	Ing.
Seriba Konaré	Mali	M	Ing.

Non-Degree Programs

Name	Home Country	Gender
Cornell Non-Degree Programs		

Name	Home Country	Gender
Cornell		
Raquel Serohijos	Philippines	F

North Carolina State University

Dagoberto Amador	Honduras	M
Leonel Castellanos	Honduras	M
Rafael Flores	Honduras	M
Edwin Garcia	Honduras	M
Wilfredo Lagos	Honduras	M
Manuel López	Honduras	M
Juan Carlos López	Honduras	M
Oscar Mejia	Honduras	M
Wilmer Mejia	Honduras	M
Elvin Murillo	Honduras	M
Reinaldo Navarrete	Nicaragua	M
Edgardo Navarro	Honduras	M
Jorge Luis Olivares	Nicaragua	M
Esmelyn Padilla	Honduras	M

Mario Piñeda	Honduras	M
Satiago Pineda	Honduras	M
Nestor Rivera	Honduras	M
Luis Urbina	Nicaragua	M

Workshops

Workshops	Location	Date	No. Attended
Carbon (Florida) (Application of DSSAT Models)	Accra, Ghana	10/05	28
(TOA and DSSAT Models)	Accra, Ghana	02/06	12
Carbon (Hawaii)	Mali	2005	5
NuMaSS (Hawaii)	Philippines	01/24-25/05	6
	Philippines	01/24-26/06	25
	Laos	01/05	35
	Laos	07/17-19/06	30
Rice-Wheat (Cornell)	Nepal	8/3/05	54
	Nepal	9/05-02/06	150
	Nepal	03/27-31/06	200
	Bangladesh	08/28,31/05	38
	Bangladesh	8/15/05	20
	Bangladesh	9/2/05	10
	Bangladesh	2/24/06	80
	Bangladesh	3/8/06	204
	Bangladesh	4/12,13/06	100
	Bangladesh	4/19/06	24
	Bangladesh	4/30/06	23
	Bangladesh	5/4,7/06	58
Trade Off (Montana)	Accra, Ghana	03/2-3/06	19
	Pallisa, Uganda	03/8/06	25

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."

Program Review

The major activity of the past year was the review of project progress and accomplishments by the External Evaluation Panel (EEP). The EEP review was finally given the green light to proceed at the end of annual meeting of the SM CRSP in Kona, Hawaii in July 2005. Confirmation was provided to the ME and the PIs by David Hess, director of the EGAT/NRM office. His attendance and participation were the first by any sitting director. Tentative plans for on-site visits were then discussed with PIs before the end of the annual meeting. On-site visits were to be planned in coordination with the PIs as they planned their annual visits to host country sites.

Next, the ME was responsible for nominating candidates to serve as members of the EEP. Three members from the 1999 Panel, Will Blackburn, Eric Craswell, and Amit Roy were contacted. All three consented to serve. James Tiedje, a biotechnologist from Michigan State, was the fourth and final member. The nominees were approved by the Agency in the early fall of 2005. Plans were then established with the CTO to hold a meeting of the EEP in Washington, DC in December.

In November, Amit Roy, President and CEO of IFDC, informed the ME of his intent to withdraw due to probable conflicts in time with his schedule to implement plans of new IFDC activities in Africa in early 2006. A possible replacement with connections to IFDC proved unsuccessful. The ME then consulted with our CTO on possibly involving one of the external members of the Technical Committee, E. Bronson (Ron) Knapp. McGahuey concurred. Knapp agreed to serve and was subsequently nominated and approved to serve on the EEP by USAID.

On-site visits would be planned for early to mid 2006. We anticipated having at least one or two members of the EEP along with the CTO and the ME participate in each of these site visits.

There was one other change after the first meeting of the EEP with USAID in December. Because of a family emergency, Knapp was not able to travel as planned in January to the Thailand, Bangladesh, and the Philippines and to Mali in February 2006. The second external member of the TC, Tom Walker, who worked in Mozambique at the time, agreed to substitute for Knapp in Thailand. His participation was approved by USAID.

Scope of Review

The first meeting of members of the EEP was held in the offices of the Africa Bureau in Washington, D.C. to review the terms of reference and a proposed schedule for on-site visits. Eric Craswell agreed to serve as chair of the EEP.

The general responsibility of the External Evaluation Panel (EEP) was to assess accomplishments and progress leading to individual project objectives and to determine the collective contributions of these projects in achieving the objectives of the SM CRSP's global plan. To complete this task, panel members performed a desk review and then made selected on-site inspections of individual Phase 2 projects to assess their current and potential impacts. A survey questionnaire was developed to help the EEP assess project impact. The questionnaire would be sent by email to host country scientists and the principal investigators before any of the on-site visits to obtain anonymous responses to questions prepared by the EEP.

The final schedule and itinerary for the EEP's on-site visits are shown below.

Schedule and Itinerary for EEP On-site Visits:

December 15, 2005 -SM CRSP
Planning Meeting of EEP members with USAID (David Hess, Jeff Brokaw, and Mike McGahuey) in Washington, D.C.

January 15 to 18, 2006 -NuMaSS
Site visit in **Thailand** by Tom Walker (EEP), substituting for Ron Knapp, and Gordon Tsuji (ME).
PI: Tasnee Attanandana and Russell Yost
January 15—Arrive in Bangkok.
January 16—On-site review and meetings at the Suphan Buri Research Station.
January 17—Meetings at Kasetsart University.
January 18—Depart from Bangkok.

January 18 to 21, 2006 -Rice-Wheat Technology Adoption/Carbon Sequestration
Site visits in **Bangladesh** by Eric Craswell (EEP), Gordon Tsuji (ME) and Bob Hedlund (USAID).
PI: John Duxbury and Julie Lauren
January 18—Meeting with USAID mission by Hedlund; Craswell and Tsuji arrive in Dhaka; drive to Rajshahi (4 hrs).
January 19—Rajshahi to Durgapur (site visit in Alipur); to Rangpur.
January 20—Rangpur to Thakugaon and Dinajpur.
January 21—Depart Dinajpur for Dhaka (6 hours) to Manila via Singapore.

January 22 to 26, 2006 -NuMaSS
Site visits in the **Philippines** by Craswell, Tsuji, Hedlund.
PI: Madonna Casimero and Russell Yost
January 22—Arrive in Manila, then to Munoz (Philippine Rice Research Institute).
January 23—Review sessions during annual meeting of collaborating national scientists at PhilRice.
January 24—Field visit to demonstrate soil identification methods and continuation of meetings/sessions.
January 25—Review session with participants at PhilRice.
January 26—Meeting with Daniel Moore and Oliver Agoncillo, USAID/Manila.

February 22 to 25, 2006 -NuMaSS/Carbon Sequestration
Site visits in **Mali** by Will Blackburn (EEP) and Mike McGahuey (USAID).
PI: Mamadou Doumbia, Abou Berthe, and Russell Yost
February 21—Arrive in Bamako.
February 22—On-site visit with meetings in Siguidolo.
February 23—Meetings with collaborators in Bamako
February 24—Meet with USAID/Bamako

February 26 to March 2, 2006 -Carbon Sequestration/Tradeoff Analysis
Site visits in **Ghana** by Blackburn and Jim Tiedje (EEP), McGahuey and Tsuji.
PI: James W. Jones (UF) and John Antle (Montana State)
February 26—Meeting with USAID mission and regional office staff in Accra.

February 27—Meetings and review sessions with carbon sequestration project lead by Florida and with the tradeoff analysis project lead by Montana State.
February 28—On-site visit and meetings at Kpeve.
March 01—Review session with collaborators in Accra.

April 19 to 22, 2006 -NuMaSS
Site visit in **Honduras** by Blackburn, Knapp (EEP), Tsuji, Uehara (ME) and McGahuey (USAID).
PI: Deanna Osmond and T. Jot Smyth
April 19—arrival into Tegucigulpa.
April 20 and 21—Meetings and review sessions with collaborators from Panama, Nicaragua, Mexico, and Honduras in Tegucigulpa.

May 11, 2006 -Biotechnology
Site visit to Cornell University by Teidje (EEP).
PI: Medha Devare and Janice Thies
May 11—Meetings and review sessions with PIs in Ithaca.

May 25, 2006 -Biotechnology
Site visit to the University of Florida by Teidje (EEP).
PI: Eduardo Vallejos, Melanie Correl, and James W. Jones
May 25—Meeting and review sessions with PIs in Gainesville.

June 27 to 30, 2006 -SM CRSP
Site: Denver, Colorado. Meeting of PIs with EEP.
June 27 and 28: Presentations of project accomplishments and progress by PIs.
June 29 and 30: Completion of first draft of EEP report.

The EEP report was printed and distributed in November 2006. In coordination with the CTO, M. McGahuey, Jr., the chair of the EEP made an oral presentation of their report to USAID on January 18, 2007 in Washington, D.C. Copies of the report are available on request.

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."

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 Denver (Aurora), Colorado at the Hilton Gardens

Inn Hotel in from June 27 to 30, 2006 as part of the EEP review process. Workplans and budgets for PY10 were presented along with progress reports made to the EEP in PY9. Both external members of the Technical Committee supported the EEP review by serving as members of the EEP due to the conflicting schedule of Dr. Amit Roy.

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
- Dr. James W. Jones, University of Florida

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 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. Tim Williams, Director of the Peanut CRSP at the University of Georgia.

Members of the Council are as follows.

Director	CRSP	Institution
Michael Carter	AMA	Wisconsin
Irv Widders	Bean and Cowpea	Michigan State

Tag Demment	Global Livestock	California, Davis
John Yohe	INTSORMIL	Nebraska
R. (Muni) Muniappan	IPM	Virginia Tech
Tim Williams	Peanut	Georgia
Hillary Egna	AquaFish	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 either 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 #16 to the Grant added $2.8M in September 2005 to the core budget for PY9 (Table 37).

Close out of bank accounts in Dili, East Timor was completed in March 2006. Titles for two Toyota 4WD vehicles purchased in 2004 were turned over to the USAID mission in Dili, also in March. The Ministry of Agriculture, Forestry and Fisheries (MAFF) received four weather stations installed in four locations in Baucau. All other remaining supply items were made available to MAFF offices in Baucau and in Dili.

Table 37. Incremental funding awards to the SM CRSP for the period covering February 11, 1997 to September 30, 2006.

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
Mod #16	9	$2,800,000	Oct. 1, 2005-Sept 30, 2006

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. Superscripts d & e refer to supplemental 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. Superscripts g & h refer to field support funds received by the SM CRSP from the AID mission in Timor-Leste & Angola respectively. Mod#15 refers to insert of the total listing of covered countries under the Management Collaborative Research Support Program Global Plan.

Expenditure Report

Tables 38a, 38b and 38c list the annual expenditure, annual cost sharing and summary of cumulative expenditure reports by institutions, respectively. Modifications to each sub agreement were executed as amendments to awards from USAID via the ME upon approval of annual workplans and budgets submitted by each Principal Investigator. In Table 38a, the UH totals reflect expenditure reports for two projects (NuMaSS and Carbon Sequestration) at UH with Russell Yost as PI, buyins from E. Timor and Angola, plus residual expenses of 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 (Carbon Sequestration, Rice-Wheat Technology Adoption, and Biotechnology) and of two projects (Carbon Sequestration and Biotechnology) at the University of Florida (UFl).

A six-month no-cost extension was requested for the field support activity in E. Timor. The project officially ended in January 2006 but close out of all accounts was not accomplished until June 2006.

The cumulative summary report also lists expenditures reported by projects from Phase 1 (1997 to 2002) involving Texas A&M, Florida and NifTAL (Hawaii).

Table 38. Financial summary statement ($'000) of expenditure, cost sharing and funding for PY 9 (Oct 1, 2005 to Sept 30, 2006) from vouchers received.

a. Summary of Expenditures reported during PY 9 (Oct 1, 2005 to Sept 30, 2006)

Institution	MSU	NCSU	CU	TAMU	NifTAL	UFL	UH	ME	Total
	561	251	668	0	0	272	717 *(SM CRSP)*	555	3,024
							223 *(Timor-Leste)*		223
							5 *(Angola)*		5
Total	561	251	668	0	0	272	945	555	3,252

b. Cost Sharing for PY 9 (Oct 1, 2005 to Sept 30, 2006)

Institution	MSU	NCSU	CU	TAMU	NifTAL	UFL	UH	ME	Total
	57	155	182	0	0	19	109 *(UH)*	N/A	522
							25 *(Timor-Leste)*		25
							2 *(Angola)*		2
Total	57	155	182	0	0	19	136	549	

c. Summary of Cumulative Core Funding (February 11, 1997 to September 30, 2006)

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	141	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 #11	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
Mod #16	531	241	723	0	0	337	601	367	2,800

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. Superscripts d & e refer to supplemental 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. Superscripts g & 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 insert of the total listing of covered countries under the Management Collaborative Research Support Program 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 in response to requests of a USAID field mission. Funds to support these additional activities are provided by the mission to the ME institution through the Office of Acquisition and Accounting (OAA). In PY9, there were no new buy-ins from missions. Closeout activities in Timor-Leste were completed in PY9.

Timor-Leste

The Timor-Leste Agricultural Rehabilitation, Economic Growth and Natural Resources Management project ended on December 31, 2005. Close out activities included termination of accounts at the ANZ (Australia/New Zealand) bank in Dili and the transfer of two Toyota 4WD pickup trucks to the USAID mission.

Follow-on activities related to ICM (integrated crop management) on rice production introduced by the project are being continued by MAFF with support provided by GTZ in Maliana and Baucau. Richard Ogoshi, UH staff, provided technical support through a contract with GTZ.

The project's final report is posted on its URL, http://tpss.hawaii.edu/tl. Additional reports and news are posted on that URL.

Angola

This one-year buy-in ended in PY8. Follow-on activities as reported by World Vision indicate this NGO will promote soil testing in Angola and neighboring countries.

The PI, Russell Yost of UH, continues to provide technical support to INIA and World Vision via email at no cost to USAID.

Cost Sharing

Table 39 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 of the modified total direct costs (MTDC) as specified in the CRSP Guidelines. The following costs are exempt from cost sharing:

- Funds to operate the ME.
- Funds committed under terms of a formal CRSP host country sub-agreement, 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.
- Costs for training participants as defined in ADS 253. Provisions for such training normally would be made in the formal sub-agreements.
- 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 list below by projects.

Table 39. The cost sharing contributions from each of the participating U.S. institutions involved with the Soil Management CRSP.

Project	Leveraged funds (est)	Subtotals
Carbon Sequestration		
IER, Mali	50,000	
ICRISAT, Mali	25,000	
NARI, The Gambia	50,000	
SARI, Ghana	50,000	
University of Ghana	50,000	
INERA, Burkina Faso	10,000	
BARI, Bangladesh	25,000	
BRRI, Bangladesh	25,000	
NARC, Nepal	25,000	
IAAS, Nepal	25,000	335,000
NuMaSS		
Kasetsart University	100,000	
Philippine Rice Research Institute	100,000	
NARFI, Laos	50,000	
IER, Mali	50,000	
NARI, The Gambia	25,000	
INIDA, Cape Verde	25,000	
INIA, Mozambique	25,000	
International Rice Research Institute (IRRI)	25,000	
ISRA, Senegal	50,000	
SARI, Ghana	25,000	
UCR, Costa Rica	50,000	
PROINPA, Bolivia	25,000	
CIAT-MIS, Honduras	25,000	
INIFAP, Mexico	50,000	625,000
Tradeoff Analysis		
International Potato Center (CIP)	50,000	
Wageningen Agricultural University (WAU)	50,000	
ISRA, Senegal	50,000	
Ecole Nationale d'Economie Applique Ecoregional Fund (ISNAR)	5,000	
Panama	50,000	
Kenya	75,000	
Sahel Agr Research Institute	5,000	
Consortium for Agr Mitigation of GHG	10,000	295,000
Rice-Wheat		
CIMMYT, Bangladesh	50,000	
IFDC, Bangladesh	25,000	
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	

Project	Leveraged funds (est)	Subtotals
RDRS, Bangladesh	10,000	
LiBird, Nepal	15,000	
FORWARD, Nepal	15,000	305,000
Biotech		
CIAT	25,000	
Zhejiang University	25,000	50,000
Field Support		
Timor-Leste		
MAFF	50,000	
GTZ	25,000	
Villages in Baucau Agricultural District	25,000	100,000
Angola		
World Vision	25,000	
CLUSA	5,000	
CRDA	5,000	35,000

TOTAL 1,745,000

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ACRONYMS

ACN	Aménagements en courbes de niveau; aka, ridge tillage
AMF	Arbuscular mycorrhizal fungi
ARMIS	Advanced Magnetic Resonance Imaging and Spectroscopy Facility
ATDP	Agro-based Industries & Technology Development Project (USAID Bangladesh)
BADC	Bangladesh Agricultural Development Corporation
BAME	Bureau of Macroeconomic Analysis
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BRAC	Bangladesh Rural Advancement Committee
BREAD	Bangladesh Rural Enterprise & Agricultural Development-Winrock
BRRI	Bangladesh Rice Research Institute
CAN	ados/courbes de niveau; ridge tillage
CARE	International NGO
CCX	Chicago Climate Exchange
Cerras	Centre d'étude regional pour amelioration de l'adaptation á la sécheresse
CIAT-MIS	International Tropical Agriculture Center-Integrated Steepland Management
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CO_2	Carbon dioxide
COF	Commercial organic fertilizer
CRSP	Collaborative Research Support Program
CSD	Chinese seed drill
CSM	Cropping System Model
CT	Conventional tillage
CURLA	Regional University Center for the Atlantic Coast
DAE	Department of Agricultural Extension (Bangladesh)
DAP	Diammonium phosphate
DADO	District Agricultural Development Office (Nepal)
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
EEP	External Evaluation Panel
ENEA	Ecole Nationale d'Economie Applique
EnKF	Ensemble Kalman Filter
EMBRAPA-CPATU	Brazilian Agricultural Research Enterprise-Humid Tropics Research Center
ETC	Educate the Children – Nepal NGO
ExKF	Extended Kalman Filter
FAO	Food and Agricultural Organization
FFS	Farmer Field School
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
IDTG	Intermediate Technology Development Group
IER	Institut d'Economie Rurale, Mali
IFDC	International Fertilizer Development Center
IGP	Indo-Gangetic Plains
IHCAFE	Honduran Coffee Institute
ILRI	International Livestock Research Institute
IMPACT	Integrated Modeling Platform for animal-Crop sysTems
INIA	Instituto Nacional des Investigacões Agricolas
INIAP	National Agricultural Research Institute, Ecuador
INIFAP	National Forestry and Agricultural Research Institute, Mexico
INPOFOS	Potash & Phosphate Institute
INTA	National Agricultural Technology Institute, Nicaragua
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
ISRA	Institut Senegalese de Recherces de Agricole, Senegal
ITC	Candelaria Community Technical Institute, Honduras
KARI	Kenya Agricultural Research Institute
KU	Kasetsart University
LCC	Leaf color chart
LEI	Landbouy Economisch Institute (Netherlands)
Li-BIRD	Local Initiatives for Biodiversity and Development
LOI	Loss on ignition method of carbon analysis
MOA	Ministry of Agriculture (Thailand)
MOET	Minus one element technique
MOU	Memorandum of Understanding
N	Nitrogen
NAFRI	National Agricultural and Forestry Research Institute
NARC	Nepal Agricultural Research Council
NARES	National Agricultural and Extension Systems
NARI	National Agricultural Research Institute, The Gambia
NGO	Non Governmental Organization
NOPT	Nutrient omission plot technique
NO_x,NO, NO_2,N_2O	Nitrogen oxides
NPK	Nitrogen, phosphate, potassium
NT	Normal tillage
NuMaSS	Nutrient Management Support System
NUTMON	Nutrient Monitoring
OC	Organic carbon
QC	Quality control
P	Phosphorus
PROINPA	Foundation for Andean Products Research and Promotion, Bolivia
RDRS	Rangpur-Dinajpur Rural Service – Bangladesh NGO
RWC	Rice Wheat Consortium
SARI	Savanna Agricultural Research Institute (Ghana)
SEPA	Sementes de Papa, Bolivia
SHABGE	CARE vegetable program in Bangladesh
SIMI	Smallholder Irrigation Market Initiative – WINROCK/IDE project, Nepal

SM-CRSP	Soil Management Collaborative Research Support Program
SOC	Soil organic carbon
SOM	Soil organic matter
SRI	System of Rice Intensification
SSNM	Site specific nutrient management
SS	Surface seeding
TAES	Texas Agricultural Experiment Station
TDR	Time domain reflectometry
TOA	Tradeoff Analysis
TOC	Total organic carbon
TPR	Transplanted rice
TRF	Thailand Research Fund
UCA	Central American University
UCR	University of Costa Rica
UF	University of Florida
UNA-Catacamas	National Agricultural University, Honduras
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 carbon analysis
WRC	Wheat Research Centre (Bangladesh)
WUR	Wageningen University Research Center (Netherlands)
WINROCK	International NGO
Zamorano	Pan-American School, Honduras
ZT	Zero tillage (surface seeding)