Soil Management Collaborative Research Support Program

Project Year 10 Annual Progress Report

2006 - 2007

Cornell University   Montana State University   University of Florida

University of Hawaii   North Carolina State University

SOIL MANAGEMENT
COLLABORATIVE RESEARCH SUPPORT PROGRAM

PROJECT YEAR 10
ANNUAL PROGRESS REPORT

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

2006-2007

Photo on cover page taken by Russell Yost.
Photo caption: Improved water availability with ACN technology allowed Sorofin Diarra of Siguidolo in Konobougou, Mali to raise vegetables in the dry season. Without ACN, the wells are typically dry.

This report was made possible through support provided by the Offices of Agriculture and Natural Resources Management, Bureau for Economic Growth, Agriculture and Trade, U.S. Agency for International Development, under the terms of Award No. LAG-G-00-97-00002-00. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Agency for International Development.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The World Bank's Development Report 2008 cites rising food production in sub-Saharan Africa. Agricultural growth there has accelerated from 2.3 percent per year in the 1980s to 3.3 percent in the 1990s and to 3.8 percent per year between 2000 and 2005. This rise in food production appears to be related to absence of drought and government subsidies for fertilizer and seeds of improved varieties. Water, nutrients and seeds have always been key elements in the war against poverty, but all three can come and go depending on weather and government policy. The future welfare of sub-Saharan African farmers, therefore, still rests in the hands of factors over which they have little or no control. What can they do to lessen the risk of drought and encourage and direct governments to pursue sounder economic policy? Resource management remains a key factor under the control of farmers. In sub-Saharan Africa, water is most often the resource that limits high and stable food production. Surprisingly it is not lack of water, but its management and control that limits agricultural production there. Based on rainfall distribution and intensity, four regions are recognized in West Africa. Annual rainfall is less than 400mm in the northern most Sahara region, increases to values between 400 - 800mm in the Sahelo-Sudanian region, further increases to 800 - 1000mm in the Sudanian region and peaks to 1000 - 1200mm in the Sudan-Guinean region. The Sudanian and Sudan-Guniean regions receive ample rainfall to produce high crop yields, but experience frequent food shortages owing to low crop yields from a combination of water and/or nutrient deficiencies. But it is in such places that the World Bank's World Development Report 2008 finds rising food production when drought is absent and government subsidies encourage fertilizer use. Can famines be avoided when occasional droughts return and subsidies end? A farming system that captures and retains water in soil and ground water is the type of land use system the Soil Management CRSP and its host-country partners are striving to refine and promote in West Africa and elsewhere in the world.

In West Africa about two-thirds of rainfall is lost as runoff, leaving about one-third for crop use and ground water recharge. Farmers who adopt a ridge-tillage (or ACN - *aménagements en courbes de niveau*) farming system are able to capture two-thirds of rainfall and enable the captured water to infiltrate into the soil, rather than flow overland as runoff to carry sediment into streams and rivers. This rain harvesting technology raises crop yields, reduces risk of crop failure, raises water levels in village wells and enables villagers to grow and market high value irrigated crops during the dry season. (See the *Carbon Sequestration Project Progress Report* within this document.) Water, retained in soils and aquifers, imparts high stability to agricultural production systems, and stability, in turn, enables farmers to invest in fertilizers without fear of crop failures. Next to water, fertilizer is the input farmers need to sustain profitable yields. In sub-Saharan Africa and in Southeast Asia fertilizer is expensive so adding the right amount and type of fertilizer at the proper time and place becomes critical. NuMaSS is a global tool designed to enable users to use fertilizers in a timely and cost-effective manner. (See the *NuMaSS Projects Progress Reports* within this document and note especially the sections on the NuMaSS applications in Africa, Asia and Latin America.)

Water control through adoption of the ridge-tillage practice adds stability to the farming system, and use of NuMass provides the means to sustain high productivity. High stability and high productivity are two properties of sustainable agro-ecosystems. (See the *Rice-Wheat Project Progress Report* within this document.) A third property of sustainable agricultural systems is resiliency. Resiliency is the capacity of ago-ecosystems to withstand and recover from stresses and perturbations imposed on it.

The cultivated soils of much of the developing world and especially West Africa have lost their resiliency through centuries of nutrient and carbon mining. Soils stripped of nutrients and organic matter have lost their capacity to adsorb and retain water and nutrients and are more susceptible to compaction, erosion and desertification. The key to restoring resiliency and soil quality is to employ management practices that sequester carbon in soils.

In West Africa, a measurable increase in soil carbon has been observed in farms that have been ridge-tilled or have adopted ACN. (See the *Carbon Sequestration Project Progress Report* within this document.) The increase in soil carbon is even greater in farms that use a combination of ridge-tillage and fertilization and the increase is directly related to the increase in crop yield. Since 30 to 40 percent of a crop's biomass is below ground, more organic carbon is returned to soils in the form of plant roots as crop yields are increased through better water and nutrient management. Thus, sound water and nutrient management not only raises stability and productivity of agro-ecosystems, but restores resiliency to soils that have been exploited for centuries.

Careful monitoring of carbon sequestered in West African soils suggests that the quantity of carbon sequestered is sufficient to, one day, pay for the cost of fertilizers, installing ridge-tillage systems and other land improvement technology through carbon trading. With this possibility in mind, CRSP African and South Asian partners are investigating ways to quantify the carbon gains so carbon can be traded for an equivalent amount of carbon dioxide emitted by polluting industries. (See the *Carbon Sequestration* and *Tradeoff Analysis Projects Progress Reports* within this document.) The capacity of sequestered carbon to restore resiliency and generate new income for farm households through carbon trading adds the fourth and last property that makes ago-ecosystems truly sustainable. This property is equitability, which involves equal sharing of benefits derived from the ago-ecosystem.

In the end our work needs to be translated into policy decisions and the Tradeoff Analysis (TOA) approach has been designed for this purpose. All of the CRSP work on ridge-tillage and water (to achieve stability), NuMaSS and nutrient management (productivity), carbon sequestration (resiliency), carbon trading (equitability) and Tradeoff Analysis for policy makers is linked to training and capacity building. Our aim is to enable our host-country partners to continue the work from field to policy levels long after the CRSP effort ends, along with our basic work on genetically modified Bt crops and genetic characterization of root traits. (See the *Biotechnology Projects Progress Reports* within this document.)

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	Russell Yost, Tasnee Attanaadana, 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	T. Jot Smyth and Deanna L. Osmond	North Carolina State University
Program Area 2. Tradeoff Analysis			
Tradeoff Analysis Project Phase 2: Scaling Up and Technology Transfer to Address Poverty, Food Security and Sustainability of the Agro-Environment	Kenya, Senegal, Peru, Equador	John M. Antle	Montana State University
Program Area 3. Rice – Wheat Systems			
Enhancing Technology Adoption for the Rice-Wheat Cropping System of the Indo-Gangetic Plains	Nepal, Bangladesh	John M. Duxbury and Julie G. 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	Russell Yost, James Jones, John W. Duxbury, Julie G. Lauren	University of Hawaii University of Florida Cornell University Cornell University
Program Area 5. Biotechnology			
Assessing the Effects of Bt Crops And Insecticides on Arbuscular Mycorrhizal Fungi and Plant Residue Carbon Turnover and Fate in Soil	United States, China, Colombia	Medha Devare, Janice Thies, John W. Duxbury	Cornell University Cornell University Cornell University
Genetic Characterization of Adaptive Root Traits in the Common Bean	United States	C. Eduardo Vallejos James W. Jones, 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 (2003-06)	Goro Uehara and Harold McArthur	University of Hawaii University of Hawaii
Improving Maize Productivity In the Planalto Area of Angola	Angola (2005)	Russell Yost	University of Hawaii

NUTRIENT MANAGEMENT SUPPORT SYSTEM (NuMaSS)

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

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

Introduction to Southeast Asia and Africa Activities

In the *Philippines,* dissemination of the NuMaSS approach to diagnosing, predicting fertilizer requirements, evaluating the benefit and cost and presenting the information producers continued in 2006- 2007. Several highlights deserve special mention: 1) the in the field soil series identification work directed by Dr. R. Badayos, University of the Philippines at Los Banos and Drs. Nicor and Garcia of the University of Southern Mindanao continued and expanded with further testing of the first system in Isabela Province, Northern Luzon and in Mindanao; 2) expansion of the program in Negros Occidental continued with continued remarkable success; and 3) an impact analysis was carried out at the Isabela Province site in Ilagan.

Summary of the Isabela Province impact analysis: A program to diagnose and ameliorate soil-based constraints to agricultural productivity has been widely disseminated in the Cagayan River Valley of the northern Philippines. The major upland crops in the area, maize *(Zea mays)* and upland rice *(Oryza sativa),* grow poorly with the standard fertilizer recommendations on acidic upland soils. At the onset of the program, the local offices of the existing national agricultural and research system had no site-specific fertilizer or liming recommendations for acidic upland soils.

The program developed a computer-based decision support system to diagnose problems with soil acidity, phosphorus, and nitrogen and to formulate fertilizer and lime recommendations. Based on the system recommendations, high rates of lime (initially 6 t/ha) were used in cropping trials at a centrally located field site in 1997. Demonstration of the positive results of soil liming and phosphorus application showed both local farmers and agricultural professionals that specific local soil problems could be diagnosed and corrected. Further trials on farmers' fields in 1999 and 2000 served as demonstrations for both farmers and professionals. At the same time the Philippine Bureau of Soils began an effort to map the extent of acid soils nationwide, which were estimated to cover 9 million ha.

The positive results of the local trials convinced the Philippine Department of Agriculture to institute an extension program for liming acid soils in four provinces. The program combines soil analysis with distribution of trial amounts of lime. In the first two cropping seasons of the program, 38 local extension agents conducted field days for 5454 farmers and set up 73 demonstration sites. A regional soils laboratory analyzes soil pH and makes recommendations to determine whether a site would benefit from liming.

A spreadsheet model based on yield data from the cropping trials and local costs predicted that the internal rate of return of liming acid soils to the individual farmer was 466 percent. When the cost of the lime, the extension program, and the research program were included, the overall internal rate of return for the program was calculated as 25 percent. The change in local awareness about acidic soils may partly have been due to increases in population in the region: farmers have been forced to cultivate lands previously considered marginal and need site-specific solutions. The establishment of a centrally located set of experiments by an outside agency served as a demonstration to both local agriculture professionals and local farmers.

There is other evidence that similar dramatic expansion of facilities and support for agricultural liming are taking place in neighboring provinces to the north of Isabela, as well as in Mindanao, and Negros Occidental. The dissemination is supported by the central programs of PhilRice as well as the national Department of Agriculture.

In *Thailand*, site-specific nutrient management technology (SNMM) was extended to paddy rice and sugarcane during the 2006 - 2007 season. The results were at least as impressive as those occurring with maize production. The field tests and demonstration plots on rice showed the beneficial effect of site-specific nutrient management where irrigated rice farmers could reduce the amount of chemical fertilizer, and thus reduce cost of production. Moreover, the farmer leaders not only learned soil improvement, but also worked in groups to solve the problem of buying input and selling products. They achieved more self-reliance, using local wisdom. In the case of sugarcane, farmers learned the site-specific nutrient management technology, but the farmers should emphasize organic matter incorporation because of poor sandy soils and some salinity problems.

In *Laos*, in order to demonstrate and teach the NuMaSS and PDSS technology to Lao farmers, a workshop was held on August 28, 2007 by the Soil and Water Management Unit, Soil Survey and Land Classification Center. During training, farmers shared their experiences on suitable fertilizer rate and sources, method and timing of fertilizer application and crop residue management after harvesting. The main problems in maize cultivation in some villages are:

1. Low rates or no fertilizer applied according to their experiences;
2. Top dressing is not always on time (only basal application);
3. No soil nutrient status information (lack of soil test);
4. Some villages lack post harvest technology, especially drying; and
5. Low and unstable price of maize.

To help solve the lack of drying technology problem, we led a farmer-to-farmer visit to a farmer who had a dryer and who shared his experiences. Many of the farmers were interested in learning where they could buy the chemicals used for soil testing by test-kit.

In *Mali*, improved management of nutrients through the use of site-specific nutrient management and decision-aids such as NuMaSS have contributed one of several factors viewed as critically important in improved food production and as a step toward providing management options that would help improve food security, either directly or indirectly.

Results of the rock phosphate algorithm work have pointed out that some of the Sahelian soils contain insufficient acidity to completely dissolve the rock phosphate and that some rock phosphates contain amounts of associated calcium carbonate that tends to neutralize the soil acidity needed to dissolve the rock phosphate. These results, moreover, suggest that the dissolution step in rock phosphate utilization may be particularly limiting in the poorly buffered soils of the Sahel.

Soil fertility is one of the limiting factors for food production in *Mozambique* (Maria and Yost, 2006). Increasing agriculture productivity through Integrated Soil Nutrient Management Research and Integrated Decision Aids that diagnose, predict, and economically evaluate benefits of soil amendments is essential. Such tools would enable extension workers and farmers to make informed decisions on soil nutrient management. Towards this goal, an inventory of soil fertility status was conducted in four agro-ecological zones in central and northern Mozambique where agricultural activities are intensifying. Two districts in northern Mozambique and two in central Mozambique, representing different agro-ecological conditions were selected for on-farm and on-station testing of soil nutrient requirements of maize crop using decision-aids. Furthermore, for selected farmer groups, maize inter-cropped with legumes was tested to assess the contribution of legume crops to maize yield. Experiments included maize with groundnut, maize with cowpea, maize with pigeon pea, and maize with fertilizer NPK application (low rate). Soil samples from experimental sites were collected and analyzed for soil chemical and physical properties prior to establishment of the experiment and after the experiment. Agronomic and socio-economic data were recorded and analyzed. Field extension agent training workshops on integrated soil nutrient management were conducted in each province. The aim of the workshop was to ensure effective participation of field extension workers in on-going joint Soil Management Collaborative Research Support Program (SM CRSP) and Soil Fertility Consortium for Southern Africa (SOFECSA) project activities.

Two major lessons were drawn from the initiative: 1) the partnership building process created greater awareness about the importance of Integrated Soil Nutrient Management than before; and 2) involvement of key stakeholders in planning, implementation and evaluation promoted their sustained participation throughout the season, and attracted the involvement of farmer with different socio-economic circumstances.

In *Ghana,* the MOU between the SARI and the SM CRSP of the University of Hawaii was signed in late 2004, which paved the way for collaborative research in 2005 and 2006. During this period, two on-station and one on-farm trials were conducted to test and adapt the Nutrient Management Support System (NuMaSS) in Northern Ghana. Experiment 1 compared the national fertilizer recommendation for maize with NuMaSS fertilizer recommendation under two cropping systems - continuous and maize-groundnut rotation. Experiment 2 compared the national fertilizer recommendation for maize with three (3) rates (full, 1/2, and 1/4) of fertilizer based on NuMaSS diagnosis and recommendation. The third study (Experiment 3) had the same treatments as Experiment 1 but was implemented on ten farmers' fields. Initial soil characteristics were used as input for NuMaSS each year. The national fertilizer recommendation for maize was the reference treatment in all studies for comparison. The results of Experiment 1 showed that there was no significant difference in grain yield between the national fertilizer recommendation and NuMaSS recommendation in all years. Total variable cost was lower and profitability higher when maize followed groundnut in the rotation with fertilizer application based on NuMaSS. Similarly in Experiment 2, there was no difference between the national fertilizer recommendation and the different rates of fertilizer based on NuMaSS. The on-farm studies showed considerable differences between farms in soil fertility and available soil phosphorus was found to be strongly and positively correlated with soil organic carbon. There was also a strong correlation between soil organic carbon and NuMaSS recommended P rate. Maize following groundnut with application of fertilizer based on NuMaSS was the best in terms of growth and grain yield being significantly higher than treatments with the national maize fertilizer recommendation. Simple economic analysis showed that net returns were greater and variable cost lower when maize was rotated with groundnut and fertilizer was based on NuMaSS. The studies showed that fertilizer application based on NuMaSS recommendation gave similar or higher yields and was more cost effective than fertilizer application based on the national recommendation.

In addition for those activities specific to each collaborator and location, we have formed a software company that is designed to provide technical support and system services for the NuMaSS-PDA software that has been developed. This company will provide technical support, maintenance and distribute improvements in the software and is described in a paper presented at the Fourth International World Congress of Computers in Agriculture and Natural Resources.

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

Southeast Asia

The Philippines

NuMaSS, in its fourth year of implementation in the Philippines, was continued to further test, compare and adapt it for use in farmers' fields. The on-farm trials were expanded further to include soils both in the uplands and lowlands where rice and corn are commonly grown in the three larger islands of Luzon, Visayas and Mindanao, Philippines. Demonstration farms were established in a known soil series to verify the response of NuMaSS and to transfer the methodology to other soil series. Classification of the soil in the NuMaSS sites was verified to permit similar recommendations at specific locations with similarly classified soils. Overall, the NuMaSS provided good prediction of the fertilizer application rates for corn in Luzon and Visayas, and both rice and corn in Mindanao.

On-farm Testing, Comparing and Adapting the NuMaSS, Years 4 and 5

We compared NuMaSS with the existing farmers' nutrient management practices (FP) and the regional recommendation of the Department of Agriculture. The tested FP is a consensus among the group of farmers who participate in the testing of the NuMaSS to minimize variation from farmer to farmer. The regional recommendation is generated by the Department of Agriculture through the use of soil tests done on soils in the region. This is a very general recommendation, which has long been found to be faulty as there is a high variability among soils. A need exists, therefore, for a test that will address specificity of soil characteristics and conditions in the area as well as the financial resources of farmers.

Soils in the selected sites were identified and classified at the series and order levels according to Soil Taxonomy. The Soil Survey Report and soil map from each province, and other related updated soil data were obtained from the Philippines Bureau of Soils and Water Management.

Soil Properties in the Technology-demonstration Farm Sites (New Sites)

Results of the soil laboratory analysis conducted for the demo-farms in Luzon, Visayas, and Mindanao are shown in Tables 2 and 3. These demos were conducted on farms in the three regions but only those from Luzon (Table 2) and North Cotabato (Table 3) are included in this year's report. The result of analysis served as the basis to generate NuMaSS recommendation.

Table 2. Soil chemical properties of demonstration farms in Luzon.

Location	Soil Series/ Soil Order	Soil pH	%OC	Available P Bray #2	Exchangeable		K	Ca	Mg	ECEC	%Al Saturation
					Acid	Al					
				mg/kg	meq/100g						
Pag-asa, Echaque	Quingua Series/ Mollisol	5.4	1.4	1.0	0.4	1.2	0.9	13.1	19.7	34.9	3.5
San Pablo, Ilagan	Cauayan Series/Ultisol	5.4	2.1	0.5	0.5	2.4	0.9	2.9	3.0	9.1	25.9
San Antonio, Ilagan	Ilagan Series/ Alfisol	4.6	1.9	1.1	3.2	3.4	0.2	1.6	2.8	8.0	42.5
Sta Victoria, Ilagan	Ilagan Series/ Alfisol	4.5	1.9	0.3	3.3	3.5	0.1	0.6	0.4	4.6	77.0
Marana 2^{nd}, Ilagan	San Manuel Series/Inceptisol	5.3	1.5	4.3	0.9	0.8	0.5	2.6	1.1	5.0	16.7
Alinguigan, Ilagan	San Manuel Series/Inceptisol	4.6	1.6	7.8	2.1	1.1	0.8	1.4	0.9	4.2	25.3
San Pablo, Ilagan	Cauayan Series/Ultisol	5.4	2.1	0.5	0.5	2.4	0.9	2.9	3.0	9.1	25.9
Sta Victoria, Ilagan*	Ilagan Series/ Alfisol	4.4	1.4	2.1	2.6	2.8	0.2	3.7	1.0	7.7	36.7

Table 3. Soil physical-chemical properties of NuMaSS technology demonstration sites for rice and corn grown under different soil series in North Cotabato.

Soil Series/ Location	Soil pH	OC	Available P (Olsen)	Acidity	Al	K	Ca	Mg	ECEC	Al Sat
		%	mg kg-	me 100g- soil						%
(Critical range)	5.5 - 6.5	2.0 - 3.0	>10		<0.75	>0.45	<8.00	>3.00	>20.00	30
Kudarangan Series (Aleosan, NC)										
Romeo Cambel	5.77	1.26	16.08	0.41	0.19	0.64	21.03	6.94	29.02	0.65
Jerry Capilitan	5.51	1.68	41.91	2.18	0.26	0.41	21.06	9.19	33.84	0.77
Kidapawan Series (Antipas, NC)										
Noel Berdeblanco	4.26	1.76	21.15	2.33	1.95	0.46	1.29	0.44	4.52	43.14
Melchor Morin	4.3	1.37	21.95	2.14	2.11	0.33	0.7	0.49	3.66	57.65
Quilada Series (Matalam, NC)										
Junecio Huelar	4.79	1.25	9.09	1.51	1.31	0.19	10.82	4.94	17.46	7.5
Langkong Series (Alamada, NC)										
Mona Zamora	5.1	2.07	20.13	0.7	0.13	0.57	2.37	2.11	5.75	2.26
Billy Sillote	5.39	2.27	12.37	0.07	0.06	0.34	3.56	2.84	6.81	0.88
Macolod Series (Arakan, NC)										
Lucio Santero	5.13	1.39	18.54	0.36	0.24	1.25	20.03	6.57	28.21	0.85
Faraon Series (Liliongan, Carmen, NC)										
Jarthon Arguilles	6.01	1.12	8.96	0.05	0.03	0.83	14.91	5.17	20.96	0.14
Tacloban Series (Tambad, Carmen, NC)										
Kidte Lamada	5.82	1.2	9.39	0.63	0.14	0.39	15.52	5.99	22.53	0.62
Buwao Ding	6.14	1.19	42.42	0.83	0.03	1.24	13.04	5.46	20.57	0.14
Aroman Series (Carmen, NC)										
Ato Secretarya	5.46	1.3	14.67	0.09	0.06	0.89	8.03	2.39	11.4	0.53
BPI-Aroman	5.65	0.92	7.11	0.09	0.12	0.4	6.54	3	10.03	1.2
Kabacan Series (Kabacan, NC)										
USMARC	5.45	1.16	33.99	0.09	0.11	0.53	11.81	1.89	14.32	0.77

Treatments

The treatments used in the trials were the following: T1- control; T2 – farmer's practice (FP); T3 – regional recommendation (RR); T4 – NuMaSS recommendation (NR); T5 – NuMaSS recommendation, nitrogen removed (NR –N); T6 – NuMaSS recommendation, phosphorus removed (NR –P); and, T7 – NuMaSS recommendation, lime removed (NR –lime). For T4, variable amount of N, P and lime was applied depending on the NuMaSS recommendation (Table 4). Plots for each treatment remained permanent in each field throughout the years of implementation of the project.

Grain Yield – Dry Season

Corn. During the dry season, on-farm trials were established only in Ilagan, Isabela in 2006 and 2007 with a 4.0 t/ha and 5.0 t/ha corn grain yields target, respectively. In 2006 (Table 5), growing corn without soil amendments resulted in 0.61 t/ha yield, significantly lower than NuMaSS plot which had 4.73 t/ha yield. NuMaSS had significant yield among other treatments with 108 percent (2.46 t/ha) and 74 percent (2.01 t/ha) higher than the farmers' practice and regional recommendation, respectively. Removing N from the NuMaSS recommendation resulted in a 43 percent (1.42 t/ha) yield reduction. Removing P also decreased yield by 178 percent (3.03 t/ha), while NuMaSS without lime application, resulted in a lower yield of 55 percent (1.67 t/ha). The results explain that P more is a more critical element than N for corn growth and applying P-fertilizer is more efficient with lime.

In 2007, the same yield response was observed under the same treatments (Table 6). NuMaSS was able to predict fertilizer and lime requirement of corn at 5 t/ha yield target. The NuMaSS recommendation resulted in 4.74 t/ha yield higher than the control plots, which only had 0.58 t/ha yield. Again, removing P from the NuMaSS recommendation resulted in a much greater decrease in yield (161 percent, 3.28 t/ha) compared to the NuMaSS recommendation without N (29 percent, 1.2 t/ha), and NuMaSS without lime (43 percent, 1.59 t/ha).

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 of the above-mentioned parameters.

Table 4. Fertilizer application rates for corn in the on-farm trial sites in Ilagan, Isabela across cropping seasons.

	Inputs (2006 Dry Season)*				Inputs (2006 Dry Season)**				Inputs (2006 Dry Season)**			
Treatments	Lime	N	P_2O_5	K_2O	Lime	N	P_2O_5	K_2O	Lime	N	P_2O_5	K_2O
	ton ha^{-1}		kg ha^{-1}		ton ha^{-1}		kg ha^{-1}		ton ha^{-1}		kg ha^{-1}	
Control (T1)	0	0	0	0	the same with the previous cropping				the same with the previous cropping			
Farmers' Practice (T2)	0	97	28	28								
Regional Recommendation (T3)	0	134	42	42								
NuMaSS Recommendation (T4)	0.5	132	64	42	1	74	69	42	0.2	74	55	42
NuMaSS-N (T5)	0.5	0	64	42	1	0	69	42	0.2	0	55	42
NuMaSS-P (T6)	0.5	132	0	42	1	74	0	42	0.2	74	0	42
NuMaSS-Lime (T7)	0	132	64	42	0	74	69	42	0	74	55	42

*Soils classified as Ultisols (San Pablo)
** Soils classified as Alfisols (San Antonio/Sta. Victoria)

Table 5. Yield and yield parameters of corn as affected by fertilizer treatments in Ilagan, Isabela, DS 2006.

Treatment	Biomass Yield	Length of Ears 10 samples	FW of Ears Harvested	FW of Ears 20 samples	FW of Grains 20 samples	Shelling	Moisture Content	Yield
	kg ha^{-1}					%	%	ton ha^{-1}
T1 - Zero Fertilizer	1.7 d	9.3 c	1.4 d	1.17 d	0.75 d	62 b	27 b	0.61 e
T2 - Farmers' Practice	4.3 bc	12.7 ab	4.3 c	1.63 bc	1.15 bc	71 a	28 a	2.27 cd
T3 - Regional Recommendation	4.3 bc	12.7 ab	4.5 c	1.89 b	1.35 b	71 a	28 a	2.72 bc
T4 - NuMaSS	8.2 a	16.2 a	9.0 a	2.99 a	2.23 a	75 a	27 a	4.73 a
T5 - NuMaSS -N	6.0 ab	12.6 ab	7.0 ab	2.16 b	1.59 b	73 a	29 a	3.31 b
T6 - NuMaSS -P	3.3 dc	11.3 b	3.1 c	1.27 c	0.88 c	68 a	29 a	1.70 d
T7 - NuMaSS -Lime	4.7 bc	13.5 ab	4.67 bc	1.89 b	1.36 b	72 a	27 a	3.06 b

Table 6. Yield and yield parameters of corn as affected by fertilizer treatments in Ilagan, Isabela, DS 2007.

Treatment	Biomass Yield	Length of Ears 10 samples	FW of Ears Harvested	FW of Ears 20 samples	FW of Grains 20 samples	Shelling	Moisture Content	Yield
	kg ha^{-1}					%	%	ton ha^{-1}
T1 - Zero Fertilizer	1.8 c	4.9 d	1.3 e	0.79 c	0.53 c	49 b	23 b	0.58 e
T2 - Farmers' Practice	5.9 b	9.9 b	6.0 c	1.95 ab	1.38 b	71 a	29 a	2.95 c
T3 - Regional Recommendation	5.4 b	10.5 ab	7.0 bc	1.99 ab	1.43 b	72 a	28 a	3.46 bc
T4 - NuMaSS	15.5 a	12.7 a	10.0 a	2.53 a	1.93 a	76 a	27 a	5.32 a
T5 - NuMaSS -N	7.1 b	11.7 ab	8.0 b	2.07 ab	1.53 ab	74 a	28 a	4.12 b
T6 - NuMaSS -P	3.9 bc	7.4 c	4.2 d	1.56 b	1.10 b	70 a	29 a	2.04 d
T7 - NuMaSS -Lime	6.5 b	11.5 ab	7.6 b	1.88 ab	1.34 b	71 a	28 a	3.73 b

Table 7. Yield of corn as affected by fertilizer levels grown under different soil series in Isabela, DS 2007.

Location	Soil Order	Soil Series	NuMaSS Recommendation					Farmers' Practice				
			Lime	N	P_2O_5	K_2O	Grain Yield	Lime	N	P_2O_5	K_2O	Grain Yield
			ton ha^{-1}	kg ha^{-1}			ton ha^{-1}	ton ha^{-1}	kg ha^{-1}			ton ha^{-1}
San Pablo, Ilagan	Ultisol	Cauayan Series	0	132	50	42	4.4	0	86	40	40	2.6
Marana 2nd, Ilagan	Inceptisol	San Manuel Series	0	104	48	42	7.2	0	74	28	28	6.5
Alinguigan, Ilagan	Inceptisol	San Manuel Series	0	104	17	42	6.3	0	90	21	21	5.8

Table 8. Yield of peanut as affected by fertilizer treatments grown under Alfisol (Ilagan, Series) in Isabela, DS 2007.

Treatment	No of pods per plants	Yield kg/ha
T1 0-0-0 (Control)	8.0	815
T2 Inoculant Alone	11.0	1,259
T3 Recommended Rate	11.0	1,556
T4 NuMaSS Recommendation	14.0	1,963

NuMaSS Recommendation: 80 P_2O_5/ha and 5.0 ton/ha lime
Need not apply N-fertilizer since peanut is a legume

Technology-demonstration farms were established during the dry season of 2007. Corn had positive response to NuMaSS recommendation grown under different soil series in Luzon and Visayas. In Luzon (Table 7), target yield of corn grown in upland area (Cauayan Series, Ultisol) was not attained due to a drought that occurred at early crop stages. However, the NuMaSS treated plot yield was 1.8 t/ha higher than the farmers' practice. Yields were notably higher for corn grown in low-lying areas (San Manuel Series, Inceptisol) and NuMaSS recommendations were 0.5 – 0.7 t/ha higher than the farmers' practice. These results show that higher yields of corn can be realized with NuMaSS recommendation both in the lowland and upland condition. NuMaSS recommendation for corn was even more responsive in upland areas, with higher yield difference than the farmers' practice despite the drought.

Peanut. Peanut was planted only in Sta Victoria, Ilagan, Isabela with soils identified as Ilagan Series classified under Alfisol. Yields of peanut at different fertilizer rates are shown in Table 8. NuMaSS predicted the P and lime requirement of peanut, which had 0.46 t/ha higher than the target yield of 1.5 t/ha. NuMaSS treated plot had yield advantage of 0.41 t/ha, 0.7 t/ha than the regional recommendation and applying the inoculant alone, respectively. Without fertilizer amendment, yield of peanut was reduced by 140 percent (1.2 t/ha).

Grain Yield – Wet Season

Corn. In the on-farm trials in Isabela, NuMaSS predicted the fertilizer requirement of corn in 2006 wet season at 5.0 t/ha grain yield target. The plots applied with NuMaSS generated fertilizer recommendation obtained significantly higher yields than the control, farmers' practice and the regional recommendation (Table 9). The yield in the NuMaSS plot was 2.26 t/ha higher than the regional recommendation and 2.6 t/ha higher than the farmer's practice. The removal of N from the NuMaSS recommendation resulted in the reduction of corn yield by 44 percent (1.55 t/ha). The absence of P application resulted in 161 percent (3.6 t/ha) reduction of yield, verifying that the most critical element for corn grown in acid soils is phosphorus. Removing lime from the NuMaSS recommendation resulted in 58 percent (1.87 t/ha) yield reduction.

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

Demonstration farms that compare the NuMaSS recommendation and farmers' practice show that yields were higher with NuMaSS recommendation for corn grown in different soil types (Table 10). Following the NuMaSS recommendation, only the site in San Pablo, Ilagan Isabela was able to attain the target yield of 5.0 t/ha. However, yields were notably higher in NuMaSS treated farms than farmers' practice. Corn had 47 percent (1.8 t/ha) and 6 percent (0.3 t/ha) yield increase grown in Ultisol and Mollisol soil, respectively. Drought that occurred at early plant stages resulted in lower plant populations in Sta Victoria, Ilagan and Isabela. Infestation of corn borer in San Antonio, Ilagan site also resulted in lower yields of corn.

In all sites in Mindanao, NuMaSS had lower N and P-fertilizer rates recommended for corn at target grain yield of 6.0 t/ha (Table 11). Grain yield of corn varied across sites but figures show that NuMaSS had generally higher yields than the farmers' practice and regional recommendation. Lower yields were attained in three lowland soil series, Kabacan, Kudarangan, and Quilada. No K-fertilizer inputs for the farmer practice treatment at sites with soils identified as Kabacan Series resulted in higher yields. In the Kabacan Series, K is sufficient (Table 11) to support crop needs, and thus, further addition of K-fertilizer may cause imbalance in other soil nutrients, affecting its growth. On the other hand, underestimation of the P-fertilizer recommendation in Quilada and Kudarangan Series resulted in lower yields of corn in the NuMaSS treated plots.

Table 9. Yield and yield parameters of corn as affected by fertilizer treatments in Ilagan, Isabela, WS 2006.

Treatment	Number of Ears Harvested	Biomass Yield	Length of Ears 10 samples	FW of Ears Harvested	FW of Ears 20 samples	FW of Grains 20 samples	Shelling	Moisture Content	Yield
		kg ha^{-1}					%	%	ton ha^{-1}
T1 - Zero Fertilizer	13 c	2.6 d	2.4 d	0.5 f	0.6 d	0.4 d	34 b	15 b	0.17 e
T2 - Farmers' Practice	57 ab	8.4 b	11.5 b	5.5 d	2.2 b	1.6 b	73 a	29 a	2.47 c
T3 - Regional Recommendation	57 ab	10.2 ab	11.5 b	6.1 dc	2.5 b	1.8 b	74 a	28 a	2.81 b
T4 - NuMaSS	63 a	12.6 a	15.3 a	10.7 a	3.5 a	2.7 a	77 a	28 a	5.07 a
T5 - NuMaSS -N	61 ab	11.7 a	13.8 ab	7.8 b	2.8 ab	2.1 b	75 a	30 a	3.52 b
T6 - NuMaSS -P	42 b	4.7 c	8.8 c	3.4 e	1.6 c	1.2 c	70 a	29 a	1.43 d
T7 - NuMaSS -Lime	54 ab	11.4 a	13.9 ab	7.2 bc	2.5 b	1.8 b	72 a	28 a	3.20 b

Table 10. Yield of corn as affected by fertilizer levels grown under different soil series in Isabela, WS 2006.

Location	Soil Order	Soil Series	NuMaSS Recommendation					Farmers' Practice				
			Lime	N	P_2O_5	K_2O	Grain Yield	Lime	N	P_2O_5	K_2O	Grain Yield
			ton ha^{-1}	kg ha^{-1}			ton ha^{-1}	ton ha^{-1}	kg ha^{-1}			ton ha^{-1}
San Pablo, Ilagan	Ultisol	Cauayan Series	0	132	76	42	5.6	0	74	28	28	3.8
Pag-asa, Echague	Ultisol	Cauayan Series	0	132	76	42	4.8	0	97	28	28	4.5
Sta Victoria, Ilagan	Alfisol	Ilagan Series	3.5	74	56	42	4.5	0	67	21	21	1.4**
San Antonio, Ilagan	Alfisol	Ilagan Series	2	74	80	42	3.3*	0	69	41	0	1.6*

*low plant population due to drought at early crop stages
** attacked by corn borer

Table 11. Yield of corn as affected by fertilizer treatments grown under different soil series in North Cotabato, WS 2006.

Soil Series / Location	Treatments	Inputs N	Inputs P_2O_5	Inputs K_2O	Grain Yield ton ha^{-1}
		kg ha^{-1}			
Aroman Series (Carmen, NC)	NuMaSS Recommendation	117	10	30	6.38
	Provincial Recommendation	120	60	30	4.90
	Farmers' Practice	122	40	0	5.31
Kabacan Series (Kabacan, NC)	NuMaSS Recommendation	117	10	30	6.83
	Provincial Recommendation	the same			6.41
	Farmers' Practice	the same			7.80
Tacloban Series (Carmen, NC)	NuMaSS Recommendation	117	10	30	5.36
	Provincial Recommendation	the same			4.67
	Farmers' Practice	the same			2.52
Macolod Series (Arakan, NC)	NuMaSS Recommendation	117	9	30	8.15
	Provincial Recommendation	the same			7.63
	Farmers' Practice	the same			7.74
Faraon Series (Liliongan, Carmen, NC)	NuMaSS Recommendation	117	15	30	5.26
	Provincial Recommendation	the same			4.80
	Farmers' Practice	the same			3.77
Langkong Series (Alamada, NC)	NuMaSS Recommendation	103	4	30	6.51
	Provincial Recommendation	the same			5.87
	Farmers' Practice	the same			5.40
Kudarangan Series (Aleosan, NC)	NuMaSS Recommendation	103	4	30	4.80
	Provincial Recommendation	the same			6.59
	Farmers' Practice	the same			5.80
Quilada Series (Matalam, NC)	NuMaSS Recommendation	117	30	30	5.13
	Provincial Recommendation	the same			6.32
	Farmers' Practice	the same			3.12

Note: Fertilizer rates for the Provincial Recommendation and Farmers' Practice treatments are the same in all sites.
Soil Series/ sites under a bracket had the same fertilizer application rates.

Table 12. Yield of rice as affected by fertilizer treatments grown under different soil series in North Cotabato, WS 2006.

Soil Series / Location	Treatments	Inputs N	Inputs P_2O_5	Inputs K_2O	Grain Yield ton ha^{-1}
		kg ha^{-1}			
Aroman Series (Carmen, NC)	NuMaSS Recommendation	79	0	30	1.86
	Provincial Recommendation	90	60	30	1.72
	Farmers' Practice	30	10	0	1.44
Langkong Series (Alamada, NC)	NuMaSS Recommendation	79	0	30	4.32
	Provincial Recommendation	the same			3.67
	Farmers' Practice	the same			3.68
Kabacan Series (Kabacan, NC)	NuMaSS Recommendation	79	0	30	2.12
	Provincial Recommendation	the same			2.24
	Farmers' Practice	the same			2.22
Kidapawan Series (Antipas, NC)	NuMaSS Recommendation	79	0	30	3.16
	Provincial Recommendation	the same			2.57
	Farmers' Practice	the same			2.94
Macolod Series (Arakan, NC)	NuMaSS Recommendation	79	0	30	4.50
	Provincial Recommendation	the same			4.31
	Farmers' Practice	the same			4.07
Kudarangan Series (Aleosan, NC)	NuMaSS Recommendation	58	0	30	2.06
	Provincial Recommendation	the same			2.53
	Farmers' Practice	the same			3.20

Note: Fertilizer rates for the Provincial Recommendation and Farmers' Practice treatments are the same in all sites.
Soil Series/ sites under a bracket had the same fertilizer application rates.

Rice. Rice was established only in Mindanao grown on six different soil series in North Cotabato. Yields varied across soil series but results show that NuMaSS had generally higher yields than regional recommendation and farmers' practice (Table 12). Yields were higher with NuMaSS recommendation except in the lowland soils, Kabacan Series and Kudarangan Series. Comparison of the fertilizer rates applied reveals that NuMaSS might have underestimated the P requirement of rice for these soil series resulting in lower yields of the NuMaSS treated plots compared to the regional fertilizer recommendation and the farmers' practice. Though soil P was reported moderate to high from results of soil analysis, soil acidity levels indicate that P may be unavailable and that a P-fertilizer source is needed as maintenance for the crop. Macolod Series and Langkong Series had notably higher yields compared to other soil series.

Testing of NuMaSS recommendations in different soil series was to generate fertilizer recommendations at specific locations with the same soil series having similar responses relative to rice and corn production. In such a case, fertilizer recommendations for rice and corn become more site specific (compared to the regional blanket recommendation) thus reducing the risk of excessive fertilizer application or nutrient deficiencies, consequently reducing fertilizer cost, and/or increasing crop yields with more appropriate fertilizer application. NuMaSS generated fertilizer recommendations can be used for three to five year periods and updating of soil chemical properties through laboratory analysis needs to be done thereafter to monitor nutrient status to attain optimum crop yields. Expenses for laboratory analysis of soil samples as data input to the software can be eliminated or minimized.

Economic Analysis

Results obtained in the dominance analysis of the different fertilizer treatments varied across sites. In Isabela, the economic analysis showed that NuMaSS was consistently dominant over the control, farmers' practice, regional recommendation, NuMaSS-N, NuMaSS-P and NuMaSS-lime (Figure 1) for three (3) cropping seasons. This result indicates that NuMaSS was a better fertilizer management practice with higher net return compared to the current farmer's practice and the regional recommendation. 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 adverse conditions.

Technology-demonstration sites for corn in Isabela also showed that corn was more profitable with NuMaSS recommendation than the current farmers' practice. Growing corn in Cauayan Series (Ultisol) was notably more profitable than Quingua Series (Mollisol) and Ilagan Series (Alfisol) during the wet season cropping in 2006 (Figure 2). Corn production was much profitable in the San Manuel Series (Inceptisol, lowland) than the Cauayan Series (Ultisol, upland) in the 2007 dry season cropping.

NuMaSS recommendation was a better fertilizer management option both for rice and corn grown in some sites in North Cotabato. Similar dominance analyses showed that the NuMaSS recommendation was more profitable for corn grown under Macolod Series, Faraon Series, Langkong Series, Aroman Series, and Kidapawan Series. Sites on these soil series had lower NuMaSS-generated fertilizer inputs but had higher yields than FP and RR. NuMaSS recommendation was less profitable for corn grown in Quilada Series, Tacloban Series, and Kudarangan Series due to lower yields attained compared to those based on the farmers' practice and the regional recommendation.

The NuMaSS recommendation was more profitable for rice grown only in Macolod Series and Langkong Series where notably higher rice grain yields at lower fertilizer rates were attained relative to the regional recommendation and the farmers' practice.

Adopting the NuMaSS generated fertilizer recommendation is very beneficial for farmers as it brings higher yields. However, with the drastic increase in the cost of fertilizer in the Philippines, farmers are feeling the impact of higher cost of production. As NuMaSS relies on the application of inorganic fertilizers to increase corn and rice grain yields, farmers are concerned about the sustainability of fertilizer management recommendations from NuMaSS. This suggests a need to look at the profitability of the NuMaSS recommendation and alternative options that may have to be developed for farmers to generate higher profit from NuMaSS. To reduce fertilizer costs, farmers need knowledge of organic fertilization and other cost-saving soil amendments. The issue of including organic fertilizer as an important input into the NuMaSS modules becomes essential with these results especially that there has been a rapid increase in the cost of inorganic fertilizer in the local market.

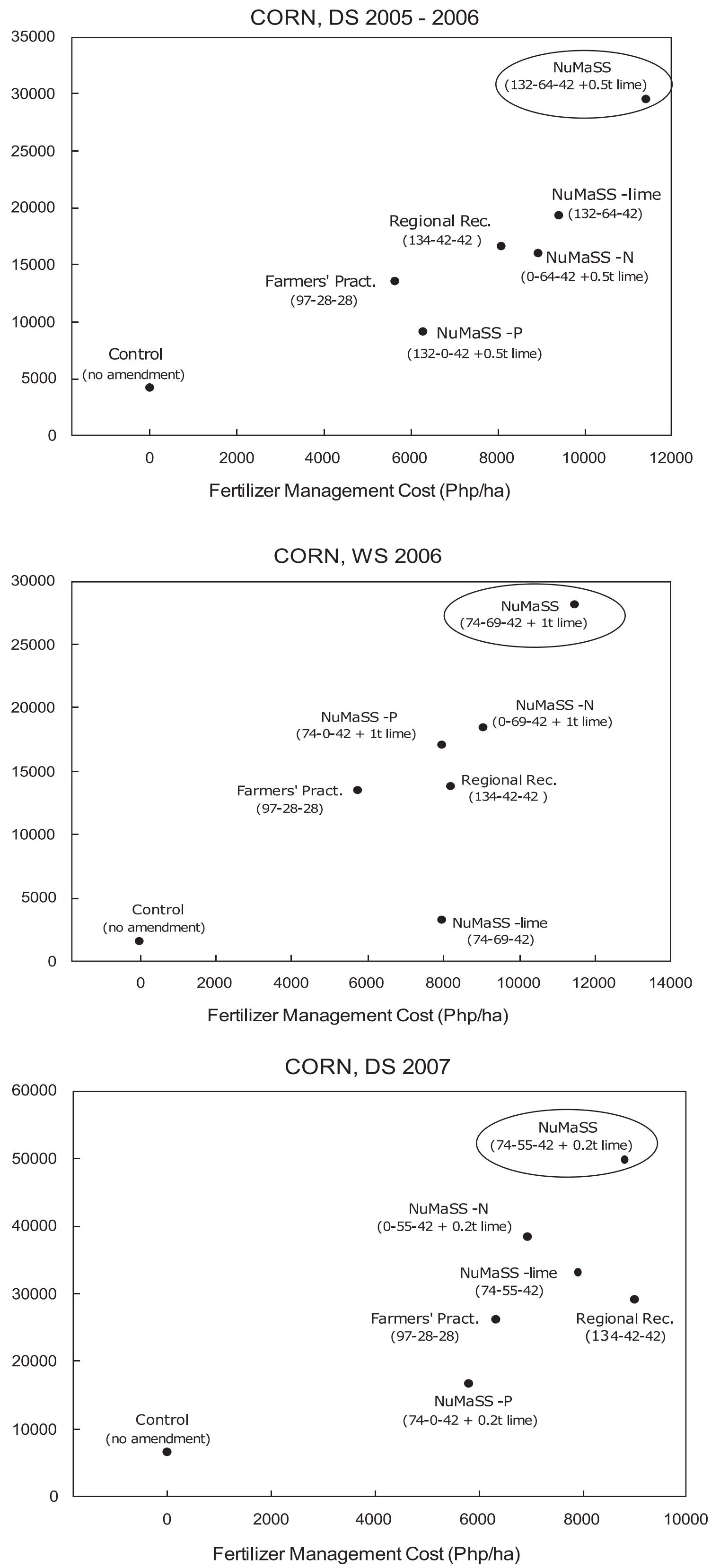


Figure 1. Economic advantage of NuMaSS generated fertilizer recommendation for corn in the on-farm trials in Ilagan, Isabela.

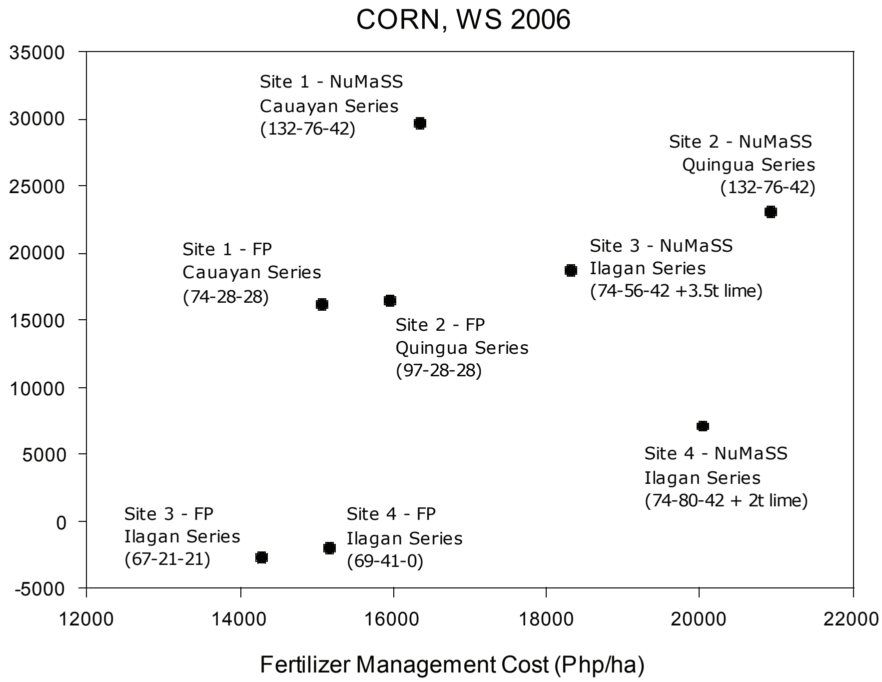


Figure 2. Economic advantage of NuMaSS generated fertilizer recommendation for corn grown under different soil series in Isabela Province, demonstration farms.

NuMaSS Recommendations for Groups of Provinces

The strength of NuMaSS as a tool to manage nutrient requirements of crops like rice, corn and legumes is that it is highly specific. However, we had found problems in doing repeated tests every season and this posed difficulty on the practicality of too frequent analysis of the soil. The adaptation that we imposed here was to test NuMaSS based on a soil grouping such as the soil series. We tested the NuMaSS recommendation and compared it with the current farmers practice on large plots of 5,000 m^2 for each unreplicated treatment. The lime recommendation that had been adopted by Region 2, which is comprised of the provinces of Isabela, Cagayan and Nueva Vizcaya, was used as an entry point in this activity. This was done in 70 sites with the farmers serving as lead extension agents teaching the farmers how to follow the recommendations of the NuMaSS.

Thailand

A methodology of site-specific fertilizer recommendation to be used in the small farms in the tropics was developed nine years ago using maize as the pilot crop and now the technology is being expanded to rice and sugarcane (Attanandana *et al.*, 2007). The modified technology on these two crops was developed with the participation of farmer leaders, who were the key persons responsible for carrying out field tests and demonstration plots and in disseminating the results to their community. They formed farmer associations to learn. While our site-specific nutrient management approach is based on several simplifications of the technology to fit farmer needs, we also sought to increase farmer capacity. One of the most powerful techniques for improving farmer success is that of increasing their self-confidence and that of convincing the farmers that they have knowledge that is useful and that, if they use it correctly, can change critical factors of production. The techniques of capacity building are designed to encourage farmers to become aware of their potential and how to use it. We describe here how we have implemented our site-specific approach as we have adapted precision agriculture concepts to some small farms of the tropics. With this approach we found that the transferred technology will be widely adopted and sustainable.

Thailand imported 3.5 million tons of chemical fertilizer in 2002 which cost about US $523 million, most of which was used on irrigated rice (Department of Agriculture, 2003). There are about 10.4 million hectares of rice in Thailand (Office of

Agricultural Economics, 2002) of which only 12 percent is used for irrigated rice in the dry season (Royal Irrigation Department, 2003). Farmers grow two to three crops of rice per year in this area. About one half of the rice production in the country comes from this irrigated area. The average yield of dry season rice is about 4,281 kg/ha (Office of Agricultural Economics, 2002). Farmers used blanket NPK fertilizer and to produce one ton of rice, the nutrient requirement of NPK is 19, 5 and 36 kg respectively (Yoshida, 1981). The current recommended fertilizer for rice is high in phosphorus (P) content, which has resulted in an accumulation of P in the soils. Moreover, the overuse of nitrogen (N) fertilizer has resulted in lodging of rice, which is frequently observed in provinces with irrigated rice. The area of sugarcane is about one million hectares, with the average yield of 50-56 ton/ha (Office of Agricultural Economics, 2002). The sugar factories produce about 5.4-6.0 million tons of sugar and more than 3 million tons is exported yearly. The low average yield of sugarcane is due to the rain fed condition and lack of knowledge of soil and fertilizer management (Department of Land Development, 1991). The objectives of this study were, therefore, to develop site-specific nutrient management for rice and sugarcane and at the same time, encourage capacity building of farmer leaders to conduct the field experiments, demonstration plots and disseminate the technology to their community.

Materials and Methods

Phase I: Capacity building of the farmer leaders. Thirty-one farmer leaders were selected to join the project to conduct field tests on rice and about six farmer leaders were selected to conduct the field tests on sugarcane. The techniques used were presented in Attanandana *et al*. 2007.

Phase II: Field test by the farmer leaders. There were 40 field tests on rice, in which 26, 9 and 5 plots were the nitrogen, phosphorus and potassium response studies, respectively. There were 14 field tests on sugarcane in which 6, 4, and 4 were the nitrogen, phosphorus and potassium response studies respectively.

Phase III: Demonstration plots by the farmer leaders. The farmer leaders disseminated the concept to their neighbors through demonstration. A total of 105 demonstration plots for rice and 30 plots for sugarcane were planted. The size of the demonstration plot for rice was 0.16 ha while the demonstration plot size for sugarcane was 0.32 ha. The chemical fertilizer and seeds were given to the farmers as the input subsidy on demonstration plots.

Results and Discussion

Phase I: Empowerment of the farmers. The farmer leaders were trained in self-reliance and in their way of thinking in order to implement changes to traditional practices. After the training, some of the farmers showed their enthusiasm and made obvious changes in their activities. Some of them began to disseminate the lessons learned to their neighbors. Some of them changed their crop production management. They attempted diversified crops, soil improvement, earning income from other jobs. The concept of self-reliance was accepted and disseminated widely.

Phase II: Field tests by the farmer leaders. The farmer leaders learned how to conduct field tests. They learned how to begin the experiments, prepare the layout of the plots and why the replications were needed. They learned how to record observations the growth and crop yield, soil series identification, soil testing by soil test kit and the amount of fertilizer to be applied to the field after learning the initial nutrient content. The results of field tests revealed a low response to nitrogen, phosphorus and potassium.

Rice response to nitrogen. Table 13 shows the response of rice to nitrogen fertilizer in Pitsanulok, Suphanburi and Chacheongsao provinces. We could see that the response to nitrogen fertilizer was much less than the DSSAT N prediction except for one field test, which showed higher response than did the predicted DSSAT recommendation. The yield for some of the field tests was lower than usual due to cold temperatures at the flowering stage of the rice plants.

In the case of rain fed rice, a lower response of rice to nitrogen fertilizer was also noted in most of the plots. Three field tests, however, showed a higher response of rice compared to the predicted values. This might be because the pH of these three soils was higher than the others, resulting in more availability of nutrients so the rice yields were higher with a higher rate of nitrogen fertilizer (Table 14).

*Rice response to phosphorus***.** Two fields had yield responses higher than the PDSS prediction. The phosphorus decision support system, PDSS, a subset of NuMaSS, was used to estimate the amount of P as P_2O_5 that was required for farmers to

Table 13. Rice response to nitrogen fertilizer in Pitsanlok, Suphanburi and Chacheongsao provinces.

Farmer	Soil series	% O.M.	Ammonium reading	N predicted w/DSSAT, kg/ha	Estimated yield (kg/ha)	Responded (or Optimum) N fertilizer (kg/ha)	1/adjR^2
Jamnong	Na	1.4	Very low	113	6625	16	0.342
Manee	Ph	2.0	Very low	100	7069	73	0.839
Yam	Ph	2.4	Very low	100	7069	18	0.207
Thawat	Utt	3.8	Very low	100	7281	12	0.329
Somchai	Na	1.3	Very low	113	6625	14	0.200
Sanong	Np	1.5	Very low	100	5900	68	0.792
Orasa	Np	2.4	Low	50	5900	23	0.368
Boonnom	Db	1.6	Low	63	6706	105	0.981
Pichit	Db	1.2	Very low	113	6706	57	0.933
Prapan	Db	2.0	Very low	113	6706	75	0.548
Surin	Pm	-	High	0	5631	-	-
Somnuk	Sb	4.7	Low	63	6050	-	-
Udon	Np	-	Low	50	5900	-	-
Ban	Pm	3.7	Very low	88	5631	88	0.971
Srinuan	Np	2.8	Medium	25	5900	-	-
Kasem	Bp	2.6	Low	50	6738	22	0.407
Pratoom	Rs	1.0	Very low	88	6888	15	0.219
Boonyarit	Bp	3.1	Low	50	6738	16	0.288
Paitoon	Rs	2.9	Low	38	6888	17	0.231

Remarks: 1/ SigmaPlot (LRP model)

Table 14. Rice response to nitrogen fertilizer in Nakhon Ratchasima and Khon Kaen provinces.

	Farmer	Soil Series	% O.M.	Ammonium content	DSSAT N (kg/ha)	Predicted yield (kg/ha)	Responded (or Optimum) N fertilizer (kg/ha)	1/adjR^2
1	Hua	Ki	1.3	VL	63	3381	88	0.802
2	Kritsana	Pm	0.5	M	25	3206	108	0.989
3	Somsak	Pm	1.8	VL	63	3206	11	0.159
4	Pithak	Tsr	0.9	VL	63	3381	12	0.456
5	Chaiyaporn	St	0.4	VL	75	2031	30	0.256
6	Han	Re	0.3	VL	75	3081	32	0.251
7	Suran	Nbn	0.4	VL	75	1794	142	0.885

Remarks: 1/ SigmaPlot (LRP model)

reach their target or predicted yield levels. Results from field tests in Table 15 show optimum yields of rice were achieved at higher levels than predicted by farmers Suchin and Chayaporn. These two soils were loamy in texture. There was no response in other clayey soils (Table 15).

Rice response to potassium. Rice showed a higher response to potassium in the Re soil series compared to St series although the K content in Re soil was higher than St soil. It should be noted that Re soil belongs to the soil order Ultisols, which is derived from sandstone, is low in fertility and highly weathered and exhibits a higher response to potassium. In the case of St soil, it is an Inceptisols, derived from river alluvium, with higher fertility compared to Re soil, so the response was lower than in Re soil. Ki soil, which belongs to the order Alfisols, is derived from old river alluvium, has a salinity problem and lower fertility measure and resulted in no response on potassium (Table 16).

Sugarcane response to nitrogen. Although the soils in Khon Kaen province are loamy sand and loamy, sugarcane response to nitrogen was low. Those farmers who used green manure also found the sugarcane had little response to nitrogen. It we look at Somyod's plot (Table 17), where he used green manure regularly, he attained optimum yields of 115 ton/ha at an N rate of 94 kg/ha instead of the predicted 188kg/ha. In the case of Sombat, who never applied any organic fertilizer and burned the cane leaves, the response to N fertilizer for optimum yield was attained at 89 kg/ha. His yield, however, was only 36 ton/ha instead of the predicted 65 ton/ha. Other farmers have reported applying filter cake (plant residue from the processing mill) to their land every year, The lack of response to nitrogen fertilizer with a yield of more than 75 ton/ha (Table 17) indicate the benefits of residue management with high N-content materials. That is, sufficient N is available from plant residue.

Phase III: Demonstration plots by farmer leaders. *Rice*. About 105 demonstration plots were conducted by the farmer leaders; only the results of some samples in each of three provinces are shown. Table 18 shows a comparison between farmers' practice plots in Pitsanulok province of the fertilizer amounts used, fertilizer costs and yields and yields of rice. We learned that immediately after the farmers were trained on site-specific nutrient management, many of them immediately reduced the amount of fertilizer they used because they had learned they'd overused chemical fertilizers and also, coincidentally, at that time, the price of fertilizer increased markedly. However, the reduction in fertilizer by the farmers was not based on the initial soil amount, so the fertilizer applied was still inefficient. The site-specific nutrient management (SNMM), which includes soil testing, is beneficial to the farmers. When the statistical analysis was done, no significant difference on the yields of the demonstration and farmers' practice plots was observed, but the fertilizer cost decreased significantly on the demonstration plots. The fertilizer cost on site-specific nutrient management plots was about 51 percent of the farmers' practice plots,

Table 15. Response of rice to phosphorus fertilizer in Pitsanulok, Suphanburi, Chacheongsao, Nakhon Ratchasima and Khon Kaen provinces.

	Farmer	Soil Series	Bray 2 P (mg/kg)	P content	PDSS (kg P_2O_5 /ha)	Predicted yield (kg/ha)	Responded P (or Optimum) fertilizer (kg P_2O_5 /ha)	adjR^2
1	Somchai	Na	3	Low	25	6625	8	0.334
2	Manob	Sb	25	Low	25	6050	-	-
3	Pranee	Db	8	Low	13	6706	-	-
4	Suchin	Pth	11	Low	13	6200	38	0.544
5	Srinuan	Np	18	Low	25	5900	-	-
6	Suparb	Cc	67	Very high	25	6794	-	-
7	Thongchai	Cc	11	Low	25	6794	19	0.416
8	Hua	Ki	5	Low	13	3381	-	-
9	Chayaporn	St	3	Low	13	2031	48	0.995

Table 16. Response of rice to potassium fertilizer in Pitsanulok, Nakhon Ratchasima and Khon Kaen provinces.

	Farmer	Series	NH_4OAc K (mg/kg)	K content	Predicted K (kgK_2O/ha)	Predicted yield (kg/ha)	Responded (or Optimum) K fertilizer (kgK_2O/ha)	adjR^2
1	Manee	Ph	60	Low	38	7069	16	0.035
2	Yam	Ph	40	Low	38	7069	17	0.565
3	Hua	Ki	29	Low	38	3381	-	-
4	Chayaporn	St	19	Low	38	2031	34	0.652
5	Han	Re	65	Low	38	3081	71	0.974

Table 17. Sugarcane response to nitrogen fertilizer in Khon Kaen province.

Farmer	Soil Series	% O.M.	Nitrate content	DSSAT N (kg/ha)	Predicted yield (Ton/ha)	Responded (or Optimum) N Fertilizer (kg/ha)	1/adjR^2
Vej	Msk	0.4	VL	188	65	no	-
Lawan	Msk	0.3	L	150	65	35	0.731
Sombat	Pp	0.5	VL	188	65	89	0.748
Somyod	Msk	0.4	VL	188	65	94	0.765
Prachak	Pp	0.4	VL	188	65	36	0.421
Janesuk	Stuk	0.5	VL	188	73	no	-

Remarks: 1/ SigmaPlot (LRP model)

Table 18. Comparison of farmers' plots in Pitsanulok.

Farmer	Series	$N\text{-}P_2O_5\text{-}K_2O$ (kg/ha)	Fertilizer amount (kg/ha)	Fertilizer cost (\$/ha)[iii]	Yield (kg/ha)
Manee	Ph	44-13-6[i]	156	46.6	5619
		25-25-0[ii]	113	36.1	6338
Srinuan	Ph	50-25-13[i]	188	67.5	3888
		25-25-19[ii]	144	45.7	3988
Samrit	Utt	81-50-0[i]	344	98.9	4994
		25-19-0[ii]	97	31.3	5044
Pitsanu	Utt	56-38-19[i]	281	81.4	5019
		25-25-0[ii]	113	36.1	4963
Jamnong	Na	44-19-0[i]	156	45.5	4813
		38-13-0[ii]	106	34.8	5019
Pratin	Utt	63-38-38[i]	313	91.1	5025
		25-19-0[ii]	97	31.3	5063
Choan	Utt	50-31-38[i]	119	80.0	4669
		25-25-0[ii]	113	36.1	4600
Sam-ang	Tp	56-0-0[i]	438	103.6	5275
		25-25-0[ii]	113	36.1	5494

Remarks: i. Farmer's plot; ii. Site-specific nutrient management plot; iii. 1US$=35baht

Table 19. Comparison of yield and fertilizer cost of rice in three provinces, 2006.

Province	No of comparison	Yield (kg/ha)		Fertilizer cost ($/ha)	
		Farmer[1/]	SSNM[2/]	Farmer[1/]	SSNM[2/]
Suphanburi	40	4645	4621[ns]	82.6	39.0**
Chacherngsao	9	4779	5009[n]	71.9	51.0*
Pitsanulok	15	4815	669[ns]	70.8	35.8**
Average†		4704	4687[ns]	78.3	40.0**

Remarks: 1/= Farmers' plots; 2/ =Site-specific nutrient management; * = 95% significance level; ** = 99% significance level; ns = not significant; †= mean of 64 comparisons

ranging from 47-70 percent in the three provinces (Table 19).

Sugarcane. There were 30 demonstration plots planted by the farmer leaders. The demonstration plots showed higher yields and profits but there was no significant difference between the farmers' practice and the site-specific nutrient management (SNMM) plots. The farmers are very poor in this area. Demonstration of the effectiveness of organic matter application should help the farmers improve their land and reduce their costs for chemical fertilizers. Because of the generally infertile sandy soils in the Northeast, the benefits of site-specific nutrient management (SNMM) methods are not easily shown. The sandy texture of the soils where sugarcane is grown increases their nutrient and water holding capacity and this can be improved with better management of organic matter through incorporation of crop residues. The farmers can reduce their costs for fertilizers by being more efficient in their application through a more site-specific means (i.e., they can apply fertilizers where it's most needed rather than generally applying them randomly over a larger area).

Summary and Conclusions

The field tests and demonstration plots on rice showed the beneficial effect of site-specific nutrient management where irrigated rice farmers could reduce the amount of chemical fertilizers and thus reduce the cost of production. Moreover, the farmer leaders learned about soil improvement, working in groups to solve the problem of buying input and selling products, more self-reliance and using local wisdom. In the case of sugarcane, farmers learned the site-specific nutrient management technology, but it was determined that the farmers should emphasize organic matter incorporation due to the poor sandy soils and some salinity problems.

Laos

Data Presentation and Training

Maize is one of the main crops in Lao economic development. Its production and cost is still low as its profit.. Therefore, increasing maize production and profitability are the main policies of the Lao government. Nutrient management under maize cultivation by Lao farmers is not well understood as they lack the knowledge and have little experience in soil fertility improvement technology. Technology transfer and farmer participatory research on nutrient management for maize in Laos could be the best chance to assist them in increasing their maize yield and its profitability. Experience with the NuMaSS and PDSS software systems offer a good method for nutrient management and are both used in a number of countries in the world.

In order to teach the NuMaSS and PDSS technology to Lao farmers, a workshop was held on August 28, 2007 by the Soil and Water Management Unit, Soil Survey and Land Classification Center. Dr. Pheng, who recently graduated from Khon Kaen University, Thailand gave the workshop. It included a discussion of results of NuMaSS activities in Laos as well as training on Nutrient Management in maize production areas and on soil test kits for villagers from Sendin Village, Naxaithong district, Vientiane Capital. Regional officers also participated in the training.

Training objectives:

1. Evaluate the farmer participatory research experimental results and make recommendations for nutrient management in maize cultivation areas;
2. Improve the villagers' skill on soil testing by using the soil test kit (Figure 3);
3. Share the experiences of farmers from the three villages on nutrient management, post harvest technology and marketing information for maize.

Participants. The training course was attended by 31 farmers who came from Sendin, Phorn Haikham and Hai villages and two district staff members; one from Xaithany and one from Naxaithong districts, Vientiane Capital.

Procedures:

- Mr. Khonepany presented on-station and on-farm experimental data, interpreted and summarized and made some recommendations for nutrient management under maize cultivation systems and discussed problems faced by the farmers;
- Dr Pheng Sengxua presented a general knowledge talk on soil, soil fertility improvement, plan nutrition and the role of farm residues and green manure on soil fertility improvement
- Test soils for NH_4, NO_3, P and K using soil test kit; fertilizer recommendations were discussed by four groups of farmers from the soil test data.

During the training, farmers shared their experiences of suitable fertilizer rates and sources, method and timing of fertilizer application and crop residue management after harvesting. The main problems in maize cultivation in some villages are:

1. Low rates or no fertilizer applied according to their experiences;
2. Top dressing not always on time (only basal application);
3. No soil nutrient status information (lack of soil test);
4. Some villages lack post harvest technology, especially drying; and
5. Low and unstable price of maize.

Africa

Mali

NuMaSS Activities

Three NuMaSS activities took place in relation to Mali during the project year. These were:

1. NuMaSS testing in Mali was part of the soil carbon sequestration package of technologies – termed the C-4 technologies. The results of that testing can also be found in this year's report in the *Carbon Sequestration Progress Report*, in the head entitled, "Impact of C-4-T on Millet Yield and Soil Carbon."
2. Continuation of the graduate training of Aminata Sidibe-Diarra and her field studies designed to compare and adapt her published rock phosphate prediction module. During the project year, Ms. Sidibe-Diarra applied for a dissertation enhancement grant under the Borlaug program sponsored by USDA and USAID through the University of California at Davis. She was awarded a Borlaug scholarship, which permitted her to expand her field testing to Niger and to include one of the moderately soluble rock phosphates of Niger. Unfortunately the timing of the late growing season made it impossible to include the Niger data in her dissertation, but it is sure to be included in her subsequent publications. A brief summary of the conclusions of her dissertation will be included. Her conclusions are found under Objective 2 of this progress report.
3. Mr. Adama Bagayoko obtained support for MSc studies at the University of Louvain, Belgium, during the project year.

Figure 3. Farmers testing soil nutrient status.

Impact of C-4-T on Millet Yield and Soil Carbon

An experiment was designed and implemented to evaluate the impact of selected management practices on soil carbon and crop yields. These management practices, referred to as C-4-technologies (C-4-T), include: ACN, NuMaSS, reduced tillage, and residues management in a 2x2x2x2 factorial experiment. This experiment of 16 treatments was implemented in a single replication, on-farm at Fansirakoro, Konobougou, and Oumarbougou. The same experiment was replicated three times at the Sotuba research station. Data collected were those for the fifth year of implementation on the same plots. The crop was millet this project year. Plant growth and yield were recorded. Soil samples were collected for laboratory analyses, for the C (Walkey-Black). The experiment and its result can be found in this year's report in the *Carbon Sequestration*

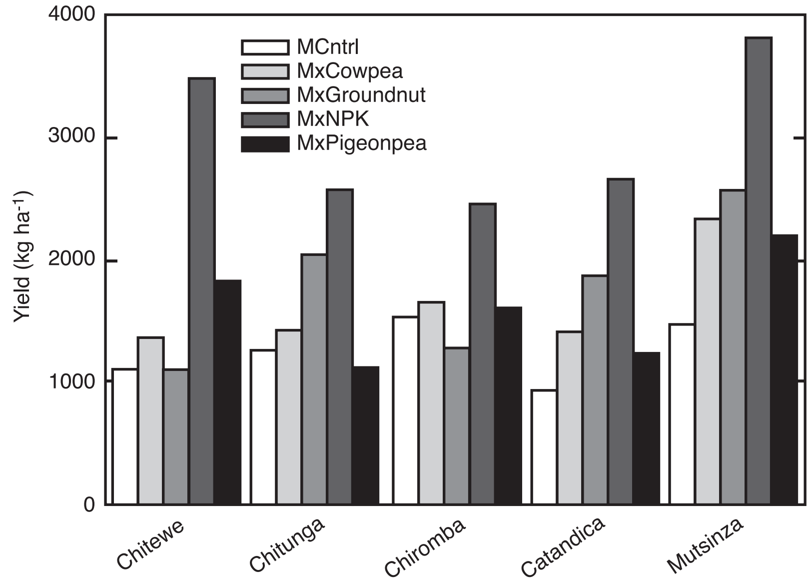


Figure 4. Effects of various legume and NPK fertilizer combinations on maize yield, Manica and Barue Districts, Moçambique.

Progress Report, in the section entitled, "Impact of C-4-T on Millet Yield and Soil Carbon."

Mozambique

Activity 1. Demonstration and Scaling-up of Maize- and Legume-based Technologies for Improving Maize Yield

The objective of this activity was to evaluate different legume crops as green manure for improving maize crop yields. To achieve this objective, five experiments were conducted in farmers' fields in different locations in Manica and Barue districts, representing different agro-ecological and farmer production conditions. Each farmer in a similar environment was considered a replication. Soil characterization of selected sites was conducted for determining initial soil conditions prior to establishment of the experiment and after crop harvest. The initial soil condition indicates low soil fertility capability. The legume- and maize-based systems were: 1) Maize with cowpea (MxCowpea); 2) Maize with groundnut (MxGroundnut); 3) Maize with Pigeonpea (MxPigeonpea); and 4) Maize with fertilizer (NPK). The crop varieties selected were Matuba for maize, Nametil for groundnut, IT 18 for cowpea and ICEAP 00040 for pigeonpea. The maize, cowpea and groundnut varieties were released by the National Agricultural Research Institute, formerly INIA. Participatory evaluation of different treatments with farmer involvement was conducted during the cropping season. Several agronomic and socio-economic data were collected for evaluating the technologies.

The results indicated statistically significant differences in maize crop yield among treatments within sites and between locations (Figure 4). The sole maize-based system yielded consistently low yield in almost all locations, which suggests that these soils are nutrient deficient. A substantial yield increase for maize was observed with 170 kg/ha of NPK (12:24:12) plus 160 of Urea (46% N). Two sites, Chitewe and Mutsinza, showed significant yield increase for maize on fertilized plots. Little increase of maize yield was achieved in intercropped plot with maize and cowpea and maize with groundnut.

Activity 2. Training of Farmers and Extension Workers of Barue and Manica Districts on Integrated Soil Fertility Management

Good understanding of soil nutrient management is essential for informed decision making on crop management. On the job training on Integrated Soil Fertility Management (ISFM) has therefore become increasingly important for strengthening the knowledge and skills of farmers and field extension workers. To help achieve this understanding, a workshop was organized to train participants in field extension skills that develop the basis for effective implementation of the on-going joint SM CRSP and SOFECSA efforts to promote research and dissemination of agricultural innovations in central Mozambique. Twenty participants from government and private extension services, including extension supervisors of Manica and Barue districts, attended the five-day intensive training workshop. The workshop addressed basic aspects of soil nutrient management including the use of the soil test kit for diagnosis of soil nutrient status, field practice in soil sampling and data collection for agronomic and socio-economic evaluation of the technologies, conservation agriculture, Integrated Pest Management and extension methods (Figure 5).

Activity 3. Maize Fertilizer Trial

Maize crop is an important cash crop and main staple cereal in Mozambique. However, the crop yields are generally low due to low soil fertility, exacerbated by soil erosion and poor agricultural practices. The farmer gate price of maize has shown significant increases in recent years as a result of high demand in the region. Increasing maize crop yield per unit of land therefore becomes increasingly important. Such increases would be possible with good soil nutrient management, including fertilizer use. To test maize crop response to fertilizer application a field experiment was conducted in several locations in Manica and Barue districts. The experimental design was Randomized Complete Block (RCBD), and farmers managed the experiment. The treatments tested were: 1) Control - 0 NPK 12:24:12 and 0 Urea; 2) 125 kg/ha -NPK and 76 kg/ha of urea; 3) 186 kg/ha of NPK and 168 kg/ha of urea; 4) 250 kg/ha of NPK and 261kg/ha of urea. The urea and NPK are generally from the nitrogen, phosphorus and potassium sources available in the market.

Maize crop yield showed significant differences among locations and within experimental sites, except for Manhimo in Manica district (agro-ecological zone 4),where crop yield averages did not show statistically significant differences among treatments. In general, sites located in the agro-ecological zone 10 of Manica province were less responsive to fertilizer application. The average crop yields in unfertilized plots range from 1.5 up to 3.4 ton/ha in some locations.

Comparison across location showed significant variation on crop response to fertilizer application among sites. In general, the sites in Chitunga, Machipanda and Bairro Novo were consistently low in all treatments. The main reason appears to be the initial soil condition.

Figure 5. Participants in the five-day training workshop in Mozambique.

Activity 4. Strengthening Collaboration between Farmers and Service Providers

Several meetings between farmers, extension services and agro-dealers were organized. It is envisaged that impact could be achieved through active and innovative collaboration of the various institutions involved in agricultural production and marketing, which could lead to improved agricultural production.

Activity 5. Study Tour and Field Visit

A study tour with researchers, farmers and input providers was organized in central Manica province. The aim of the field visit was to identify strengths and weaknesses in the implementation of the program and to identify mechanisms for improving the methodology.

Several participants, including media, attended the field day and panel discussion in each district after the field visit. There was general consensus among participants that the Integrated Soil Fertility Management brought more collaboration between different partners at provincial, district levels, which contributed to building a partnership. Moreover, farmers were also able to identify differences on crop yield for fertilized compared with unfertilized plots, as well as differences on crop yield for different maize-legume based systems. Input supply on time were requested for future activities as rain patterns have changed in recent years in central Mozambique as a result of climate change.

Ghana

Low soil fertility especially nitrogen, phosphorus and organic matter content are major constraints to increased maize production in northern Ghana. Maize yields are often very low, without some form of fertilization. In the past, bush fallowing played an important role in improving soil fertility in this area. However, rapid population growth in many areas has drastically shortened the fallow period. Applications of inorganic fertilizer, compost, retention of crop residues, crop rotations involving legumes and agro-forestry are all ways to overcome low soil fertility. Generally, farmers welcome the use of inorganic fertilizers but only a few can afford them because they are costly and risky in the savanna environments where rainfall is uncertain.

The results of various fertilizer experiments carried out in Ghana have led to fertilizer recommendations that gave blanket nutrient requirements for maize in ecologies having varying soil conditions and under varying levels of soil management. The current fertilizer recommendation of 64 kg N, 38 kg P and 38 kg K per ha, respectively, for maize was made in the 1980s irrespective of the initial fertility status of the soil. Fields vary in fertility and it is, therefore, important to determine if supplementary fertilizer may be needed. Recent exploratory surveys conducted in the Upper West region revealed that increased soil carbon and high soil fertility were synonymous from farmers' standpoint. The findings also showed that crop yields correlated negatively with a decrease in soil carbon. Synergism between soil carbon and inorganic fertilizers is widely acknowledged. In practical terms, it means that by applying the same fertilizer at modest rates, yields would be much higher in fields with greater C levels than fields with less C content.

NuMaSS is an expert system purposely designed to manage soil fertility of cropping systems . Major outputs of NuMaSS are diagnoses and prescriptions of fertilizer rates. NuMaSS is a useful tool to determine whether or not supplementary fertilizer is required. The advantage is that NuMaSS can help minimize risk in the savanna environments where rainfall is unpredictable and the cost of fertilizer is usually expensive.

The MOU between the Savanna Agricultural Research Station at Wa and the SM CRSP of the University of Hawaii, was signed in late 2004 to pave the way for collaborative field activities in 2005 and 2006. The objective of the Ghana component of the project was to use the NuMaSS as a research tool to guide the recommendation of supplementary inorganic fertilizers in cropping systems. Following exploratory surveys in the 2003/2004 cropping season, we hypothesized that 1) NuMaSS would predict low P fertilizer rates in fields with greater soil carbon and 2) treatments based on NuMaSS fertilizer recommendations would be 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. A combination of on-station and on-farm trials was conducted during the period 2005 to 2007 to test these hypotheses. This report incorporates in the most part activities and achievements for 2005 and 2006 followed by an update of current season activities.

Soil Analysis and NuMaSS Predictions

Prior to initiation of the field experiments, soil samples were taken from the top 0-20 cm depth of each treatment plot, in three replicates, and analyzed for texture, pH, soil organic carbon, extractable phosphorus (P), and total nitrogen (N). Soil texture was determined by the hydrometer method, pH in water at 1:2.5 soil to water ratio (Peech, 1965); soil organic carbon (Walkey and Black, 1934); total nitrogen (Bremner and Mulvaney, 1982); extractable phosphorus by extraction with 0.1 *N* HCl and 0.03 *N* NH_4F at pH of 1.2. The analytical results, together with field history, environmental conditions as well as default values residing in NuMaSS, were used as input variables of the model to diagnose and recommend the requisite fertilizer rates for each treatment and the different sites.

Field Experiments

Three separate field experiments were implemented in 2005. The first two studies were established on-station while the third experiment was established on farmers' fields. In 2006, Experiment 2 was terminated. The details of the studies are as follows:

Experiment 1. The first study was conducted during 2005 and 2006 growing seasons at the Savanna Agricultural Research Station farm near Wa, Northern Ghana. The treatments were: 1) recommended regional fertilizer rate for continuous maize, 2) NuMaSS recommended fertilizer rate for continuous maize, and 3) NuMaSS recommended fertilizer rate for maize following groundnut in rotation. The regional recommended fertilizer rate was considered as the reference point. Treatments were assigned in a randomized complete block design with four replications. Plot size was 8m by 6m.

Experiment 2. The second study was a continuous maize study located at the same site as Experiment 1. The treatments were: 1) recommended regional fertilizer rate for maize (T1), 2) full NuMaSS recommended fertilizer rate (T2), (3) half NuMaSS recommended fertilizer rate (T3) and (4) one quarter NuMaSS recommended fertilizer rate. Similarly, the regional recommended fertilizer rate was the reference point. The experimental design was randomized complete block with four replications. Plot size was 8m by 6m.

Experiment 3. The third study was a farmer managed cropping systems experiment conducted at Tumu in the Sissala East district. The treatments were the same as in Experiment 1, that is, 1) regional recommended fertilizer rate for continuous maize, 2) NuMaSS recommended fertilizer rate for continuous maize, and 3) NuMaSS recommended fertilizer rate for maize following groundnut in rotation. No fertilizer was applied to the groundnut in rotation with maize. The treatments were replicated on 10 farmers' fields, with each farmer being a replicate. The NuMaSS fertilizer recommendations were derived based on soil properties of the individual farms.

Crop Husbandry

In all experiments, an improved maize variety, Obatanpa, was sown on flat seedbed at the recommended spacing of 75 cm x 40 cm. As is the practice, the regional recommended fertilizer rate (38 kg N/ha) was applied four weeks after planting to the maize using compound fertilizer (15-15-15, $N:P_2O_5:K_2O$) and top dressed with ammonium sulphate at a rate of (26 kg N/ha) at 6 WAP. The NuMaSS recommended rates of fertilizer, mainly phosphorus and nitrogen, were applied using single super phosphate and ammonium sulphate fertilizers respectively. The two straight fertilizers were mixed and spot applied four weeks after planting too; no additional fertilizers were used as top dressing. Weeds were controlled manually using hoes when necessary.

Cost – Benefit Analysis

To compare the benefits of each fertilizer recommendation, simple economic dominance analyses were carried out. The profit or marginal net returns (MNR) was computed for each treatment as follows:
MNR = Y x P – TVC
Where Y is grain yield of maize crop (kg/ha), P is the selling price of maize at harvest (US$/kg), and TVC is the total variable cost or costs of inputs related to the treatment in US$/ha. The marginal rate of return (MRR) for each treatment was calculated using the formula:
MRR = MNR/TVC.

Data Analysis

Data on total dry matter, grain and stover yields at final harvest were analyzed using SAS statistical software. Also, soil carbon, extractable P, pH and percent clay were similarly examined.

Accomplishments

Experiment 1. Initial soil properties of the experimental site in 2005 were soil carbon=0.80%; mean available P was 8.3 μg/g, s.e.= 0.39; and mean pH was 5.35 (Table 20). Soil carbon was relatively high

Table 20. Some initial soil properties at the site of experiment 1 in 2005 and 2006.

Year	% Clay	pH (1:2.5)	Organic C (%)	Total N (%)	Available P (μg/g)
2005	13.19±1.33	5.35±0.28	0.80±0.06	0.05±0.01	8.31±0.39
2006	-*	5.91±0.06	0.79±0.01	0.07±0.002	30.90±0.88

*Not yet determined

and comparable with soils of the Sahel that ranges between 0.2 and 1.0 percent, respectively. Threshold of available P of the soil of the tropics is usually pegged at 10.0 μg/g. Therefore, not much deviation from the threshold value was found. As well, soil pH tallies with typical Sahelian soils. In 2006, measurements showed that total N and available P had increased significantly compared to 2005.

The effect of the regional and NuMaSS fertilizer recommendations on total dry matter accumulation with time are shown in Table 21. In 2005, there were no significant differences between treatments in dry matter on all dates of measurements except at 77 DAP when T1 had a higher dry matter than T2 and T3. In 2006, there was no significant difference in dry matter between treatments on all dates of measurements. Table 22 shows the effect of the national and NuMaSS fertilizer recommendations on maize total dry matter, grain yield and harvest index at final harvest. In 2005, total dry matter of maize fertilized with the national recommendation was significantly higher than maize fertilized based on NuMaSS recommendation. Total dry matter of maize following groundnut with fertilizer based on NuMaSS recommendation was higher than continuous maize with fertilizer based on NuMaSS recommendation but not significantly different. There was no significant difference between treatments in maize grain yield although grain yield of continuous maize with fertilizer based on the national recommendation was higher than grain yield of maize following groundnut with fertilizer based on NuMaSS recommendation which was also higher than continuous maize with fertilizer based on NuMaSS recommendation. There was no difference in grain harvest index.

Simple economic analysis show that in 2005, total variable costs for fertilizer application based on NuMaSS were lower than fertilizer application based on the national recommendation (Table 23). Fertilizer application to maize based on national recommendation was more profitable than, but not significantly different from, fertilizer application based on NuMaSS recommendation. No difference was found in the marginal rate of return for fertilizer application based on either the national or NuMaSS. In 2006, profitability and marginal rate of return were higher when fertilizer was applied to maize following groundnut in a rotation (Table 23).

Experiment 2. The soil at the site of Experiment 2 was similar to the soil at the site of Experiment 1 in terms of available P (P= 7.38±0.90 and pH=6.43±0.33). However, mean soil organic carbon at this site (C=0.46±0.03) is almost half of that of the previous site. Granted the importance of soil carbon in the Sahelian soils, sustainable yields are threatened at the site of the second experiment. There was no significant difference between treatments in all parameters measured (Table 24). Information presented in Table 24 clearly makes economic sense to use a quarter of the fertilizer recommended by NuMaSS.

On-farm studies. Generally all farms had high sand content (>70%), and very low clay content, which ranged from 3.53 to 8.53 percent. Soil pH ranged from neutral to slightly acid, except one farm where the pH was 5.9. Organic carbon levels varied from 0.42 to 1.30 percent, respectively, and total N and available P were all low except on farms that had high organic carbon and this is confirmed in Figure 6. Figure 7 shows that increasing soil organic carbon levels is associated with decreasing amount of P recommended by NuMaSS.

In 2005, application of fertilizer based on NuMaSS recommendation to continuous maize or to maize following groundnut gave lower total variable costs and higher profitability than application of fertilizer to maize based on the national fertilizer recommendation As a result, the marginal rate of return was significantly (P> 0.05) greater for maize in rotation with groundnuts with addition of fertilizer based on NuMaSS. Similarly, in 2006, total variable cost was lower and profitability higher when maize followed groundnut in rotation and fertilizer was applied based on NuMaSS diagnosis and recommendation (Table 25).

Table 21. Effects of fertilizer based on regional and NuMaSS recommendations on total dry matter of maize as a function of time, DAP (days after planting), in Experiment 1 in 2005 and 2006.

Year	Treatment	31	48	62	77
		------------------- kg/ha -------------------			
2005	T1	607	4081	6982	12526
	T2	737	4244	5538	8841
	T3	590	2960	5763	8285
	LSD (0.05)	NS	NS	NS	2919
2006	T1	1101	2613	3382	7378
	T2	955	3740	4143	7901
	T3	812	2282	4791	7142
	LSD (0.05)	NS	NS	NS	NS

T1 = continuous maize with national fertilizer recommendation; T2 = continuous maize with NuMaSS fertilizer recommendation; T3 = maize following peanut with NuMaSS fertilizer recommendation

Table 22. Effect of national fertilizer recommendation and NuMaSS recommended fertilizer rates on total dry matter, grain yield and harvest index of maize in 2005 and 2006 in experiment.

Year	Treatment	Grain yield	Total dry matter	Harvest index
		………………kg/ha …………….		
2005	T1	2708	10547	0.26
	T2	1854	6248	0.29
	T3	2208	6968	0.31
	LSD (0.05)	NS	2427	NS
2006	T1	2125	4771	0.44
	T2	1458	3292	0.44
	T3	3104	6938	0.45
	LSD (0.05)	1130	2446	NS

T1 = continuous maize with national fertilizer recommendation; T2 = continuous maize with NuMaSS fertilizer recommendation; T3 = maize following peanut with NuMaSS fertilizer

Table 23. Profitability, total variable cost (TVC), and marginal rate of return (MRR) of maize with fertilizer based on national and NuMaSS recommendations, in Experiment 1 in Ghana.

Treatment	Profit (US$/ha)	Increase over reference (%) (MRR)	Total variable cost (US$/ha) (TVC)	Benefit/cost
	2005			
T1	381.0	-	207.1	1.84
T2	233.0	-38.8	168.9	1.38
T3	310.0	-18.6	168.9	1.84
LSD (0.05)	NS		-	NS
	2006			
T1	237.0	-	224.6	1.05
T2	112.0	-52.7	204.1	0.55
T3	506.0	113.5	167.4	3.02
LSD (0.05)	245.2		-	1.22

T1 = continuous maize with national fertilizer recommendation; T2 = continuous maize with NuMaSS fertilizer recommendation; T3 = maize following peanut with NuMaSS fertilizer recommendation

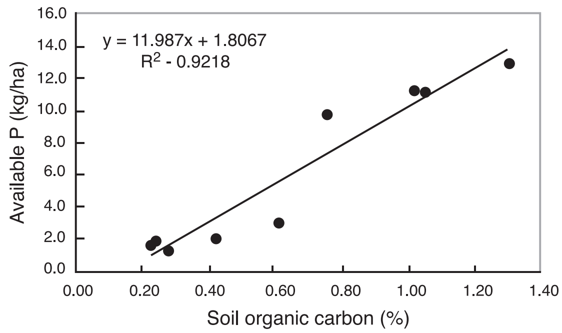


Figure 6. The relationship between soil organic carbon and extractable P on on-farm experiments. Ghana.

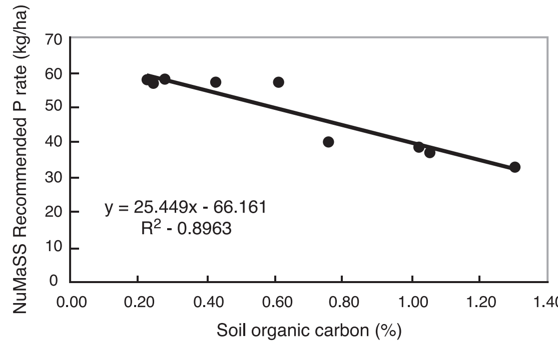


Figure 7. The decrease in apparent NuMaSS P recommendations with increasing soil organic carbon. On-farm experiments, Ghana.

Table 24. Stover and grain yield, total dry matter (TDM) and harvest index (HI) of maize as influenced by fertilizer based on regional and NuMaSS recommendations in Experiment 2.

Treatment	Stover yield	Grain yield	TDM	HI
Regional recommendation	1962	1792	4170	0.42
Full NuMaSS	1968	1333	3572	0.36
1/2 NuMaSS	1964	1312	3652	0.34
1/4 NuMaSS	2187	2062	4729	0.39
LSD (0.05)	NS	NS	NS	NS

In 2005, total dry matter production ranged from 6113 to 10,000 kg/ha and grain yield ranged from 1900 to 3167 kg/ha. Averaged across farms, total dry matter of maize following groundnut with an application of fertilizer based on the NuMaSS recommendation was significantly higher than continuous maize with addition of fertilizer based on the national or NuMaSS recommendation. No difference was found between continuous maize with addition of fertilizer based on the national or NuMaSS recommendation, which suggests that because the groundnut is a legume it might have contributed some nitrogen to the succeeding maize crop. Similarly, averaged across farms, grain yield of maize following groundnut was significantly higher than continuous maize with addition of fertilizer based on the national or NuMaSS recommendation. In 2006, total dry matter and grain yields of maize following groundnut with addition of fertilizer based on NuMaSS recommendation were significantly higher than in continuous maize with application of fertilizer based either the national or NuMaSS recommendation. Previous experience in the USA has demonstrated that crop 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).

Conclusions

The studies so far shows that for both the on-station and on-farm trials, treatments which depended on NuMaSS fertilizer recommendations were more sustainable in terms of cost effectiveness as it considered the initial soil fertility status (Yost, et al, 1988). Evidently, maize groundnut rotation with NuMaSS fertilizer recommendation was the best in terms of yield, total variable cost and profitability. The national system is typically based on a blanket fertilizer recommendation regardless of baseline fertility levels. This system largely ignores the fact that majority of farmers use other organic soil amendment such as compost, household refuse including wood ash, green manure or animal manure.

2007 Activities

For the 2007 season, the on-farm trials initiated in 2005 were continued at Tumu in the Sissala district of the Ghana. Ten (10) trials were established on farmers' fields in June of this year. Soils were sampled before establishment of the trials to determine changes in soil fertility status (pH, organic carbon, total N and P, and available P) and to provide the input for use in the NuMaSS model for diagnosis

Table 25. Profitability, total variable cost (TVC), and marginal rate of return (MRR) of maize with fertilizer based on national and NuMaSS recommendations, in on-farm trials in Ghana.

Treatment	Profit (US$/ha)	Increase over reference (%)	Total variable cost (US$/ha)	Benefit/cost ratio
	2005			
T1	319	-	207.0	1.54
T2	350	9.7	193.1	1.89
T3	409	28.2	189.0	2.29
LSD (0.05)	53		NS	0.49
	2006			
T1	403	-	208.8	1.93
T2	385	-4.5	185.0	2.16
T3	574	42.4	184.9	3.18
L	86.3		16.7	0.56

and recommendation of nutrients. Plant samples were also taken at maize silking for determination of tissue N and P concentrations. Data collection is currently ongoing and a field day is planned for mid September when farmers, extension agents, agricultural related NGOs and policy makers will be invited to participate.

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

Southeast Asia - Thailand

See the *SM CRSP Annual Progress Report, 2005 – 2006, NuMaSS, Objective 2 (UH),* for a detailed explanation of the study of the rock phosphate (P) algorithm for Thailand.

West Africa – Mali

Field Test Rock Phosphate (RP) Algorithm

(From the dissertation of Ms. Aminata Sidibe-Diarra)

According to the World Bank (1989), food production must increase by four percent in order to achieve self-sufficiency and alleviate poverty. This challenge can be attained only through agricultural intensification by replenishing and improving soil fertility, which requires use of external inputs. Because 1) West African soils are phosphorus (P) deficient, 2) soluble fertilizers are expensive and beyond the means of resource-poor farmers in West Africa and 3) several rock phosphate (RP) deposits exist throughout West Africa, the ability to predict RP fertilizer requirements and to develop accurate and specific RP recommendations will represent an enormous contribution to improve P fertility status and to increase crop yields in that region. While RP may be a cost-effective way to supply P and sustain the often deficient nutrient P, it is also clear that soluble P is needed in many cropping systems and soils of West Africa. Examples include intensive vegetable production. The large number of factors affecting RP suitability for direct use justifies the need for a modeling approach that could identify, quantify and combine the factors into a prediction algorithm.

Rock Phosphate (RP) Algorithm

A simple algorithm considering dissolution and sorption processes is proposed to predict amounts of RP needed to meet crop P requirements. Soil KCl-extractable acidity, Ca saturation and the effective cation exchangeable capacity and the ratio between ΔNaOH-P and ΔBray 1-P are the potential parameters for predicting amounts of RP needed for crop production in West African soils. It is also worthwhile to mention that this proposed algorithm is so far the only approach that attempts to quantitatively predict the amount of RP needed that considers plant and soil P status.

In this study, the amounts of RP dissolved were estimated using the changes in 0.5M NaOH-P between RP-treated and untreated soils (ΔNaOH-P). Based on the comparison with the changes in exchangeable Ca (ΔCa) between RP treated and untreated soils, ΔNaOH-P can be used as an estimate of the RP dissolution especially for RP containing $CaCO_3$ and in conditions where Ca losses occur and are not estimated. Because of the high susceptibility of Ca to be lost either by leaching or by plant uptake, ΔCa cannot be recommended as a measure of RP dissolution in field conditions.

The millet growing soils in West Africa are sandy, and deficient in P and characterized by a natural variability resulting in extremely difficult situations for field experiments. Because of this large variability in the field, the capability of the RP algorithm to accurately predict RP to meet crop P requirement was not well established. Additional experiments in more controlled conditions are needed to assess the accuracy of the RP algorithm and to define modifications needed to the algorithm. However, it can be already pointed out that the extremely high RP application rates are not needed.

The use of RP in millet growing soil of West Africa has an enormous potential in increasing millet yield and soil P status.

When opting for the use of RP to correct soil P deficiency, the choice of RP to apply should carefully consider the RP properties itself and the soil properties to which the RP will be applied. For example, highly reactive RPs with some CCE (carbon carbonate equivalent) are not the most suitable for sandy soils with pH close to 5.5 and with low buffering capacity.

It is important to integrate RP properties into the RP algorithm. The rock phosphate algorithm tested in these field experiments considers only soil properties. The different results obtained from Konobougou 1 and 2 experiments using Tilemsi RP (same origin but most probably different sampling time) support the need to also consider RP properties in the algorithm.

For identifying P deficiency conditions and predicting amounts of P needed to meet crop P requirements, one single Bray 1-P critical level of a given crop could be used for both water-soluble P and RP materials. Considering that millet yield was affected by the locust attack at Keur Madieng, a Bray-1 P value of 11 mg/kg could be considered as the P critical level for producing maximum millet yield for millet producing soils of West Africa.

Leaching probably did not substantially affect RP dissolution in Keur Madieng soil because of the limitation appeared likely due to the low soil acidity and P retention capacity.

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* sorghum, maize and cotton only responded to N fertilization. Yields for NuMaSS fertilizer recommendations were similar or superior to four other recommendation practices for all crops. Fifty-four participants attended a software training workshop held in Reynosa, Tamaulipas in February 2007.

In *Honduras* and *Nicaragua*, maize yields and net returns with NuMaSS fertilizer recommendations were equal or superior to producer yields in 9 of the 12 sites. Fertilizer costs for the NuMaSS recommendation were less than producer practices in 8 of the 12 sites. In some regions producers were applying too much N and P fertilizer for the yields they expected to achieve. In other regions, producer N applications were too low and/or P was applied in excess, or K fertilizers were applied to soils where K was not limiting.

In *Bolivia* optimum potato yield was achieved with 80-120 kg urea-N/ha or 7 t/ha of chicken litter. Legume N carryover after harvest of faba bean to a subsequent potato crop was only effective if improved rhizobium inoculum was provided to the faba bean crop. Optimum yields in the third potato crop in Andisols of *Ecuador* were in the order of 25-40 t/ha and required fresh P application ranging from 133-163 kg/ha. Yields with only 132 kg P/ha applied to the first crop corresponded 68, 36, 30 and 48% of the respective maximum yields achieved with fresh P applications.

Soil critical values for % Al saturation, Mehlich-1 extractable P and K were defined for grain crops in the sandy Oxisols/Ultisols of Northeast Pará in *Brazil*. Comparisons of corn and upland rice fertilizer N response between ammonium sulfate and urea confirm that S is deficient in these soils, especially after several years of cultivation. Forty-three participants, largely extension agents from 17 municipalities in Northeast Pará, attended a three-day NuMaSS training workshop held in Bragança, Pará in August 2007. In the clayey Oxisols of the Paragominas region, soil acidity and K remain non-limiting to corn and soybean production two years after land conversion from degraded pastures. Corn and upland rice response to N fertilization is also marginal during these initial crops.

Through volunteered services from five Latin American collaborators, NuMaSS was translated into Portuguese and Spanish. The final multiple-language version of the software, NuMaSS 2.2, will be released in early October 2007. (Version 2.2 released 5 October 2007 after this reporting period ended; url: http://intdss.soil.ncsu.edu/ ~ *Editor*)

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

INIFAP, Mexico

N x P Fertilization Trials

Only 111 mm of rainfall was received in Rio Bravo, Tamaulipas during the growing season, and dryland sorghum yields were below average. Eight of the 10 test sites for the factorial N x P trials were cropped with sorghum under either dryland (5 sites) or supplementary irrigation (3 sites). Two additional sites were cropped with either irrigated corn or cotton.

As with previous crop years, P fertilization and the interaction between N and P fertilization did not influence sorghum yield on any of the test sites; however, N fertilization improved sorghum yield on two of the dryland sites and all irrigated sites. All but one of the sorghum sites that did not respond to N yielded less than 3 t/ha, which is consistent with results from previous years. Fertilizer N rates to achieve optimum economic sorghum yield among the N responsive sites were in the range of 40 - 80 kg/ha with yields of 4.3 - 7.5 t/ha. Pre-plant residual soil NO_3-N across sites ranged from 54-76 kg/ha within the 0-30 cm depth and 90-130 kg/ha within the 0-60 cm depth; but the quantity of residual soil NO_3-N could not be used to separate responsive and non-responsive sites to N fertilization. Apparent fertilizer N efficiencies among N-responsive sorghum sites averaged 25 percent for the increment of 0-40 kg/ha fertilizer N and 16 percent for the 40-80 kg/ha increment.

Sorghum trial sites during the last two cropping seasons were separated into dryland and irrigated categories, and pre-plant residual soil NO_3-N was related to aboveground N accumulation in the zero-N fertilizer treatments. Crop N accumulation increased linearly with residual NO_3-N at 0-30cm depth in the irrigated sites ($r = 0.55$), but there was no correlation ($r=0.05$) among the dryland sites. Chlorophyll meter readings at sorghum boot stage also were positively correlated ($r = 0.71$) with residual NO_3-N in the 0-60 cm soil depth.

The two trial sites with either corn or cotton only responded to N fertilization, with yield maxima of 8.4 t/ha of corn at 80 kg N/ha and 4.5 t/ha of cotton seed at 120 kg N/ha. Neither site had a significant yield response to P fertilization. Apparent fertilizer N efficiencies for the corn trial site were 45 percent for the increment of 0-40 kg/ha fertilizer N, 22 percent for the 40-80 kg/ha increment and 17 percent for the 80-120 kg/ha increment.

On-farm Comparisons of Fertilizer Recommendations

Replicated comparisons between NuMaSS and other local fertilizer recommendations were conducted at a dryland and irrigated site 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 is 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.

Recommendations ranging from 0-80 kg N/ha and 0-30 kg P_2O_5/ha did not influence dryland sorghum yields, that were inferior to 3 t/ha (Figure 8). NuMaSS and TAES-60 correctly recommended no fertilization under these conditions. With irrigated sorghum, yields with N recommendations ranging from 63-120 kg N/ha were similar and superior to the control, but there was no difference between those with and without P fertilization.

Irrigated corn yields with recommendations of 73-161 kg N/ha were superior to the unfertilized treatment and there was no yield difference between treatments with and without fertilizer P (Figure 9). Irrigated cotton yields were also improved by amounts of N fertilization among the different recommendations. Adjustments of the TAES recommendations for residual soil NO_3 over-compensated for this source of N, when a 0-60 rather than a 0-30 cm depth was considered.

N and P Requirements for Potato in Bolivia and Ecuador

N and P fertilization in Bolivia Inceptisols

Fertilizer trials initiated at Toralapa with potato in 2004 and cropped to wheat in 2005 were continued with an additional potato crop in 2006. In the N experiment yield response to 7 t/ha (fresh weight) of cow or sheep manure and 3.5 or 7 t/ha of chicken litter were compared with that of six urea fertilizer treatments (0-200 kg N/ha). A uniform application of P fertilizer to all treatments ensured that nutrient was not limiting. As with the 2004 crop, optimum tuber yield was achieved in the 80-120 kg/ha range of urea-N; however, the absence of frosts and better rainfall distribution in 2006 were conducive to higher yields (maximum of 24 t/ha fresh weight) than in 2004 (maximum of 14 t/ha) (Figure 10). Urea-N fertilizer N equivalencies for the 7 t/ha organic applications were 0 kg/ha for cow manure, 6 kg/ha for sheep manure and >90 kg/ha for chicken litter; yield with the application of 3.5 t/ha of chicken litter was equivalent to that achievable with 76 kg urea-N/ha.

Tuber and vegetative N accumulation was constant across both crop years and increased by 0.025 kg/kg of dry matter. Native soil N supply, estimated by crop N accumulation in the zero N fertilizer treatment, was considerably higher in 2006 (152 kg/ha)

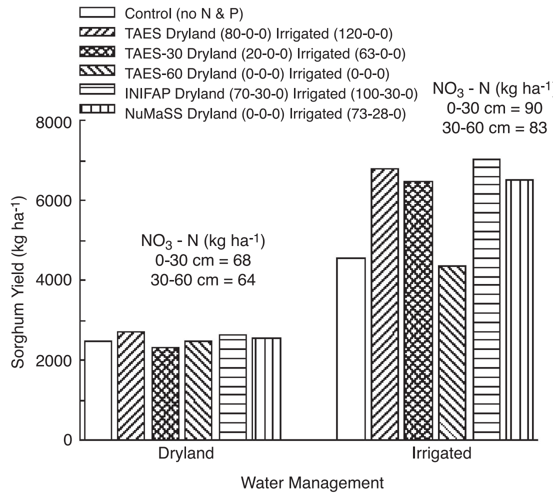


Figure 8. Dryland and irrigated sorghum yields as affected by fertilizer recommendations and water management.

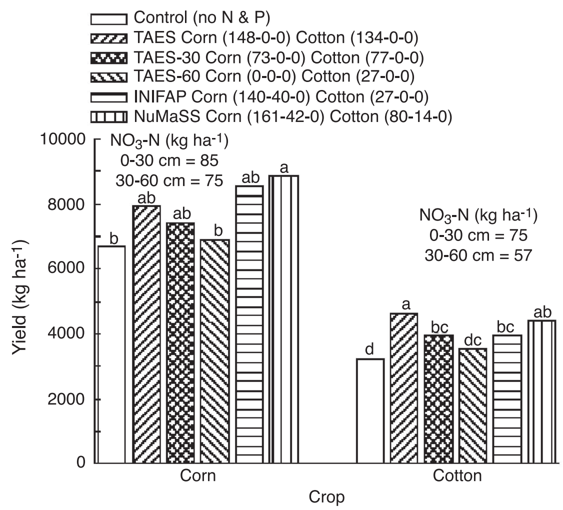


Figure 9. Irrigated corn and cotton yield as a function of different fertilizer recommendations.

than in 2004 (32 kg/ha). Likewise, fertilizer N use efficiency within the yield-responsive range of urea-N treatments was greater in 2006 (51 percent) than in 2004 (41 percent).

Yield response of varieties Waych'a and Desiree to P fertilization were compared in 2006, wherein supplemental P was added to broadcast and banded P rates established in 2004. Fresh tuber yields of Waych'a were considerably greater than for Desiree (mean of 19.5 vs. 9.6 t/ha), and response to total broadcast-applied P was also greater for the Waych'a variety (115 vs. 36 kg P/ha) (Figure 11). Fertilizer P economy via cumulative banded applications of 46

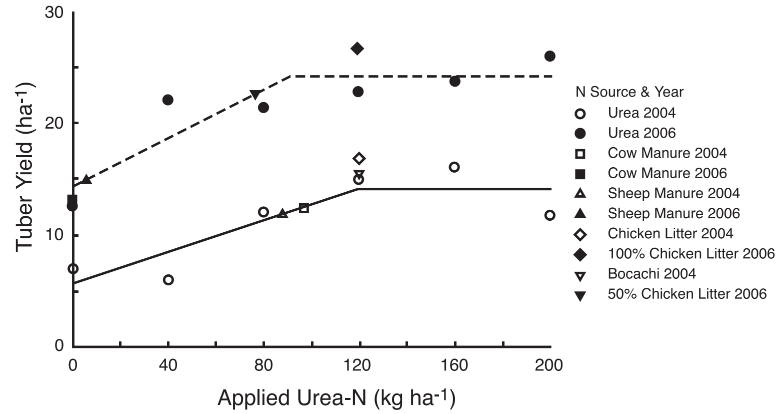


Figure 10. Potato tuber yield at Toralapa, Bolivia as a function of N fertilizer and animal manure applications in the 2004 and 2006 cropping seasons.

and 92 kg P/ha are readily apparent when compared to the yield response with broadcast-applied P.

P management for potato in Andisols

The third and final potato crop was harvested from four P fertilization trials on Andisols in Ecuador. Optimum yields were in the order of 25-40 t/ha and required a third P application ranging from 133-163 kg/ha (Figure 12). The importance of fresh P applications to each crop was apparent when considering that yields with only 132 kg P/ha applied to the first crop corresponded 68, 36, 30 and 48 percent of the respective maximum yields achieved at the Cochabamba, Quinua, Santa Ana and Chaupi sites when P was re-applied prior to planting the third crop.

Phosphorus accumulation in tubers and plant tops across the 4 sites and the three crop years increased linearly with tuber yield at the rate of 0.43 kg P/t of tuber fresh weight. Upon completion of soil test P analyses for the third crop, the combined data for the 3 crops will be evaluated to determine whether oxalate-extractable Al and Fe are suitable substitute proxy variables to estimate soil P buffer coefficients and critical levels in soils with amorphous clay mineralogy.

IDIAP, Panama

P fertilization for corn in Alfisols in Azuero

Corn yields for the third corn crop averaged 6.9 t/ha. The residual effect of broadcast P resulted in increased yields in the third crop ranging from 4.3 t/ha with 0 kg P/ha to 7.5 t/ha with 75 kg P/ha. When averaged across residual broadcast P rates, fresh applications of banded P to each crop increased yields

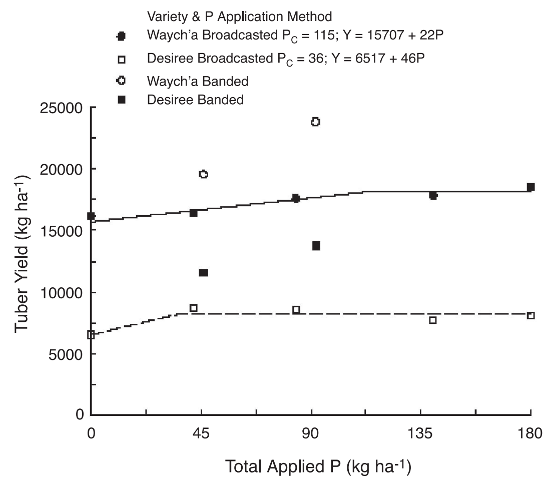


Figure 11. Potato tuber yield in 2006 at Toralapa, Bolivia as a function of variety and P fertilizer applied either broadcast or banded.

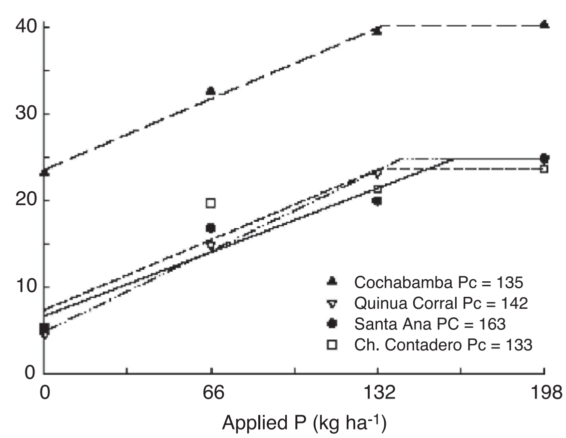


Figure 12. Potato tuber yield for the third crop in Andisols of Ecuador as a function of fertilizer P applied to each crop.

from 6.3 t/ha without band-applied P to 7.2 t/ha with 30 kg P/ha crop. Upon the completion of soil test P analyses, data for the three crops will be combined to estimate the critical P level for this maize production region of Panama.

EMBRAPA-CPATU, Brazil

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

Continuation of on-station and on-farm lime, N, P and K trials at Terra Alta and Tracuateua has enabled establishment of critical soil test levels for the most widely used hybrids or varieties of corn, cowpea and rice grown in the region. The critical Al saturation for cowpea variety BR3, based on six site-years of data, was established as 10 percent (Figure 13); whereas, the critical Al saturation for cowpea variety 'Milênio' was 33 percent. Corn yield response to decreasing soil acidity was similar among variety BR 106 and hybrids AG 1051 and BR 2110, with a critical Al saturation of 14 percent

The Mehlich-1 critical soil test P level for cowpea has been established at 13 mg/dm^3, based on three site-years of data for a P fertilization trial at Terra Alta (Figure 14), whereas the critical P level for corn, based on a combined three site-years of data in trials at Terra Alta and Tracuateua was 11 mg/dm^3. The soil P buffer coefficient for three separate P fertilization trials was similar across % clay of 9-14, with a value of 0.35 kg/ha increment of Mehlich-1 P/kg/h of applied Relative Yield (%) P.

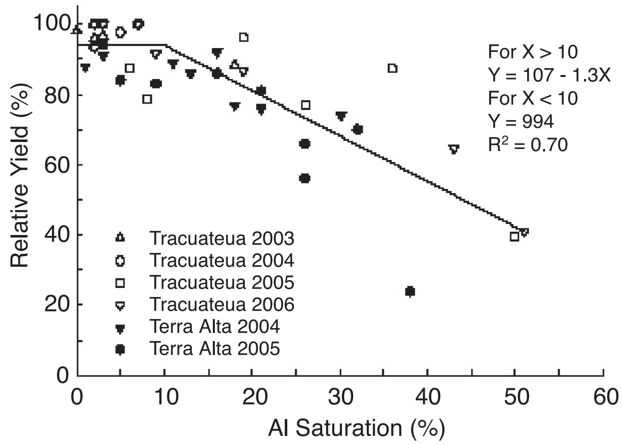


Figure 13. Relative yield of cowpea variety BR3 as a function of % soil Al saturation in liming trials at two sites in sandy soils of Northeast Pará, Brazil.

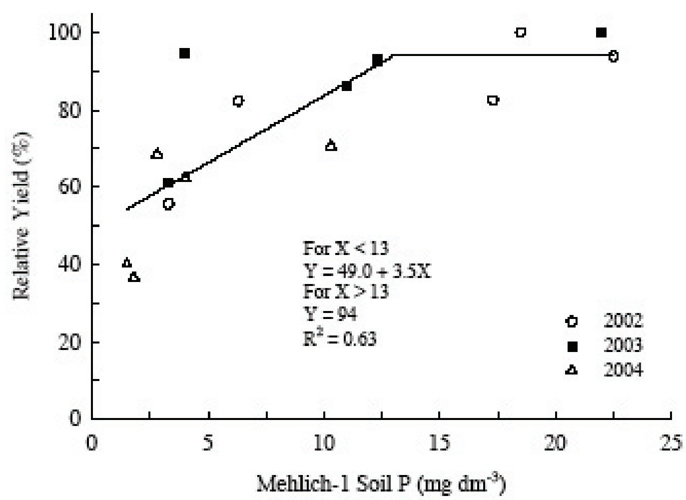


Figure 14. Cowpea yield as a function of soil test P for three crops in a P fertilization trial at Terra Alta, Brazil.

These critical levels and P buffer coefficient value are considerably less that those estimated by NuMaSS for soils with 9-14% clay, and illustrate the types of regional adjustments which can be made to improve the software's local performance in P fertilizer recommendations.

Potassium needs for these sandy soils have been investigated in trials where corn or rice receives K fertilization each year and where response to residual soil K by the succeeding crop of cowpea is also evaluated. Data for nine site-years of these trials at Terra Alta and Tracuateua indicate that the critical soil K level for cowpea was 26 mg/dm^3 (Figure 15), whereas the critical soil K value for corn, planted during periods of greater rainfall and potential K leaching, was 36 mg/dm^3. We have found that corn and rice response to urea-N fertilization in these sandy soils are often confounded by an S deficiency. Therefore, N trials at Terra Alta and Tracuateua have been modified to compare crop responses to both rates and source of N fertilizer (urea vs. ammonium sulfate). Corn yields at both sites support our contention of an S deficiency; yield response to N supplied as ammonium sulfate were significantly greater than with urea, with achievement of optimum yields at a lower fertilizer N rate. Fertilizer N use efficiency at Tracuateua also was greater with ammonium sulfate (56 percent) than with urea (30 percent).

Land use history has a significant impact on the occurrence of S deficiencies, and is illustrated in upland rice yield response to N sources between trials at Terra Alta and Tracuateua (Figure 16). Both sites showed a yield response to N fertilization, but an S constraint was only evidenced at Tracuateua (despite lower yields due to birds). The N trial at Terra Alta was established on land recently cleared from a five-year fallow, whereas the Tracuateua site had been cultivated continuously, without S inputs, for at least the same amount of time.

We have also found moderate, yet significant, yield increases in cowpea cropped after corn on residual treatments of ammonium sulfate, when compared to residual urea. In Northeast Pará, the cost of a kg of fertilizer N as ammonium sulfate is approximately 1.5 times greater than that of a kg of fertilizer N as urea. In other regions with S deficiencies, this constraint can be corrected with applications of 20-40 kg S/ha/year (17-34 kg N/ha as ammonium sulfate). Therefore, a likely S management scenario would be to apply only a fraction of the total N fertilizer for corn and upland rice as ammonium sulfate, with the remainder supplied as urea.

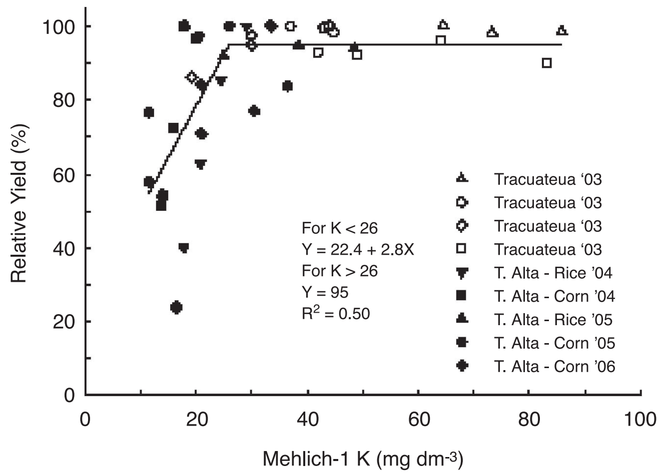


Figure 15. Cowpea yield as a function of Mehlich-1 soil K at Tracuateua and Terra Alta in nine site-years. Crops at Terra Alta denote whether rice or corn preceded the cowpea crop.

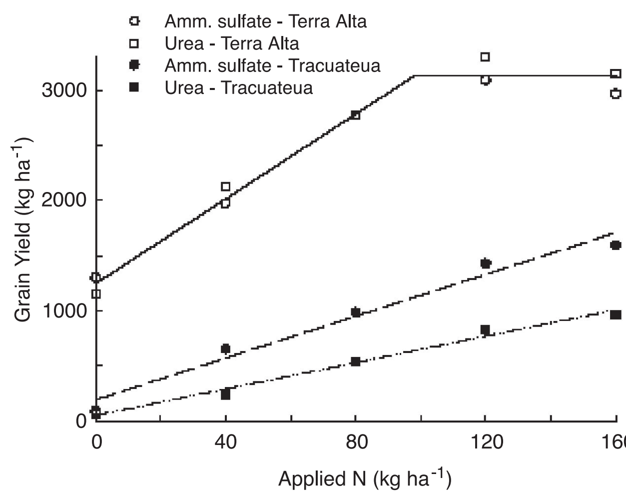


Figure 16. Upland rice yield of variety 'Curinga' in 2007 at Terra Alta and Tracuateua as a function of applied N and N sources.

Lime and fertilizer trials in clayey Oxisols of Paragominas, Pará

The second crop cycles of corn, soybean and upland rice were harvested from N and P fertilization trials designed to validate/refine NuMaSS soil and crop coefficients in soils with 80 percent or more clay. In this region, degraded pastures of *Brachiaria*, initially established after slash-and-burn clearing of rainforests in the 1970s, are being converted to grain production. A unique feature of these degraded pastures is the absence of an acidity constraint; even after two years of fertilized corn and soybean production in a trial site reserved for a future liming trial, soil pH remains above 5.0 and Al saturation is <10%. Therefore, the results for N and P fertilization, reported herein, have been achieved without any lime inputs. Broadcast P fertilization trials receive annual P inputs designed to maintain a particular range of soil test P. For the 2006 crops, corn yields (second crop) increased from 2.4 to 5.0 t/ha with the total addition of 50 kg P/ha, and soybean yields (third crop) increased from 0.5 to 1.9 t/ha with the total addition of 88 kg P/ha.

The Mehlich-1 soil P critical level across two crop cycles and two varieties of soybean was estimated as 7.6 mg/dm^3 (Figure 17), which is similar to the estimated value for two crop cycles and three corn hybrids, and matches the value predicted by NuMaSS for clayey Oxisols.

Corn yield response to N fertilization over two consecutive years has depended on the yield potential of the hybrids tested. In 2005, Pioneer out-yielded BR 106 by more that 2 t/ha and achieved its yield optima with 80 kg N/ha, whereas native soil N supply was sufficient for the lower yield optima

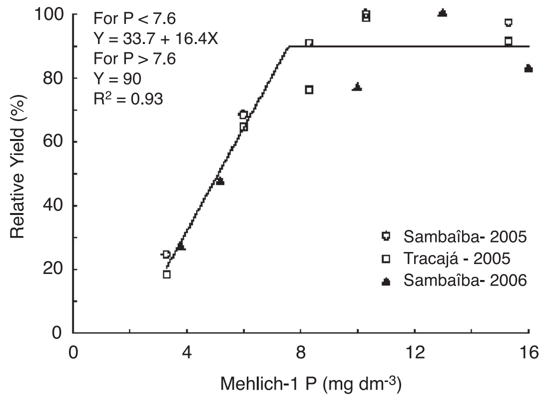


Figure 17. Relative soybean yields of two varieties during two cropping seasons at Paragominas, Pará as a function of soil test P.

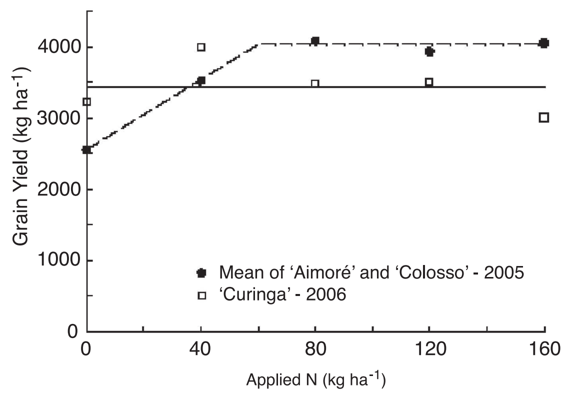


Figure 18. Upland rice yield response to fertilizer N at Paragominas, Pará.

of the latter hybrid. In 2006, BR 3003 achieved a similar yield level as for BR 106 with 40 kg N/ha1. Native soil N supply, estimated by N accumulation in above-ground corn dry matter, ranged from 142 kg/ha in both BR 106 and BR 3003 to 218 kg/ha in the higher yielding Pioneer 30F80. Fertilizer N use efficiency values were 20 percent for the Pioneer hybrid and 58 percent for BR 3003. We anticipate that native soil N supply will diminish and fertilizer N requirements will increase with continued cultivation over time.

Upland rice yield response to fertilizer N for three varieties, during two consecutive years, has varied from no response to up to 60 kg N/ha (Figure 18). Excess N fertilization was particularly detrimental, as it increased plant lodging up to 40 percent.

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

Translation of NuMaSS to Portuguese and Spanish

During the first trimester of 2007, teams of Latin American collaborators translated the 36 page NuMaSS manual and over 95 percent of the text displayed throughout the software into Portuguese and Spanish. Translation of displayed text was especially cumbersome, because they had to insert appropriate text into separate 40-page, single-spaced files for each language, wherein each text line was coded for the corresponding form and item on each of the software's multiple tab pages. Their patience and diligence in working with this large file, expedited the process of importing the translations into the software.

On behalf of all current and future software users throughout Latin America and other Portuguese- and Spanish-speaking countries, special recognition and enormous appreciation goes out to the following teams who volunteered their time for these translations:

- Portuguese - Dr. Manoel da Silva Cravo of EMBRAPA-Oriental Amazon (CPATU) in Belém, Pará, Brazil; Dr. Ivo Ribeiro da Silva of the Soils Department, Federal Univ. of Viçosa in Viçosa, Minas Gerais, Brazil; and Mr. Augusto Farias Cravo in Computer Science, Mathematics and Statistics Institute, Univ. of São Paulo in São Paulo, Brazil.
- Spanish - Dr. Alfredo Alvarado of the Center for Agronomic Investigations, Univ. of Costa Rica in San José, Costa Rica; and Dr. Jaime Salinas-García of the National Institute for Forestry, Agriculture and Livestock Investigations (INIFAP) in Rio Bravo, Tamaulipas, México.

During two separate weeks in June-July 2007, team-members for the Portuguese (Drs. Cravo and da Silva) and Spanish (Drs. Alvarado and Salinas-García) met in Raleigh to review their independent translations and produce the final versions for NuMaSS.

Release of the Final, Multi-language NuMaSS Software - Version 2.2

Several pre-release versions of the software have been tested, including a workshop in Bragança - Brazil, to correct minor problems in the importation of text for multiple languages. The software is now scheduled for posting and international release in early October, 2007 via the download site http://intdss.soil.ncsu.edu/. A 22 Mb file contains the installation software and Adobe Acrobat Reader manual files in three languages. Once installed on a Windows computer, the user can choose between English, Portuguese and Spanish when NuMaSS is launched for the first time. Collaborators throughout Latin America will help notify in-country users of the final software release. The website keeps a record of user names, institutional affiliation and country each time the software is downloaded.

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

Field Tests of NuMaSS Fertilizer Recommendations in Honduras and Nicaragua

Twelve un-replicated corn field trials comparing NuMaSS recommendations to local farmer practices were conducted this year by both governmental and non-governmental organizations. Each trial was located in a different farm community. NuMaSS recommendations were based on pre-plant soil analyses of each site, previous cropping history, targeted corn yields and variety-specific crop and soil N coefficients developed in previous project years.

NuMaSS yields and net returns were equal or superior to producer yields in nine of the 12 sites (Table 26). Fertilizer costs for the NuMaSS recommendation were less than producer practices in eight of the 12 sites. In the Candelaria region of Honduras, producer fertilization entailed too much N and P fertilizer for the yields they expected to achieve. In other regions, producer N applications were often too low and/or P was applied in excess. Some producers were applying fertilizer mixtures that contained K, although soil tests for all sites indicated that K was not limiting. Results clearly show that corn fertilization is a common practice, even among the subsistence farmers in Honduras and Nicaragua.

On average, a soil test analysis costs $20 in Honduras and $40 in Nicaragua. It is of interest to note that net returns on all of the 12 test sites were greater than soil testing costs.

Workshop on NuMaSS Adoption in Honduras and Nicaragua, March 2007

A two-day workshop was held at Peñas Blancas, Honduras to assess results of the on-farm NuMaSS trials and strategize about post-project approaches for continued software adoption in Honduras and Nicaragua. In contrast to previous annual meetings of investigators from NARS, universities and NGOs, this event also included participation of farmers where the field trials were conducted and directors from relevant programs within the national and international agricultural support services in both countries.

As in most of these annual meetings, there were new participants who needed a brief “refresher course” in use of the NuMaSS software (at the time still available only in English). We were very delighted that, this time, a team of veteran project collaborators from both countries provided this training component of the workshop.

Group discussions among farmers, investigators and directors of national/international programs focused on how to address “bottlenecks” to the expanded adoption of NuMaSS software used in both countries. Farmers highlighted the costs of soil tests and fertilizers, continued technical support for generating NuMaSS recommendations, greater community participation via schools and municipal governments and development of “laymen” guides to collecting soil samples and how they are used to produce fertilizer recommendations. Investigators highlighted the need for expanded training in NuMaSS use within their institutions and educational curricula, improved linkages between field agents and soil test laboratories, and an “umbrella structure” for continued interaction and support for the “ambassadors” of the NuMaSS technology dispersed among various institutions in Honduras and Nicaragua. The directors highlighted national regions and programs wherein initial NuMaSS adoption should be focused through both training and usage.

NuMaSS Training Workshop in Tamaulipas, Mexico - February 2007

A one-day training workshop on NuMaSS held in Reynosa was attended by 54 participants from throughout the Tamaulipas region. Participants

Table 26. Fertilizer inputs, yields and economic data for on-farm maize trials comparing NuMaSS recommendations and local fertilization practices in five regions of Honduras and Nicaragua.

		Fertilizer Inputs							Economic Data			
	Maize	Producer			NuMaSS		Maize Yields		Fertilizer Costs		Net Return[d]	
Location	Variety	N	P	K	N	P	Producer	NuMaSS	Producer	NuMaSS	Producer	NuMaSS
		--------------------------Kg/ha--------------------------							---------------------$/ha---------------------			
Candelaria,	D. guay.[a]	126	40	0	18	15	1103	2434	29.42	5.85	158	348
Honduras	D. guay.	126	40	0	34	15	2745	1525	29.42	8.69	393	218
	D. guay.	126	40	0	18	13	1590	110	29.42	5.49	227	159
	D. guay.	126	40	0	50	12	1545	2771	29.42	10.99	221	396
Las Cuchillas Honduras	HB104	37	18	0	13	4	2180	2368	9.75	3.01	312	339
Guinope	D. guay.	53	11	10	114	8	1927	713	13.12	21.62	276	102
Honduras	S. Marta[b]	56	12	12	51	0	5279	6071	14.18	9.04	755	868
Jinotega	N. blanco[c]	66	8	5	113	0	3609	3953	14.00	20.03	516	565
Nicaragua	N. blanco	67	8	5	77	0	3619	4321	14.18	13.65	518	618
S. Dionisio	NB6	60	0	0	90	0	3224	4354	10.63	15.95	461	623
Nicaragua	NB6	60	0	0	90	7	3109	3590	10.63	17.19	445	513
	N. blanco	60	0	0	34	5	3111	4059	10.63	6.91	445	580
	Mean	80	18	3	59	7	2753	3106	18	12	394	444

[a] Dicta guayape; [b] Santa Marta; [c] Nutrinta blanco
[d] Calculated as difference between fertilizer cost and market value of yields

included governmental technical support services (52%), farmers (11%), consultants (28%) and fertilizer dealers (9%). The morning session entailed presentations about basic concepts in soil nutrient management, results of project-related field trials with dryland/irrigated N and P fertilization of sorghum, corn and cotton, and a description of the NuMaSS software structure, operation and results. The afternoon session was devoted to hands-on use of the software, wherein NuMaSS recommendations for soil and crop data were compared against field results obtained in the experiment. Each participant received a copy of the NuMaSS (version 2.1) program and all the presentations given during the morning session. INIFAP collaborators at the Rio Bravo Station have received various requests from municipalities throughout Tamaulipas for similar software-training workshops. (*See* list of participants (http://tpss.hawaii.edu/sm%2Dcrsp/training/list_non_degree.htm))

NuMaSS Training Workshop in Northeast Pará, Brazil - August 2007

Forty-three participants attended a three-day workshop on the NuMaSS software and project-related research results, held in Bragança, Pará. Most of the participants (63%) were State Extension Specialists from 17 municipalities throughout the Northeast Region; others included municipal governments (12%), farmers (5%) and EMBRAPA investigators (20%). Presentations about soils, soil testing, the principal crops (cassava, corn, cowpea, upland rice) grown in Northeast Pará, and project-related results from lime, N, P and K fertilization trials within the region were made during the first day. The second day focused on the Portuguese pre-release version of NuMaSS v2.2: description of the software structure and operation, hands on software practice with local soil-crop data, and a group discussion as to how the software and regional field/laboratory research results could be used in future activities of extension agents throughout Northeast Pará. A field tour of on-farm field research plots at Tracuateua, planted to cowpea and cassava, encompassed the third day. Each participant received a copy of the NuMaSS software and all slide presentations given during the initial two days. (*See* http://tpss.hawaii.edu/sm%2Dcrsp/news/2007_EMBRAPA.htm/)

Customized NuMaSS Database Entries for Northeast Pará, Brazil

As with our previous project activities on N fertilization in Honduras and Nicaragua, we have assembled crop variety and soil coefficients specific to our investigations on sandy soils in the Northeast Pará region. Crop variety coefficients include grain:stover ratios, % N in grain and stover, tuber:vine fresh weight ratios for cassava, fertilizer N use efficiency, yield levels without N fertilization and at optimum nutrient management, and critical soil test values for P and % Al saturation. Soil coefficients include native soil N supply and soil P buffer values. Workshop participants were instructed on the addition of new data entries to NuMaSS, via the Database Editor Module, and provided with the crop variety and soil coefficients that they can add to NuMaSS after the software is installed on their computers.

TRADEOFF ANALYSIS

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

Principal Investigator: John M. Antle, Montana State University

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

Project Years 6, 7, 8 and 9

For Objective 1, the Project Year 6, 7, 8 and 9 reports can be found in the *SM CRSP Annual Progress Report* for those years. URL: http://tpss.hawaii.edu/sm-crsp/publications/

Project Year 10

Data from a set of case study sites were integrated into a unified database to for the Senegal Peanut Basin region. This data set was used to complete construction of a model of the regional production system. A training meeting was held with principal ISRA collaborators in October 2006. A stakeholder workshop was held with Senegalese stakeholders in July 2007. Manuscripts based on the Peanut Basin work are being prepared for publication:

- Application of the minimum-data approach to soil carbon sequestration.
- Analysis of policy alternatives and their impacts on poverty and sustainability.
- Biophysical modeling of climate change impacts.
- Economic impacts of climate change and adaptation strategies.

The final workshop for the FAO/TOA PES activity was planned for late 2007 or early 2008. The key Ugandan collaborator (Nalukenge) and TOA PI Antle participated in an FAO workshop on PES in December 2006. Two publications were prepared based on the project in Uganda.

Collaboration with FAO/CIP and the Panamanian Ag Research Institute continued. Antle visited Panama in November 2006 to continue training and work with collaborators on data. A meeting was held with stakeholders including the Canal Authority. The Panama team is continuing its work on the data collection for the minimum-data analysis.

Collaboration with CIP's NRM program continued in Peru. Antle and Valdivia worked with CIP collaborators in October 2006 and May/June 2007 to train a TOA team to implement PES analysis of biodiversity conservation funded by IDRC.

Collaboration with CIP continued to develop CIP's use of TOA. Antle met with researchers and CIP leaders in June 2007 to plan further collaboration. Antle, post-doc Claessens, and collaborator Stoorvogel worked with CIP to prepare a funding proposal for the German BMZ on adaptation to climate change in East Africa.

Antle collaborated with the ARS Northern Plains Research Station in Mandan, ND, to develop a minimum-data analysis of the potential for switchgrass adoption in the northern plains region. A paper was presented at the Farming Systems Design conference held by the European Society of Agronomy, September 2007.

Claessens, Antle and Stoorvogel continued collaboration on analysis of dual- purpose sweet potato in Kenya, using both minimum-data and full-data models.

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, 7, 8 and 9

For Objective 2, the Project Year 6, 7, 8 and 9 reports can be found in the *SM CRSP Annual Progress Report* for those years. URL: http://tpss.hawaii.edu/sm-crsp/publications/

Project Year 10

The market equilibrium TOA software was implemented and is being tested using the Machakos model.

Minimum-data analysis methods for multi-crop systems were developed, and applied for Kenya and Senegal case studies. A paper is in preparation for publication.

A version of the TOA software with feedbacks from economic decisions to soil productivity was further developed and tested. Analysis is in progress and will be the subject of a publication.

Analysis of climate change for the Peru, Senegal and Kenya case studies was mostly completed; further work was carried out to investigate the behavior of the millet model in Senegal under climate change scenarios. Two manuscripts are in preparation.

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, 7, 8 and 9

For Objective 3, the Project Year 6, 7, 8 and 9 reports can be found in the *SM CRSP Annual Progress Report* for those years. URL: http://tpss.hawaii.edu/sm-crsp/publications/

Project Year 10

The graduate course materials developed in PY 9 were adapted to be used for an intensive, two-week course planned for Wageningen in November 2007.

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

Knowledge support systems for the Healthy Seedlings Technology (HST) are needed to provide critical, sustainable support for technology dissemination, backstopping and scaling up. A major emphasis during PY10 was to lay the groundwork for scaling-up by building technical backstopping networks of national agricultural scientists and extension officers and private sector associations (seed companies, input suppliers and commercial nursery groups) as a means of disseminating HST to more farmers beyond the life of the project.

Scaling-up Activities

Nepal

National agricultural research and extension. In April-May 2007 NARC scientists/technical officers at regional research stations and training centers and Agricultural Development Officers/Subject Matter Specialists based at agricultural extension offices across the central and eastern districts of the Nepal Terai (Figure 19) were trained on HST. We focused on these Terai districts as this is where our nematode gall surveys showed the greatest problems with rice root-knot nematode and also where many projects are working with poor farmers to develop high value crop production (vegetables, spices). In total, 71 resource persons from 8 research stations, 2 regional training centers and 14 district extension offices received training and informational materials for distribution to interested farmers.

Figure 19. Locations of NARC/Extension resource people with HST training in central and eastern Nepal.

Media linkages. Our approach was to link these trainings with radio and television programs that described the benefits of HST, procedures for doing solarization and to indicate the locations of resource people for more information. A show featuring HST was broadcast June 18, 2007 on Birgunj Radio reaching Para, Bara, Rautahat and Chitwan districts in the Bhojpuri language. Another regular agricultural radio show highlighting Healthy Seedlings was aired nationally on Radio Nepal on September 19, 2007. In collaboration with NARC Communications, Publication and Documentation Division, we also prepared a 20 minute video on HST. A television program on Nepal Television entitled "Krishi Karyakram" included this video during its June 22 and September 11 broadcasts. We will distribute copies of this video and electronic copies of informational materials to all our partners in Nepal as well as other key Nepal NGOs working in agriculture.

Winrock-SIMI Agro-Vet network. Value chain approaches linking farmers with agricultural input suppliers also are increasingly being used to establish knowledge support systems. The Winrock-SIMI project works with an established network of input suppliers (agro-vets) in 10 Nepal districts to provide agricultural inputs (fertilizer, seeds, plastic) along with embedded training for their smallholder farmer customers. In January 2007 we provided training on HST for 36 agro-vets as part of SIMI's annual refresher program. Simi staff trained an additional 100 agro-vets in June 2007.

In addition we developed a poster (Figure 20) for use in the shops to raise farmer awareness and generate curiosity about the technology. The poster and HST informational materials were given to Winrock-SIMI for distribution to their agro-vet network.

Ongoing surveys of Winrock-SIMI agro-vets trained by the SMCRSP indicate that the poster is effective in drawing farmers' attention and curiosity. On average five farmers per month ask about the poster and want additional information about solarization. In addition 85 percent of the surveyed agro-vets were selling clear plastic for solarization purposes.

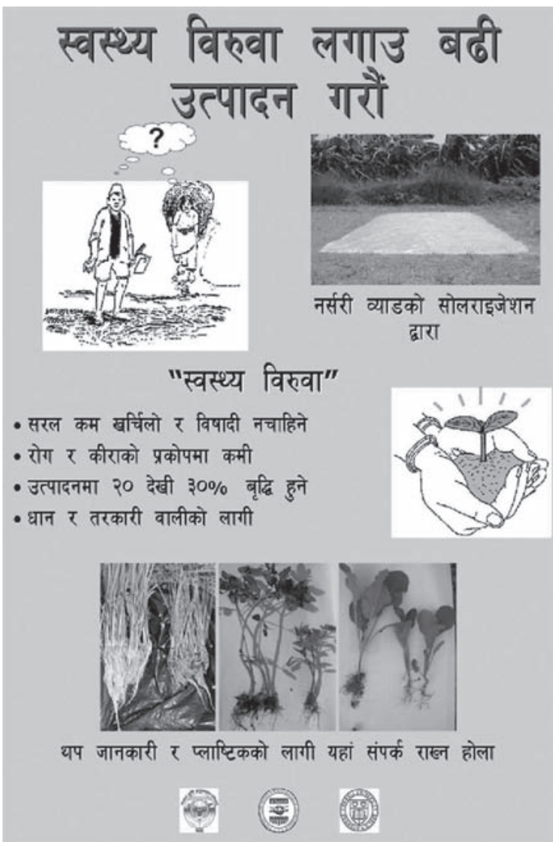


Figure 20. Poster for Nepali agro-input supplier shops.

Bangladesh

National extension. A 'white paper' describing HST along with its benefits and impacts was submitted to the Bangladesh Research Council (BARC) as a first step to getting the technology approved for extension by the government. We planned to build a technical backstopping network for HST in Bangladesh with BARC's Technology Transfer Monitoring Unit (TTMU) and the Department of Agricultural Extension (DAE) through the recently funded National Agricultural Technology Program (NATP). However delays in getting the NATP project started have made it difficult to move forward with this plan.

IC service provider/nursery owner network. During PY10, we began to work with a large international NGO, Intercooperation (IC), sponsored by the Swiss Development Fund. Our reasons for linking with IC at this late date were 1) because they have a very large command area through their current projects (Figure 21); 2) they emphasize high value crops and agro forestry products that are highly responsive to HST; 3) they promote and build the capacity for sustainable knowledge support through local service provider/resource farmers and commercial nursery operators; and 4) they work closely with government research and extension organizations to provide technical information for these service providers and nursery owners. Currently IC works with over 3,600 service providers and 6,000 commercial nursery growers in their command area. During May and June 2007, we provided hands-on training and informational materials on HST for 58 Local Service Providers (LSP) and 168 commercial nursery owners. IC staff will train additional LSPs and nursery owners during the upcoming winter vegetable cropping period. IC and SM CRSP will monitor and evaluate the impacts of the training during the no cost extension period.

IDE input supplier network. Linkages with agro-input suppliers in Bangladesh, similar to those in Nepal, were established through an existing network organized by International Development Enterprises (IDE), an international NGO, based in Denver, CO. IDE agro-input suppliers are located in the NW Bangladesh districts of Rangpur, Nilphamari, Panchagarh and Lalmonirhat. These businesses receive 100-200 customers per month, so have the potential to influence many farmers with embedded training. In May 2007, a total of 149 input service providers were trained on HST. Posters for shop owners (similar to the Nepal version but in Bangla) and HST handouts were given to IDE for distribution to their agro-input supplier network. Flooding and other logistical problems have delayed IDE from getting the posters and handouts distributed to the whole network. However a recent survey indicated that 33 percent of the shops with posters and handout materials were selling plastic for solarization (6-13 farmers per shop) and that 10-40 farmers per shop were asking for information

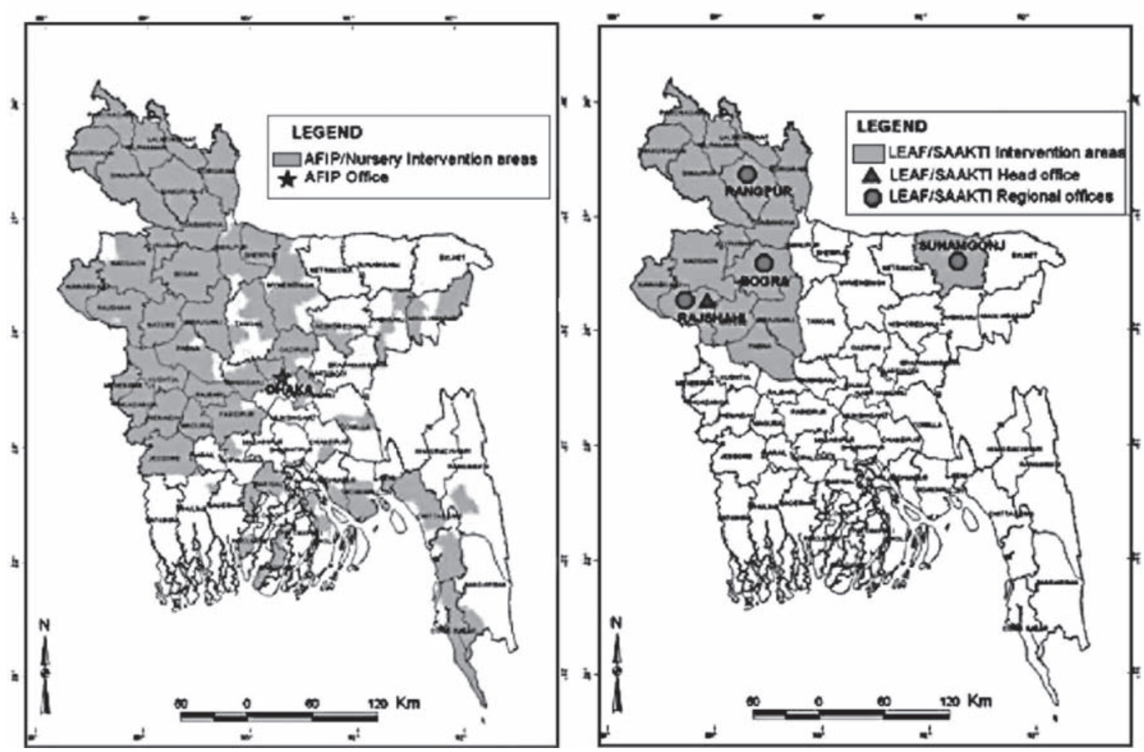


Figure 21. Current command areas of Intercooperation projects.

about the technology. We will continue to monitor the response of IDE's input supplier network to HST training during the no cost extension period.

East West Seed Company contract seed growers. Very positive effects of HST on seed yields were obtained in collaboration with East West Seed Company (*see SM CRSP Annual Progress Report, 2005 - 2006*). The company sees the improved seed quality, size and yields from healthy seedlings as a simple, low cost technique to increase their quality seed stocks and sales. As a result, the company, with their own resources, trained 17 production managers on solarization, who will disseminate the technology to ~3,200 hybrid contract seed growers in NW Bangladesh. As an incentive, East West will give elite lines to contract growers using solarization. In addition solarization was included in East West's 2007 annual training program for 2,400 seed retailers/distributors and a one page write-up on HST was featured in the April 2007 edition of "Lal Teer Barta," the company newsletter.

Focal Area Forum (FAF). In 2002, RDRS and IRRI took the lead to constitute a Focal Area Forum (FAF) of government organizations, NGOs and private sector companies. The purpose of this Forum was to identify improved rice technologies and develop delivery systems to encourage the uptake of these technologies, thereby assuring more sustainable livelihoods for poor farmers in Bangladesh. In February 2007, we were invited to present the Healthy Seedlings Technology to the FAF. Cornell and colleagues from the Wheat Research Centre presented the HST technological approach as well as data from our various partners. While response to the presentation was very positive and the FAF approved HST as a "validated" technology, development of an Action Plan for disseminating HST more widely is stalled for lack of funds.

Information materials. A Bangla language video describing the benefits of HST and the step-by-step procedures for solarization was made during PY10. CD copies of this 20-minute program will be distributed to key government research and extension offices, national and international NGOs, nursery associations and appropriate private companies. Electronic versions of the HST fact sheet, farmer handout and poster will also be distributed to potential users.

Impacts and Adoption

Dissemination of the Healthy Seedlings Technology also continued through existing partners in Nepal (CARE-ITDC, ETC, Morang District DADO), Bangladesh (RDRS, East West Seeds) and Thailand (Mahasarakham University, Thai Rice Research Institutes). New observations to date include:

- Despite the enthusiasm of farmers interested in using solarization for rice and vegetables at CARE Nepal's Sarlahi and Mahottari district sites, availability of medium gauge plastic was a constraint to adoption. We provided a grant of $250 to ITDC, a local NGO working with CARE in this area, to buy a supply of plastic and to distribute it to local agro-input suppliers in the area. These businesses would then sell the plastic to farmers and regenerate the funds for future purchases. As of July 2007, 7 agro-input suppliers work with ITDC and have sold 254 meters of plastic specifically for solarization (~36 m per supplier).
- It should be noted that uptake and dissemination of HST through CARE Nepal's other programs has been sluggish, primarily because of a change in CARE's program priorities and donor expectations. Nevertheless we can report that HST has now been incorporated into two additional CARE Nepal programs, JIWAN and UJYALO. CARE and ITDC staff have provided HST training for these two projects.
- An adoption survey was undertaken in April 2007 with 25 farmers (16 percent male; 84 percent female) who had participated in the initial ETC program with solarization in 2005. A majority of respondents (76 percent) were still utilizing HST for tomato (32 percent), cole crops (16 percent), rice (8 percent), chili (12 percent) and flowers (32 percent). Most farmers (71 percent) invested in new plastic from local shops, but 29 percent also reused the original plastic given by ETC.
- Economic data were also collected from 29 ETC clients growing rice, flowers and vegetables. We documented significant improvements in food security and incomes for ETC households utilizing Healthy Seedlings. Households using HST for rice increased food security by 36 days. Net returns from HST flowers were Rs1,000/ropani (1 ropani = 508 m^2) higher than conventionally grown flowers. For vegetable growers, HST gave Rs300 to Rs2,900/ropani higher net returns than conventional. High rates of return obtained by tomato farmers were due to savings on pesticides normally used to control diseases and insects. Stronger, healthier plants from Healthy Seedlings appeared to resist pests better than normal plants, without the added pesticide cost.
- Solarization has been linked with extension of the System of Rice Intensification (SRI) by Rajendra Upreti, a particularly active Nepal extension officer working at the DADO-Morang district. Mr. Upreti mobilized his staff in 2006 to provide training and establish demonstrations on HST and SRI for rice and also HST for vegetables in Morang and Siraha districts. Mr. Upreti has also been instrumental in getting write-ups on solarization included in several Nepali extension publications, including "Krishi Prabadi Pustak," a 2006 agricultural technology handbook and "Krishi Ko-Sathi," a monthly newsletter distributed to extension offices throughout the country. A recent survey of 42 farmers and nine farmer groups in Morang and Siraha districts indicated that 65 percent of respondents were using HST for SRI rice. Monitoring data from eight farmers in Morang district indicates HST improved SRI yields by an additional 15-33 percent, while four farmers found a much smaller yield benefit of 10 percent or less.
- The Bangladesh NGO, RDRS, has collaborated with us since 2004 to disseminate HST through its extensive Farmer Field School (FFS) network. Solarization is still included as a key technology for new FFS established by RDRS and their partner NGOs. To assess the success and impact of HST through the RDRS technology dissemination process, we surveyed 31 FFS who had been introduced to HST in 2005, utilizing a Focal Discussion Group format. In addition socio-economic/livelihood dimensions were determined from selected individual farmers in each FFS who had adopted the technology. The survey was completed in September 2007, but analysis is still ongoing.
- Additional information was acquired this year from East West Seed Company about the impacts of HST on seed quality and onion seed. As expected vegetable seed quality improved using healthy seedlings. Germination rates improved by 36, 5, 28 and 7 percent for eggplant, onion, chili and tomato seeds, respectively. In addition 1000 seed weight of eggplant, onion, chili and tomato produced from HST increased by 3, 5, 8 and 8 percent, respectively. Onion bulbs from last year's trials (produced from normal and HST seedlings) were planted in 2006-07 for seed production. Seed yields from onion bulbs produced from HST were 3.3 kg/decimal, while seed from conventional bulbs were 1.8 kg/decimal, an increase of 81 percent!

- To date 38 trials/demonstrations with HST have been established across five of Thailand's Northeast rice growing provinces. Yield responses to the technology have ranged from 9-23 percent over conventional practice. In addition our collaborators have actively promoted this technology with farmer groups in Chum Phae, Mahasarakham, Yasothon and Ubon Ratchani provinces using hands-on training and informational materials. A survey of farmers introduced to the technology in 2005 is currently underway in Mahasarakham and Khon Kaen provinces to assess adoption and impacts.

Permanent Raised Beds

ACIAR Workshop

Cornell University was invited to present the SM CRSP experience with permanent raised beds (PRB) at a final project review workshop sponsored by the Australian Centre for International Agricultural Research (ACIAR) in September 2006. Our presentation compared productivity between permanent beds and conventional flat practice, time course trends as well as nitrogen and mulch responses from replicated experiments under a triple crop rice-wheat-mungbean rotation at two sites in Bangladesh (Nashipur and Rajshahi) and one site in the Nepal terai (Ranighat). We also discussed the positive experiences that farmers in Rajshahi Bangladesh are having with the technology. Our experience with permanent raised beds has been quite different from others in South Asia. The reasons for these differences are unclear, but irrigation and crop variety may be two possibilities. A full paper was developed from the workshop presentation and will be published in a peer reviewed ACIAR proceedings in December 2007.

Farmer-to-Farmer Dissemination of Permanent Beds

Response to dissemination of PRB by the Alipur/Durgapur farmer group to other farmer community groups has been very good. Hands-on equipment trainings were held prior to rice and wheat cropping seasons and farmer rallies were arranged during crop growth to get farmer feedback about the technology. As for the wheat 2006-07 season, we have recorded 347 farmers using beds on ~ 420 hectares. Farmers from seven of the 15 groups who participated in training last year are now utilizing the technology for rice, wheat, maize, mungbean, jute and sesame. We will continue to provide technical backstopping for these new users, to document adoption, impacts and farmer modifications and to address biophysical and economic problems that may arise as the technology spreads to new environments and groups.

Where farmers had side-by-side comparisons of beds and conventional flat, average yields from beds were 18 percent higher than conventional for rice, 60 percent higher for wheat and 26 percent higher for maize. Farmers were also able to diversify their cropping systems with this technology by growing mungbean and maize on beds that would otherwise be fallow under conventional practice. Two farmers in the Alipur/Durgapur group and another in Uzalkolshi grew hybrid rice on beds because of the observed seed savings benefit from the technology. (Table 27).

Table 27. Yield results (t/ha) reported by farmers from the various groups.

Group	Rice		Wheat		Mung		Other Crops	
	Beds	**Flat**	**Beds**	**Flat**	**Beds**	**Flat**	**Beds**	**Flat**
Alipur	5.99-7.48	4.50-4.80	3.59-4.49	2.40-3.29			6.59-7.48^{M}	4.79-5.99^{M}
Shanpukuria	5.99-6.59	4.19-5.39	2.99-3.89	2.40-2.99	0.52-0.90	--	1.65-1.80^{S}	1.20-1.49^{S}
Namodorkhali	4.79-5.98	3.59-4.79	2.99-3.89	2.10-2.69	0.45-0.75	--	--	--
Tiorquri	--	--	--	--	--	--	6.59-8.08^{M}	5.39-6.59^{M}
Nandigram	--	--	3.59-3.96	1.61-1.80	--	--	4.05-4.49^{M}	--
Nowpara	--	--	3.29-4.19	2.69-2.99	0.45-0.60	--	4.34-4.64^{M}	--
Kasipur	--	--	3.59-3.96	1.78-1.87			4.04-4.34^{M}	--
Uzalkolshi	6.29-6.59	4.79-5.39	2.99-4.19	2.40-2.69			4.04-4.34^{M}	--

Other crops: M=Maize, S=Sesame

Machinery

Last year we reported that a constraint to further expansion was lack of credit for purchasing two-wheel tractors and bed formers. We provided a loan to the Alipur/Durgapur group, which has been repaid; however, we did not feel that this approach was sustainable. Attempts to get group loans from banks failed, but four of the farmer groups (Namodorkhali, Shanpukuria, Tiorquri and Alipur) recently obtained loans for purchasing power tillers and bed formers from CARB, a local NGO. Linking farmers to other GO and NGO groups who provide loans for farmers without collateral will be a critical factor with any future expansion programs.

Weed Control and Residue Return

Residue return is considered an important factor for the long-term sustainability of permanent beds, especially where soil organic matter levels have been severely depleted. Crop residue mulches also help to control weeds, which can become a problem in minimal tillage systems like permanent beds. Farmers using PRB have reported that weeds are a problem for rice and wheat. However few farmers are willing to use rice or wheat straw as mulches to control weeds, because straw is used for feeding animals or cooking fuel. Recently several farmers gathered water hyacinth from ponds and used it as a mulch for wheat. While they found the water hyacinth effective, there is insufficient quantity to provide mulch for all farmers using PRB. We will continue to work with the farmers using PRB to develop effective and acceptable methods to control weeds and to encourage residue return.

Economic Impacts

Additional surveys were completed during PY10 for rice and spring crops to assess the economic impact of PRB on farmers using the technology. After rice harvest, 24 farmers were interviewed, 13 continuing with permanent beds with only reshaping between crops and 11 farmers who had constructed new beds before rice (Table 28).

Making new beds entailed 33 percent higher costs relative to conventional flat cultivation; however, for those "permanent" farmers only reshaping beds prior to rice, land preparation costs were reduced 63 percent compared to conventional practice. As we observed during the wheat season, substantial seed, fertilizer and irrigation cost savings also were documented for rice on beds. New beds and conventional practice had similar weed control costs, but farmers with "permanent" beds had to spend 22 percent more for weeding than on conventional plots; thus confirming feedback from farmers about weed problems. All combined total costs for PRB from both farmer groups were 12-15 percent lower than for conventional.

Table 28. Economic survey for 2006 rice crop.

Factor	Permanent (n=13)			New Beds (n=11)		
	Bed	Flat	Change	Bed	Flat	Change
Cropped Area (bigha)[1]	10	14		7	12	
Land Prep. -Tillage (Tk/bigha)	135	363		360	360	
Bed prep. (Tk/bigha)	0	0	63%	120		33%
Seed Cost (Tk/bigha)	141	198	-29%	119	200	-41%
Fertilizer & Pesticides (Tk/bigha)	605	715	-15%	516	684	-25%
Irrigation No	1.9	2		1.9	2	
Irrigation Cost (Tk/bigha)	488	708	-31%	469	690	-32%
Weeding Cost (Tk/bigha)	395	323	22%	411	417	-1%
Harvest Cost (Tk/bigha)	539	512		476	489	
Threshing Cost (Tk/bigha)	237	182		193	175	
Total Costs	**2,541**	**3,001**	**-15%**	**2,664**	**3,016**	**-12%**
Yield (kg/bigha)	742	571	30%	629	562	12%
Total Value @ Tk10/kg (Tk/bigha)	**7,415**	**5,714**	**30%**	**6,293**	**5,619**	**12%**
Net Return	**4,874**	**2,713**	**1.8X**	**3,629**	**2,603**	**1.4X**

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

Survey respondents indicated that a majority of the rice produced (68 percent) was consumed and only 23 percent was sold in the market. Nevertheless for comparison purposes, we calculated the total rice value using farmers observed yields and the current market price of Taka 10/kg. Increased rice yields and overall lower costs with PRB combined to give higher net returns compared to conventional practice. Net returns from sales of rice were estimated to be Taka 1,026 per bigha higher from new beds and Taka 2,161 per bigha from permanent beds.

Economic data were also collected from 30 farmers growing a variety of pre-monsoon/spring crops: mungbean, maize, sesame and jute (Table 29). No conventional plots were available for comparison since tillage and irrigation operations are often limited during the hot and dry conditions of this season. However, the minimal tillage and improved water use efficiency of permanent bed systems makes cultivation during this period more feasible, thereby diversifying farmer practice with an extra crop.

PRB made it possible for farmers to obtain net returns of Taka 1,802-3,559 on land that otherwise would be fallow during this season. Sesame and jute production on beds gave the highest net returns followed by mungbean and lastly maize. Actual returns for jute are probably much lower because labor costs for retting and processing were not included in this analysis. High net returns with sesame on beds indicate a particularly lucrative cropping option for resource poor farmers because of the low cost investment (Taka 613/bigha). While the costs for mungbean cultivation on beds were also low, low yields (currently averaging 470 kg/ha) are limiting potential returns. Additional investments in fertilizer (especially P; lime where appropriate), irrigation (at least one) and weed control would significantly improve yields and returns, given the high market price for mungbean. Surprisingly, maize returns were the lowest of all the pre-monsoon/spring crops grown on beds. Average yields were low (4.4 t/ha) and costs of cultivation were the highest of all crops. Farmers are putting a lot of resources into extra tillage (hilling up) and irrigation that is not necessary. Also it is likely that soil acidity in this area is limiting maize yields. We will continue to work with farmers in this area to optimize production and reduce cultivation costs for these crops.

Table 29. Economic survey for 2006 pre-monsoon/spring crops.

Factor	**Mung**	**Maize**	**Sesame**	**Jute**
Number of Respondents	13	9	4	4
Cropped Area (bigha)[1]	13	10.2	2.8	3.6
Land Prep. -Tillage (Tk/bigha)	175	391	151	110
-Bed prep. (Tk/bigha)	0	0	0	0
Seed Cost (Tk/bigha)	161	314	124	151
Fertilizer & Pesticides (Tk/bigha)	0	743	0	179
Irrigation No	2	3	0	2
Irrigation Cost (Tk/bigha)	38	538	0	283
Weeding Cost (Tk/bigha)	12	235	115	308
Harvest Cost (Tk/bigha)	201	282	115	399
Threshing Cost (Tk/bigha)	89	200	108	481
Total Costs	**676**	**2,703**	**613**	**1,911**
Yield (kg/bigha)	59	596	201	415
Market price	42	8	20	18
Total Value (Tk/bigha)	**2,478**	**4,768**	**4,020**	**7,470**
Net Return	**1,802**	**2,065**	**3,407**	**3,559**

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

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

Major activities during PY10 involved finalizing all the replicated trial work; collecting information on lime impacts for crops other than rice, wheat and maize; and determining the trade and long term availability of dolomite from Bhutan (sole supplier of dolomitic lime for Bangladesh).

Replicated Trials

Md. Bodruzzaman's PhD thesis research compares wheat, maize and rice yield responses across a range of lime levels (0 to 6 t/ha), which brackets lime requirements for these soils based on NuMaSS, soil-lime incubation and SMP approaches. Dolomitic lime (dolochun) was applied once starting in 2005 in replicated trials set-up at six sites in four districts of NW Bangladesh (Panchagarh, Birgonj, Kharol and Patgram). Wheat and maize were grown during the 2005-06, 2006-07 winter seasons, followed by rice in the summers.

At all sites wheat and maize yields responded significantly to the 1 t/ha lime rate but few additional increases were obtained at the higher lime rates (2, 4, 6 t/ha). In almost all cases the maximum yield response to lime was equivalent to that indicated by the NuMaSS prediction. At a few sites, yields actually declined at the 6 t/ha rate, indicating a possible induced Zn deficiency. For rice, four of the six sites showed small but significant increases in yield to 1 t/ha lime in the first year after application.

Maize was the most responsive to lime applications. Yield increases to lime in the first year ranged from 1,358-3,107 kg/ha for maize (2,359 kg/ha averaged across all sites); 450-968 kg/ha for wheat (754 kg/ha averaged across all sites); and 321-672 kg/ha for rice (474 kg/ha averaged across sites). Similar wheat and maize yield responses to lime were obtained in the second year after two crops, indicating a sustained residual benefit from lime which also has been observed at our on-farm lime demonstration sites. Averaged across sites, a single lime application of 1 t/ha increased wheat and maize yields relative to the unamended control, in the first year by 35 and 47 percent, respectively. The residual benefit of lime on wheat and maize yields in the second year was roughly the same at 34 and 40 percent, respectively. While the replicated trials will end after the 2007 rice crop is harvested, past experience from our lime demonstration plots indicates that the lime benefit will continue for another year before another application of lime is necessary.

Lime Impacts on Other Crops

Because of the obvious visual impact of lime on crop growth, farmers in these acid soil areas are trying the amendment with other crops. We interviewed several farmers to get an assessment of the potential impact on crops in addition to wheat, maize and rice (Table 30). Lime rates applied ranged from 0.75 to 1 t/ha and yields were based on farmer estimates. While these results need to be corroborated, there clearly is much potential for lime to increase production for a whole suite of crops grown on Bangladesh's acid soils.

Lime Availability and Trade

Bhutan is the sole supplier of dolomitic lime for Bangladesh. According to the Bhutan Department of Geology and Mines, dolomitic lime reserves in the country are quite substantial. Easily mined, proved reserves are estimated at 31.04 million tons, while probable reserves are as high as 13,341 million tons. While annual production has increased 62 percent since 2000 to 476,516 MT in 2006, it is generally agreed that the dolomite mining industry in Bhutan is underdeveloped. At current production rates, Bhutan's proven reserves will be able to supply lime for ~100 years and probably longer with further exploration of the probable reserves.

A majority of Bhutan's dolomite is exported to India (91 percent) and the remainder is exported to Bangladesh. Imports of powdered dolomite to Bangladesh were 40,015 MT in 2004; 85,983 MT in 2005 and 40,756 MT in 2006. Dolochun is imported through eight major Bangladeshi importers primarily for fish production and agricultural purposes. Importers and local dealers indicate the demand for dolochun, by the agriculture sector, is increasing. For example in 2005-06, nine input traders/dealers

Table 30. Farmer observed yield benefits from 0.75-1 t/ha lime applications.

		Mean Yield (t/ha)		
Crop	**n**	**With Lime**	**Without Lime**	**% Change**
Boro (winter rice)	7	7.09	5.41	31%
Aman rice	2	4.52	3.80	19%
Maize	6	8.36	5.91	42%
Wheat	1	2.96	2.09	42%
Potato	2	11.78	7.08	66%
Sweet Potato	3	9.17	6.51	41%
Tomato	1	23.47	17.82	32%
Jute	2	3.22	1.78	81%
Garlic	1	6.70	2.68	150%
Ginger	1	16.09	11.17	44%
Bitter Gourd	1	9.76	7.51	30%
Okra	1	21.47	14.52	48%
Tobacco	2	1.88	0.94	110%
Long Bean	1	36.93	23.47	57%
Peanut	1	3.00	1.31	129%

in NW Bangladesh reported total sales of 292 MT of dolochun, but in 2006-07, the amount increased 150 percent to 733 MT. Currently the market price for dolochun is Taka 10/kg (one kg of lime is sufficient to cover one decimal of land at the 1 t/ha rate). While prices will likely rise with increasing demand, price control policies may be required to ensure this valuable input remains affordable for Bangladeshi farmers.

Next Steps

We have developed the knowledge base on lime requirements and impacts for Bangladesh to the point that moving quickly to a national scale adoption program is justified. Development of a ‘white paper’ describing the requirements and impacts of a country-wide lime program will be completed and submitted for implementation by BARC’s TTMU and DAE program during the no-cost extension period. Harvest of the 2007 rice crop will complete the fieldwork portion of Md. Bodruzzaman’s PhD research; analysis and write-up will be completed by March 2008.

CARBON SEQUESTRATION

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

Principal Investigators: Russell Yost, University of Hawai'i at Manoa James W. Jones, University of Florida 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.

Key activities implemented during year 2006 for Project Year 10 include the following

- Extending ACNs;
- Impact of ACNs on ground water recharge;
- Assessing gains and losses of soil carbon;
- Impact of C-4-T on cotton cropping system and soil carbon; and
- Estimating soil and biomass carbon.

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)

Estimating Soil and Biomass Carbon

(Dissertation by Antonio Querido)

Antonio Querido, Cabo Verde, is doing a comprehensive analysis of a technique to measure soil and above ground C, which he has developed. Initial results by geospatial analysis suggests that sampling can be economized and that "soft" data can be very useful to enhance the prediction of soil C though use of the Bayesian Maximum Entropy (BME) approach. The use of BME as a tool to predict soil C provided approximately a 24 percent decrease in the variance of prediction. This approach also provides some estimates of equivalency of variation in time and space. Among other results from the dissertation of Mr. Querido are the following: 1) quantitative secondary data such as measured soil clay content can contribute more to improving precision of predictions as a component of the BME analysis than as a cokriged variable.; 2) ACN leads to biodiversity among tree species, with the selection of the land manager (farmer) seemingly being more important than increasing rainfall; and 3) the spatial/temporal variograms indicate that dependence of carbon seems to be approximately two years while the spatial dependence of soil organic C doesn't seem to change dramatically with time.

Recent results with a new technology, Visible Near Infrared (VNIR) spectroradiometry show considerable promise for providing a non-destructive, no wet-chemical approach to soil analysis. Major issues regarding calibration, available nutrients, and repeatability remain, but the potential is exciting. This might also provide a portable device that can be taken to the field for plant nutrient assessment as well as soil property assessment *in situ*. Results also continue to improve the Loss on Ignition approach that holds promise to enable laboratories with a relatively low cost muffle furnace and an analytical balance to determine soil organic C. The dissertation of H. Konaré is expected to provide some useful updates on these two new technologies.

Assessing Gains and Losses of Soil Carbon

(Results of Laura Delisle's MS Thesis)

This thesis was the first in our experience to implement an example of "model-based" geostatistic using the R programming language. One of the most attractive features of the approach was that uncertainties in fitting the variogram were propagated through to the estimates of uncertainty in the conditionally-simulated results. This resulted in an improved, more realistic estimate of prediction uncertainty. The results indicated that there continued to be some uncertainty as to whether soil organic C was increasing in a couple of cases. The amounts of soil organic carbon were much greater in the high rainfall zone, Sikasso, and in the zone with heavier soils, Fansirakouro. Precision in estimating soil organic carbon by the spatial approach increased on the order of 25 percent.

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)

Simple Soil Organic Matter Model for Biomass Data Assimilation in Community-level Carbon

Model simplification is particularly relevant to the study of SOC dynamics, because the lack of fractionation methods and methodological unification to substantiate turnover-based pool structures can increase uncertainty in model outputs (Larocque *et al*., 2006). Under such conditions, total SOC prediction is clearly more an issue of formulation tractability and ease of computation (Bolker *et al*., 1998) than a problem of potential physical, chemical or biological conceptualization. Over the last two years of research in this project, Bostick *et al*. (2006) proposed the use of a simple model with 2 SOC pools for use in data assimilation methods for scaling up field measurements of soil carbon for monitoring soil carbon at community or larger spatial scales. They showed that this 2-pool model, which operated with one-year time steps, described changes in soil carbon in a cropping system study conducted in Burkina Faso over 11 years. Results from that study showed good accuracy in simulating soil C changes in this study (Bostick *et al.,* 2006). However, the form of that proposed model was only loosely based on widely used SOC models, such as the Rothamsted soil-carbon turnover (RothC) and CENTURY models. Statistical methods used in that study to estimate the size of the pools and decomposition rates were based on data from the experiments, not from theoretical considerations. Therefore, an additional model simplification study was performed, starting with the widely used RothC model.

We compared the performance of the 5-pool RothC with the simpler compartmental model proposed for stochastic data assimilation (after Bostick *et al*., 2007). We hypothesize that: 1) RothC's HUM slow pool can be considered stable over a 20-year contractual period, allowing for a consolidation of RothC's HUM and IOM components into a single stable pool; 2) a yearly time step will not significantly affect a model's ability to simulate short-term C dynamics for trading purposes; and 3) there is no significant difference amongst crops in terms of their residue decomposition rates on annual time scales, allowing for simplification of RothC's DPM:RPM ratio of fresh biomass into a constant. Total soil organic C estimated by each approach is compared with field data from the 11-year rotation experiments in Burkina Faso. Results are then discussed in terms of the tradeoffs between model complexity and sampling density, in the larger context of C certification for candidate smallholder farming communities.

Figure 22 shows results of both model simulations of changes in SOC during the 11-year experiment in Burkina Faso. Measured data with error bars are shown in this figure at times when SOC was measured. Differences were very small. These data were included in the set used for parameter estimation as explained in Traore *et al*. (submitted). Figure 23 shows comparisons in simulated SOC for different treatments with different cropping systems, fertilizer input, and residue management.

We concluded that, for the purposes of approximately 20-year C contracts, the RothC model could be simplified by combining several C pools and operating it on an annual average time basis, thereby supporting the results of Bostick *et al*. (2006). The discrete, yearly 2-pool SOC model composed of one stable (nearly inert on contractual timescales) and one labile compartment successfully predicted C decomposition in the controlled long-term fertilization trial in subhumid Burkina Faso. In hindcast mode and after parameter estimation, it performed equally well as RothC26.3 for total SOC simulation (with only a 0.2 percent increase in RMSE for the 2-pool model), and exhibited comparable predictive skill on independent treatments, including those with residue incorporation. RothC sensitivity analysis (Janik *et al*., 2002) and exploratory optimization provided a heuristic base for this simplification approach. At comparable predictive levels, a simpler structure should mitigate risks of equifinality and resulting simulation uncertainties.

With benefits of simplification including a better understanding of the system and various derived applications including upscaling (Brooks and Tobias, 1996), this model features an adequate level of complexity for spatial integration over patchy contract areas on relevant time spans. In fact, if statistical appraisal cannot positively identify outstanding performance across a set of models, then other evaluation criteria, including simplicity, should be

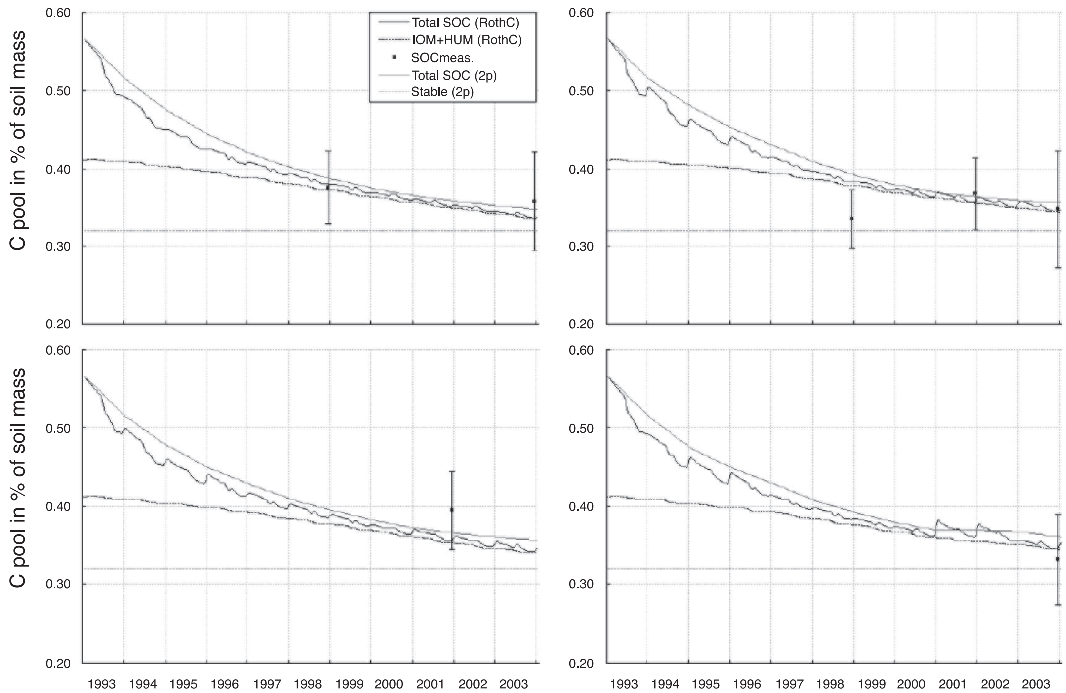


Figure 22. Total and stable SOC content (%) simulated by RothC and a yearly 2-pool model. Error bars represent one standard deviation from measurement means (reported by Bado *et al.,* 2002; Bostick *et al.,* 2007). Rotations were continuous cotton (a), groundnut (b), sorghum (c), cotton-maize-sorghum (d). (Traore *et al*., *submitted*).

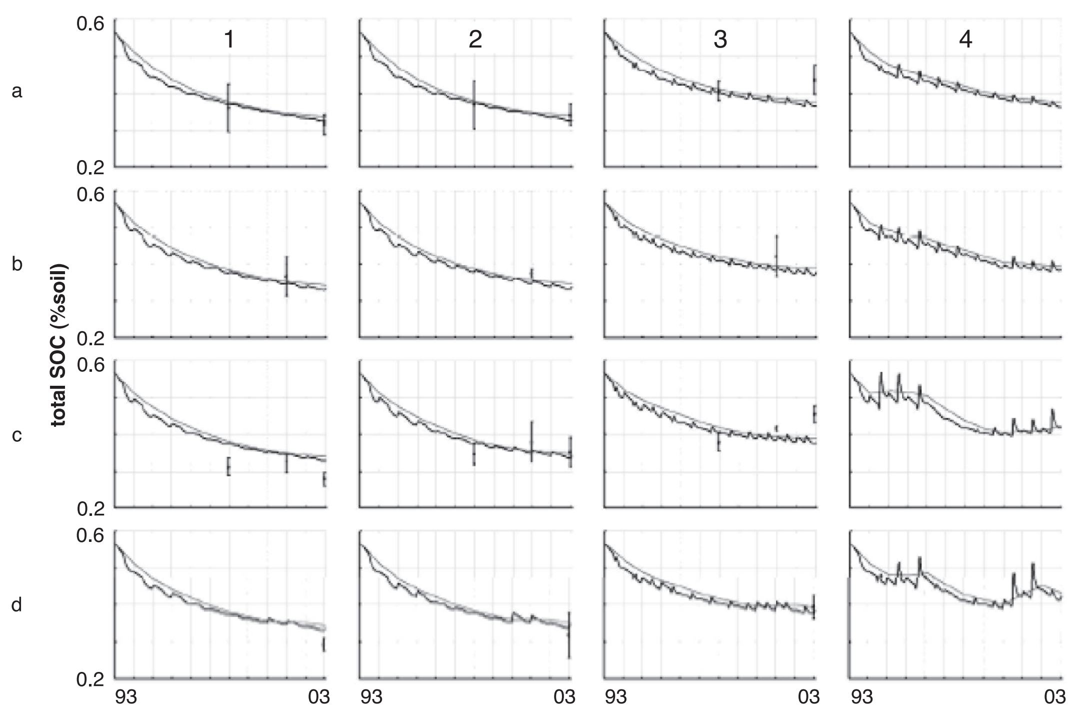


Figure 23. Simulated C management options for 16 rotations (a,b,c,d), levels (1,2,3,4). Continuous cotton (a), groundnut (b), sorghum (c), cotton-maize-sorghum (d), control (1), NPK+dolomite (2), PK+manure (3), NPK+crop residue (4). Legend and scale as in Figure 25. (Traore *et al*., *submitted*).

considered. Unavoidable residual errors arising from model structure, limited baseline information, data quality and quantity will be handled more efficiently in a light, stochastic data assimilation framework involving the use of remote sensing and complementary *in situ* measurements.

Methods for Using Remote Sensing in the EnKF

We studied the use of remote sensing for two purposes: 1) to estimate crop biomass in fields over large areas for use in scaling up of soil C monitoring and 2) to identify fields, their areas, and management practices implemented on them over time.

Last year, 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 (Koo, 2007). Originally, our goal was to use remote sensing to estimate above-ground biomass for use as inputs to the Ensemble Kalman Filter (EnKF) data assimilation method for scaling up field measurements of soil C. These estimates were to be used to estimate soil C input annually over space (in a simple soil C model) or to be used to refine parameters of a crop model (DSSAT-CENTURY, for example) in the EnKF. However, since multiple images over time would be necessary to estimate above ground biomass, we concluded that it may not be practical to use this approach in West Africa using existing satellite products. The frequency of cloudy days is so high that it is very difficult to obtain high resolution images multiple times during a growing season.

Research is still in progress on use of remote sensing for our second purpose by Traore *et al*., submitted. This work will be completed during the no-cost extension period and reported in the final project report. Preliminary results show that remote sensing may be very useful for identifying fields, their areas, and management practices.

Development of the EnKF Approach for Combining Measurements and Models

In previous research, a method was developed for combining soil C measurements made in a field with simulated soil C values using dynamic, stochastic soil C models. In those two studies, the approach was described and implemented for a single field using a very simple soil C model in one case (Jones *et al.,* 2004) and the complex DSSAT-CENTURY cropping system model in the other (Koo *et al*., 2007).

The goal of the study reported this year was to assess the potential of using data assimilation taking into account the more realistic spatial variability among fields in a large area, extending the work described earlier. This study considers a more complex cropping system in large area in northern Ghana. The general objective was to obtain estimates of soil carbon during a 20-year time period aggregated over many fields when there are limited and uncertain *in situ* measurements in time and space. The specific objective of this study was to assess the EnKF data assimilation approach by comparing its soil carbon estimates and associated uncertainties with those based solely on *in situ* measurements of soil carbon in a subset of fields using spatial interpolation for fields that were not measured.

The study area was about 18 km^2 and is located south of Wa, Upper Western Region of Ghana (Latitude: 9.89 and 10.12, Longitude: -2.58 and -2.50). Crop production provided the main source of household income in the area. The climate is classified as an “Aw” type (dry winter region) with one pronounced rainy season (Osei and Aryeetey-Attoh, 1997). Average annual rainfall (1953-2004) was about 1000 mm, and the rainy season generally started in April and ended in October.

The study area consisted of 132 fields managed by smallholder farmers. The area of each field was not measured, but based on a survey in this region by Braimoh and Vlek (2004), it was assumed that each field was one ha in area. Soil analyses of composite samples taken from the 132 fields in the study area in April 2006 showed very low soil organic carbon contents in most of the fields, ranging from 0.3 to 1.3 percent (median value of 0.44 percent). Some lowland fields with frequent floods and compound fields (i.e., fields adjacent to farm households) with routinely-applied domestic animal manure showed relatively high soil carbon contents. Soils in the fields were mostly sandy in texture (median sand-sized particle content of 78 percent). When the soil carbon and texture measurements were correlated, a positive linear relationship was shown between soil carbon content and silt plus clay content (correlation coefficient of 0.77). The majority of soils were classified as Alfisols (J.B. Naab, Savannah Agricultural Research Institute, personal communication, August 2006).

A scenario of soil C changes over a 20-year period was created and used as true values for the comparisons in this study. The DSSAT-CENTURY model was used to create the scenario for the 132 fields. The simple soil C model described by Jones *et al*. (2004) was used in the EnKF procedure. We compared two different methods of spatially-aggregating estimates of soil C changes over time: A) randomly sampling 1/4 of the 132 fields each year then using co-kriging to estimate soil C over all other fields and B) randomly sampling 1/4 of the fields and using them in the EnKF data assimilation method for all fields to estimate soil C over space. Aggregated changes in soil C with time were also computed. The kriging process used spatial correlations between soil C and texture determined from initial field sampling. The average soil C sequestration rate over the 20-year time period in the created scenario was about 170 kg/ha/yr, and the aggregated C mass increase over the 132 fields averaged about 22,400 kg/yr, which amounted to about 449,000 kg increase in the study area during the 20-year time period.

Figure 24 compares the estimated C aggregated over the 132 fields for both methods. We found that errors in estimates using method A (annual measurements aggregated spatially using kriging) were high initially but decreased with time. The kriged estimates in each year were independent, and consequently SOC estimates fluctuated due to the uncertainties of SOC in fields not measured and due to sampling and measurement errors. Computed errors of estimated SOC using method B (EnKF) were generally less than half of those values obtained by kriging on a per field basis. However after several years, the estimates of soil C produced by both methods were similar (Figure 25). Overall, uncertainties in SOC sequestration estimates over the 20-year period were about 10 percent of true soil C sequestration amount on a mass basis. These results from Koo (2007) are being reviewed and may be revised for publication, which will be done during the no-cost extension period.

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 (UF)

Evaluate the Phosphorus Model in DSSAT

The phosphorus module for the DSSAT models was completed and implemented this year. Figure 26 shows a schematic diagram of the major components

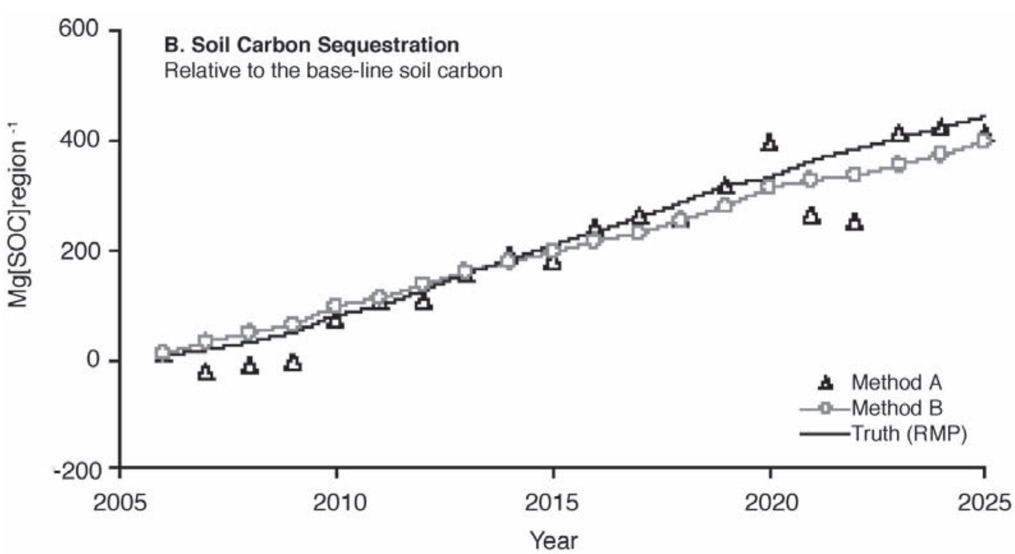


Figure 24. Soil carbon sequestration estimated from two methods and true values under the business-as-usual (base-line) and recommended management practices (RMP). Soil carbon sequestrations were calculated relatively from the base-line values (Koo, 2007).

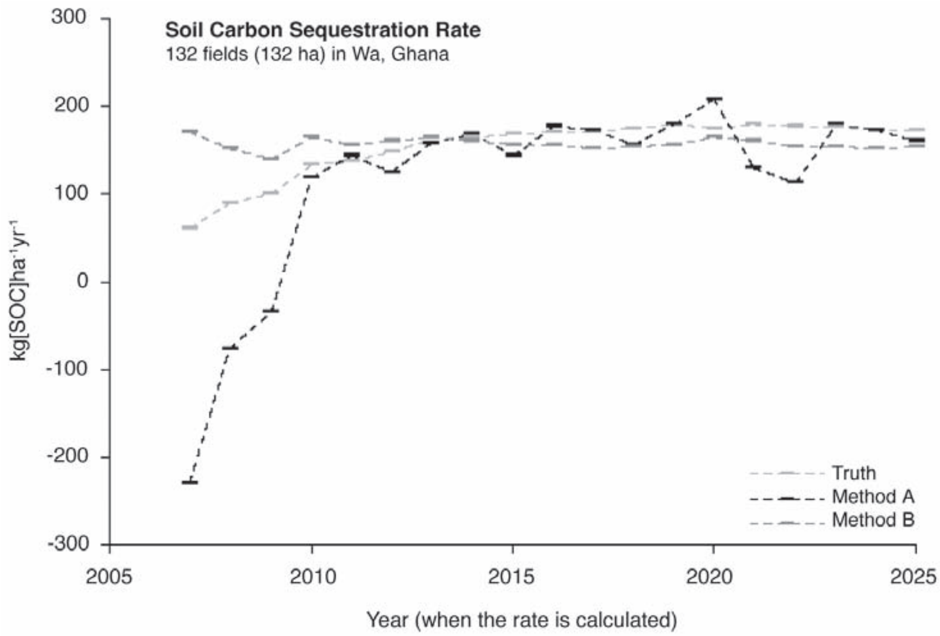


Figure 25. Estimated soil carbon sequestration rates from two methods, compared with the true rates. The rate changes depending on which year the rate was calculated (Koo, 2007).

of the soil and plant P components and the flows among the different pools. 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. The plant component was designed for use by all of the crops in the DSSAT software. The only requirements are P parameters specific to each crop and small changes in the code of each crop model to make use of the P stresses (e.g., to shift growth partitioning to roots, to reduce photosynthesis, and to modify phenological development). Currently, this code will work for all crops modeled using the CROPGRO code and also for maize. Our focus has been on maize cropping systems in Ghana. Here, we summarize research on a sensitivity analysis of critical P variable effects on maize biomass production and yield using soil, management, and weather inputs from Kpeve, Ghana. Also summarized is the initial evaluation of the P model for simulating maize biomass and grain growth and yield in two different environments in Ghana.

The sensitivity analysis of the model for six P input factors P showed that initial PiLabile and P fertilizer are the most important ones driving simulations of plant production. The fraction of PiLabile in solution and the shoot and seed P critical limits had less impact on the simulated growth and yield. Accurate predictions require, therefore, that at least initial PiLabile be measured or estimated correctly. If PiLabile cannot be measured directly and has to be indirectly estimated based on available P like P-Bray1 or Olsen, careful attention needs to be paid to the relationships derived and their agronomic validity. Diagnosing causes of poor model predictions should not only focus on checking measurements compared to simulations but also verifying the validity of input data, including initial PiLabile in situations where P may be a limiting factor. A more comprehensive sensitivity analysis will be carried out to study all of the factors in the new P module to determine where additional refinements in the model may be needed.

Datasets used to evaluate the model came from two phosphorus experiments carried out in Ghana in 2004 (Wa) and 2006 (Kpeve). In Kpeve, treatments were levels of P (0, 10, 30, and 80 kg/ha). In Wa, J. B. Naab conducted a randomized complete block experiment with three P levels (0, 60, and 90) and three N levels (0, 60, and 120). In the experiment in Kpeve in 2006, maize did not respond to P levels even though available P measured using Bray-1 method was low. The soil in Kpeve had relatively high organic matter content, and P from organic

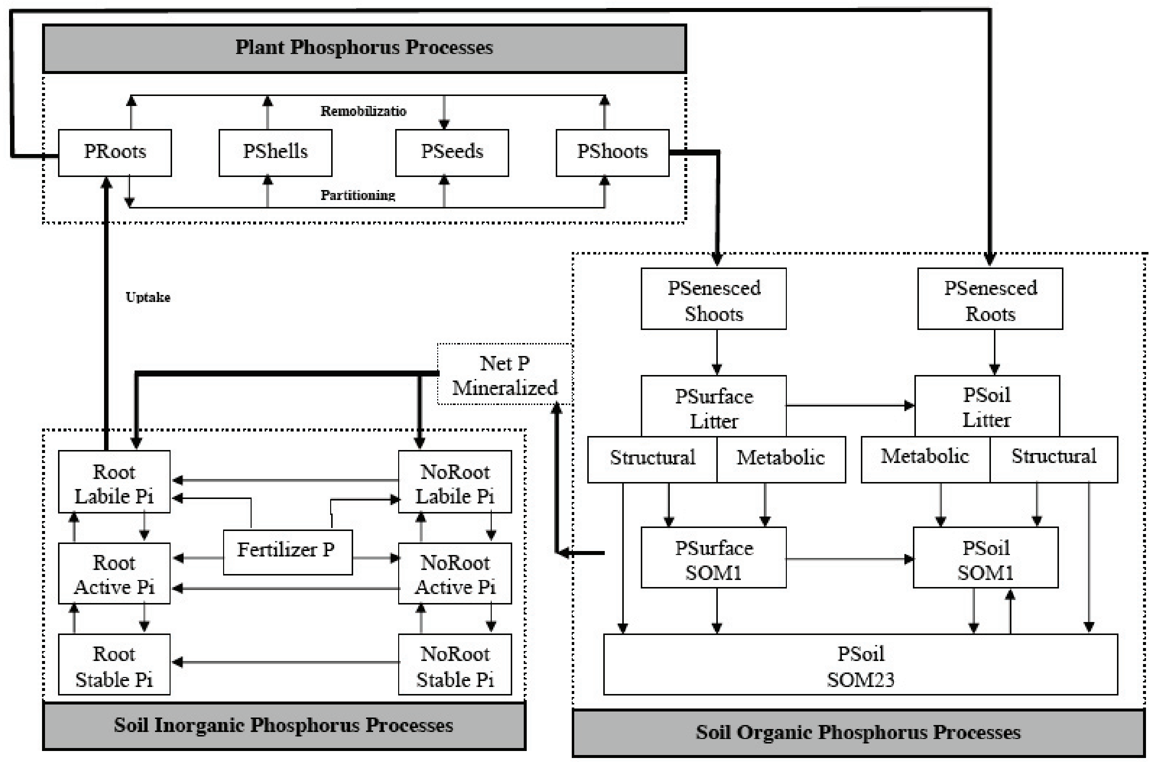


Figure 26. Diagram of the plant and soil phosphorus module in the DSSAT cropping system model (K. Dzotsi, *in preparation*).

matter decomposition could have been made available to the plant during the growing season. The second experiment, conducted in Wa, responded well to both phosphorus and nitrogen fertilizer applications. These two experiments provided a useful contrast in environments and a test of the model responses over a wide range of soil conditions using the same maize cultivar in two locations in Gana. Details of these comparisons are given in K. Dzotsi (*in preparation*).

Simulation of accumulated biomass over time during the Kpeve growing season was in good agreement with measurements. At anthesis and final harvest, the errors were very small. In agreement with measurements, simulated results showed very little response to P in this study where P was varied using 0, 10, 30, and 80 kg P/ha for the treatments. Final grain yield simulations also showed very little response to P levels (Figure 27) in the Kpeve 2006 experiment.

Maize grain yield and biomass response to P and N in the Wa experiment in 2004 varied considerably among treatments. Final grain yield varied from about 500 kg/ha to over 4000 kg/ha (Figure 28). There was a strong interaction between N and P, indicating that both nutrients were limiting. Providing only one of these nutrients was not sufficient for high yield. In the treatment with high N and high P, observed yields were similar to simulated potential yield for those conditions. The model simulated these differences very well overall (Figure 29). These results suggest that the P model can describe such variations in maize responses to P and N when inputs that describe the states of soil and nutrients are accurate. Simulated P concentrations in the plant followed the same pattern as observed (not shown here), but there was a tendency for the model to under-predict P concentration early and over-predict it later in the season for all treatments. More testing of this part of the model is needed to determine the cause and make adjustments in plant parameters if needed. Figure 29 shows the overall comparison of observed vs. simulated yields for Wa. Additional model evaluations are needed using independent data. J. B. Naab has additional years of data from Wa that will be used for additional testing of the model during the no-cost extension.

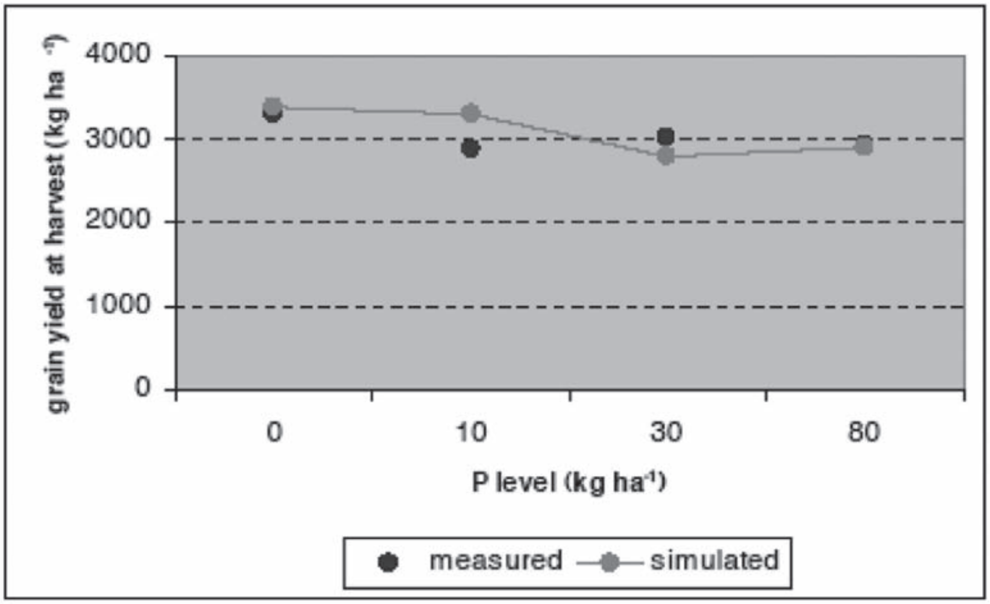


Figure 27. Comparison of simulated and measured grain for different phosphorus levels in the Kpeve experiment (K. Dzotsi, *in preparation*).

Quantify the Effects of Plant Composition and Soil Water on Organic Matter Decomposition

One of the major tasks of the carbon project was to describe the effect of soil water on residue decomposition. For this we carried out incubation studies under green house conditions in Ghana with residues of varying C/N ratio. Soil water was varied from near field trash, (iii) cowpea trash, (iv) mucuna trash, and (v) elephant grass which benefited from residual fertilizer.

In 2006, analysis of the data collected continued and a paper was submitted to the *Agronomy Journal* describing results from this experiment (An analysis of plant composition and soil water effects on residue decomposition, S. G. K. Adiku *et al.*) Results indicated that the rate of residue decomposition was highly correlated with the C:N ratio of residue. A literature search of prior studies suggested that other residue composition variables were also important. In our analysis of our own data and data from published sources, we showed that composition variables may be highly correlated and that advanced statistical measures are necessary to properly compare effects of individual and interacting residue composition variables. In addition, the paper showed strong soil water effects on organic matter decomposition rate.

An example of the data from the C mineralization studies at the University of Ghana is shown in Figure 30 for the different soil water levels. The data from each treatment were fitted to a double exponential equation describing evolution of CO2 vs. weeks. One way to translate these results into rate effects is to take the derivative of these double exponential equations fitted to data as shown in Figure 30. From these derivatives, or rate equations, the rate at t=0 (initial rate of CO2 evolution) was computed. Figure 31 shows these initial rates for one treatment and for each of the four soil water contents. Results from this study support the of the linear relationship between rate of decomposition and volumetric soil water content. contained in the DSSAT-CENTURY model for modifying decomposition rate parameters with soil water content.

Develop Methods for Initializing Soil Carbon Pool Sizes when Only Total C is Measured in the Field

Initializing dynamic soil organic matter (SOM) models is important for their application in agriculture and natural systems. Most SOM models assume that total carbon (C) is contained in different pools and C in each pool must be known to initialize the models. For example, the CENTURY model has 3 soil C pools as well as C in fresh organic matter and the RothC model has 5 pools. To

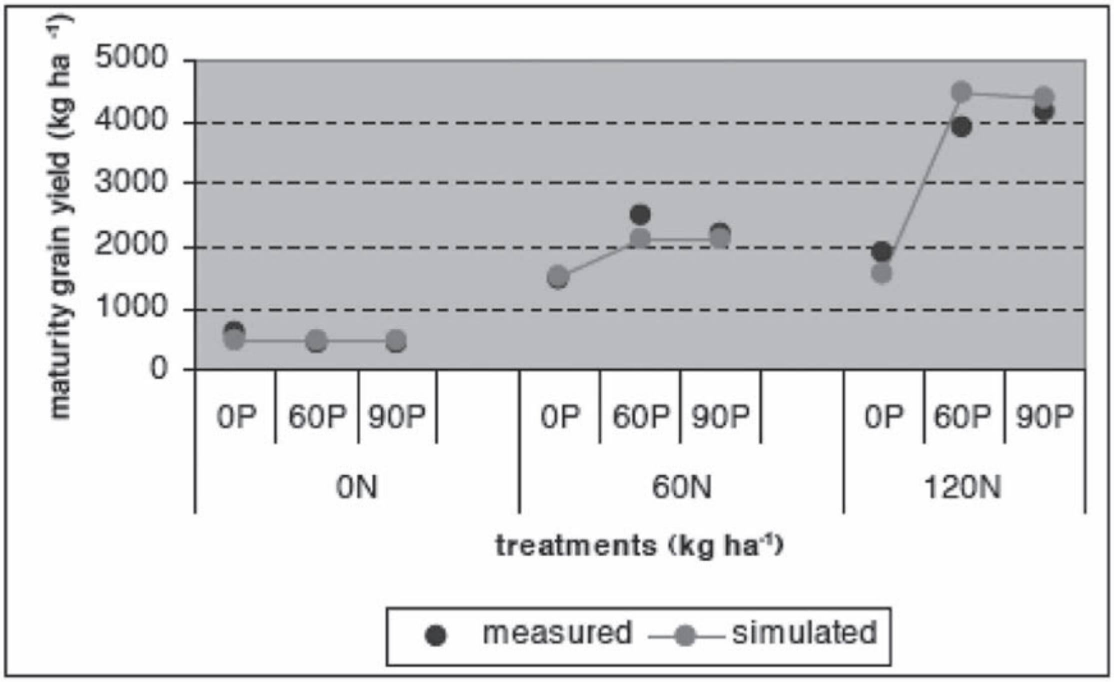


Figure 28. Measured and simulated responses of maturity grain yield to different combinations of nitrogen and phosphorus levels in the Wa experiment (K. Dzotsi, *in preparation*).

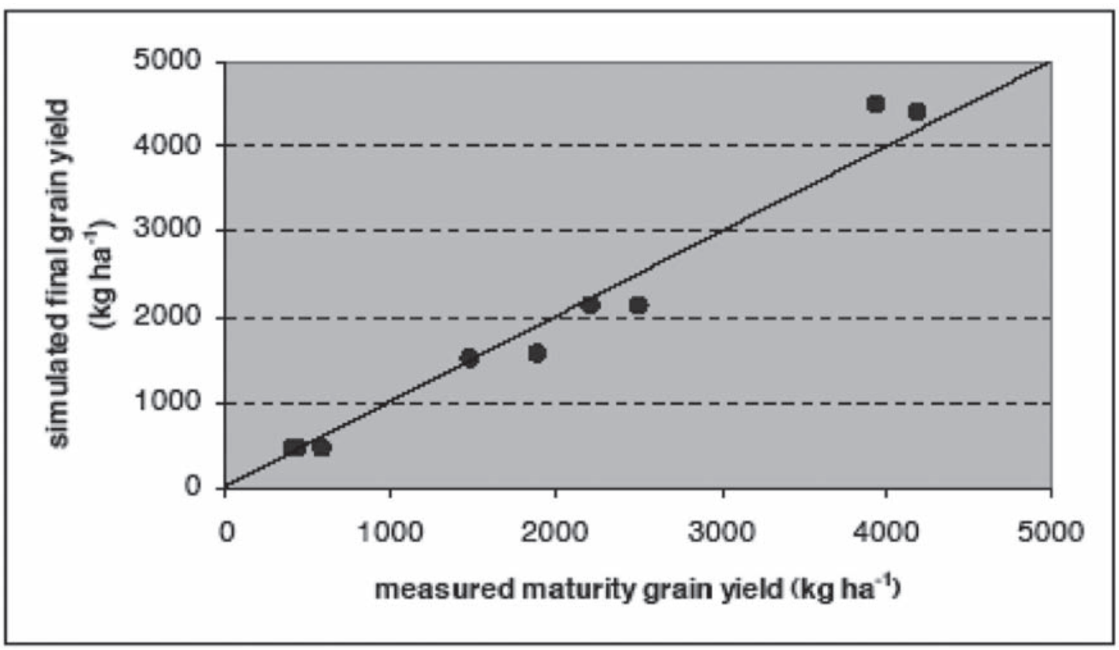


Figure 29. Comparison of measured and simulated maturity grain yield obtained in the Wa experiment using the 1:1 line (K. Dzotsi, *in preparation*).

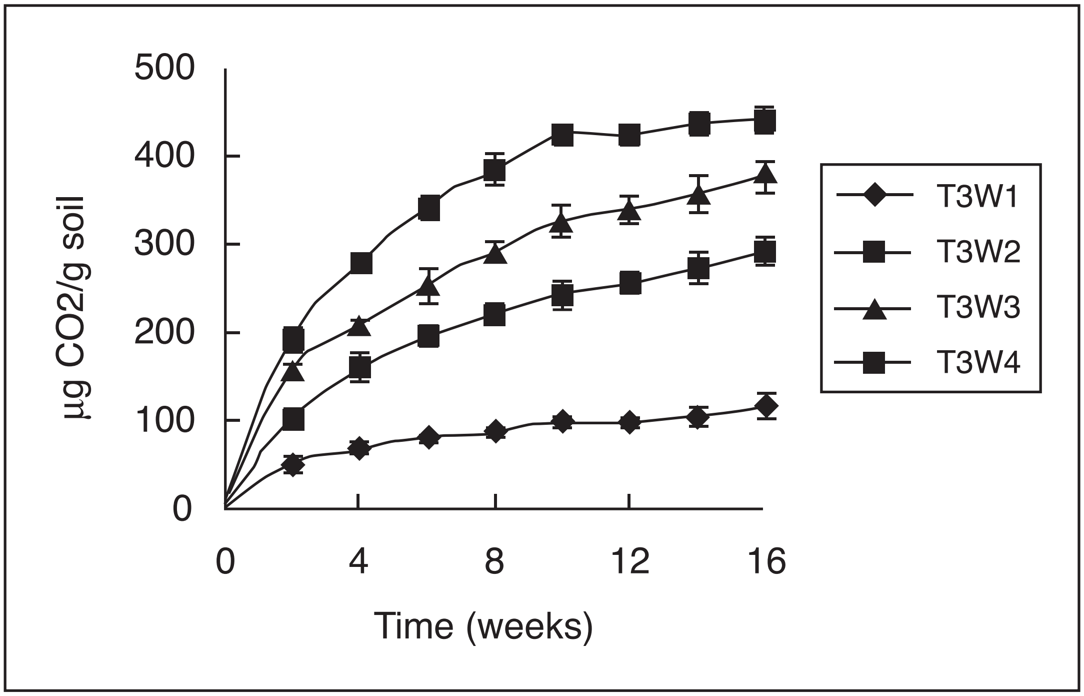


Figure 30. Cumulative carbon mineralization for Pigeon pea fallow that was slashed and surface applied (T3), for low (W1) through high (W4) soil water contents. (Adiku *et al.*, *in progress*. Soil samples taken from experimental field in Kpeve, Ghana).

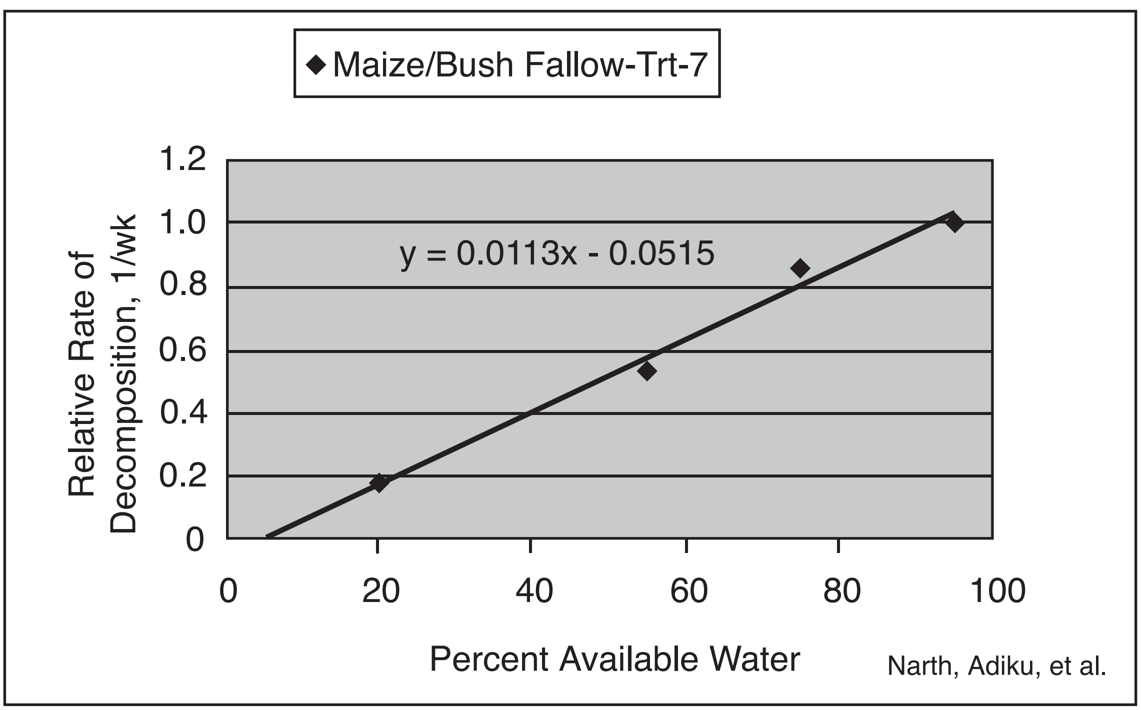


Figure 31. Effect of soil water on initial rate of CO2 evolution in the Ghana study (Adiku *et al.*, *in progress*).

some extent, the importance of initializing the different pools of C has not been emphasized enough, especially in agricultural systems in which land use and practices change frequently over time. We have demonstrated the importance of reliable estimates of initial pool sizes; it is not sufficient to have reliable measurements of initial total soil C. Depending on the fractionation of soil C into the different pools, decomposition of SOM during a growing season may result in very low levels of mineralization of nutrients or very high levels. Thus, for the same initial soil C level, the model may simulate less than one ton of maize grain per ha or more than five tons, for example, everything else being fixed.

Model developers usually provide default values of the fractions of C in each, but they should not be used unless one is confident that they are reliable for the soil and cropping system or natural system being simulated. These default values in CENTURY for example are for grassland soils or for agricultural soils. Although the default active fraction of soil C pool for agricultural soils is lower than grasslands (0.54 vs. 0.64), this value means that over 50 percent of the SOM in soil will decompose and release nutrients at an intermediate rate of decomposition (time constant in the order of several years depending on environmental conditions). We are finding that this pool depletes rapidly in West African conditions. After a few years of production, very little additional decomposition occurs, nutrient supply from organic sources is very low, and yield drops considerably.

Thus, if one simulates crop growth in a field after several years of production, one should not use the default initial pool fractions. One approach to initialize the pools of C in SOM models (as well as total C if it is not measured) has been suggested by model developers. In this procedure, the model is simulated for hundreds or thousands of years under the same conditions to arrive at steady state SOC values. However, agricultural systems change over relatively short time periods, sometimes every 3-10 years, and during this time period soil C would not reach steady state conditions. Furthermore, for agricultural applications, it is not too difficult to measure total soil C, but this still is not enough. We have thus been studying ways to estimate initial soil pools for use of the models in low input agricultural systems.

Our research on this topic is divided into two parts. First, we are exploring the behavior of total soil C and fractions in each of SOM1, SOM2 (the active pool), and SOM3 using the DSSAT-CENTURY model. In this study, we are using maize as a sole crop growing in one season every year, varying soil texture from sand to clay, and varying management from no inputs to high fertilizer and irrigated conditions. In addition, we are running the simulations for long time periods (hundreds of years) initializing the soil using default pool fractions. We also run the model iteratively, initializing total soil C every few years to its measured value (20 years in our current work), using the fractions at the end of each simulation period to initialize the next sequence. In this way, steady state fraction pool sizes are estimated for the constraint that total soil C is equal to the measured value. We are analyzing this constrained steady state value and also the transient changes in SOM pool fractions. We are finding that these constrained steady state values are a lower percentage of total C than those values obtained after running the model for very long time periods and taking the ending pool fractions. These differences translate into differences in simulated yields where these two different estimated fractions are used to initialize the SOM model. Figure 32 shows an example demonstrating the large differences in SOM decomposition depending on fractionation of C into the different pools. The implications are that for cropping systems that depend on mineralization for its nutrients, simulated results would be very different in these two cases. Of course, simulated differences in yield associated with different fractions of SOM pools are small if adequate nutrients are provided by fertilizer applications.

Our results show that SOM2, the active pool, approaches its steady state absolute value after a few years (less than 20 years in the conditions used until now). Thus, we hypothesize that we can use the DSSAT model to simulate the past 20 years of cropping history to estimate the active pool size (absolute magnitude), then use that value and measured initial condition total soil C to estimate pool fractions. We will evaluate this method during the no-cost extension.

The second part of this research is to develop practical methods to initialize the SOM pools for CENTURY. We have an approximate analytical solution to the equations in CENTURY. We will develop algorithms that use these analytical solutions along with soil, management, and climate conditions, averaged over different time periods, to compute SOM2. We will then compare this simpler analytical approach

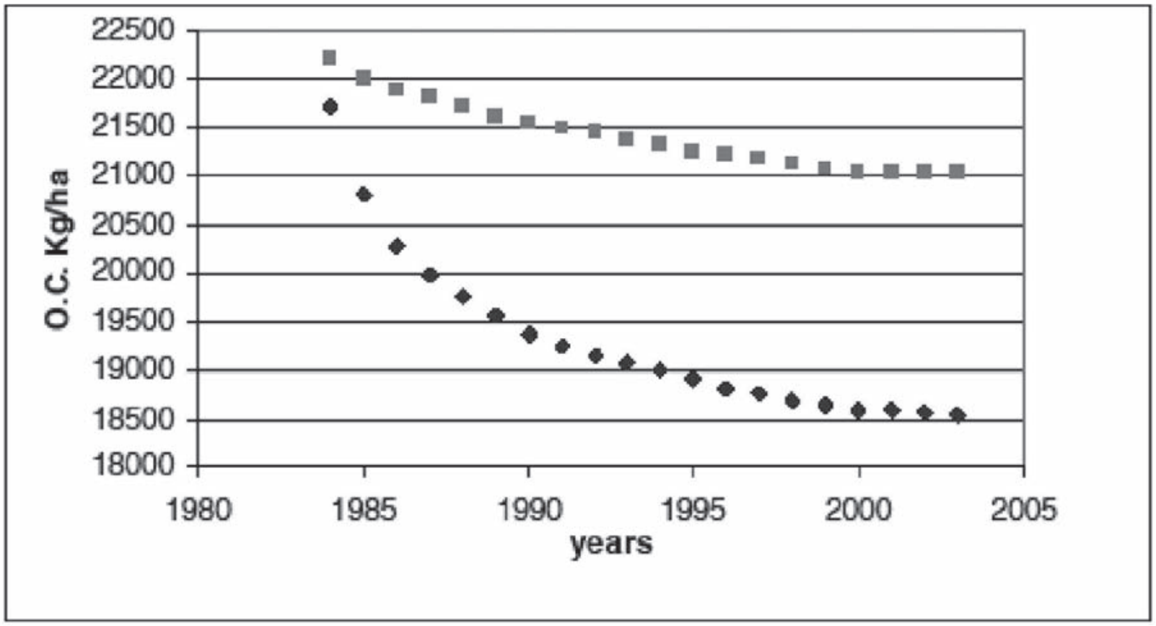


Figure 32. Simulated changes in soil C over a 20-year period demonstrating the effects of different soil C pool fractions. Total soil C was initially the same for both simulations. Triangles are for default C pool fractions and the squares represent a soil with a low fraction of active soil C (SOM2) using DSSAT-CENTURY (Gargiulo, *unpublished*).

for estimating SOM fractions with the use of the DSSAT simulations outlined above. Our hypothesis is that this method will provide a reliable and practical method for initializing the DSSAT-CENTURY SOC model for use in low input cropping systems and in degraded soils that occur in much of the developing world.

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

Objective 1, Output 1: Development of Soil Organic C-Texture Relationships

Overall SOC-Texture Relationships

We presented the following conceptual model (Figure 33) to describe soil organic carbon (SOC) levels as a function of texture and tillage at the beginning of the project (*see SM CRSP Annual Progress Report*, 2002-03). How well data we have gathered over the five years of the project fit this model is shown in Figure 34, where the thick black lines represent the mean C stocks (0-60 cm) for forest and RW soils; these lines are based on regressions of measured soil C contents and texture in increments to 60 cm soil depth and a fixed soil bulk density of 1.25 g cm^3 for all soil depths. The broad pattern observed, where higher SOC stocks are found in the forest and as texture becomes finer, and a divergence between the forest and RW soil stocks as texture becomes finer clearly matches our conceptual model shown in Figure 33. The mean carbon sequestration potential for RW soils RW soil stocks as texture becomes finer clearly matches our conceptual model shown in Figure 33. The mean carbon sequestration potential for RW soils - based on the difference between the regression lines for the RW and forest sites - varies from 8.2 to 32.8 Mg/ha for soil containing 25 to 100% silt + clay (Table 31). However, considerable variability in soil C stocks was observed for both the RW and forest sites. The solid and dashed thin red lines represent the envelopes for all soil C stock data from RW and forest sites, respectively. Clearly, there is a wide range in observed soil C stocks both in the natural (forest) and cultivated agricultural (RW) ecosystems - to the point that the maximum stock for the RW soils was equal to the minimum stock for the forest

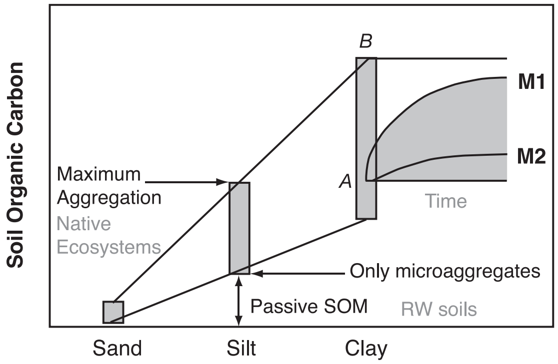


Figure 33. Conceptual framework for soil texture and tillage controls on SOC stocks.

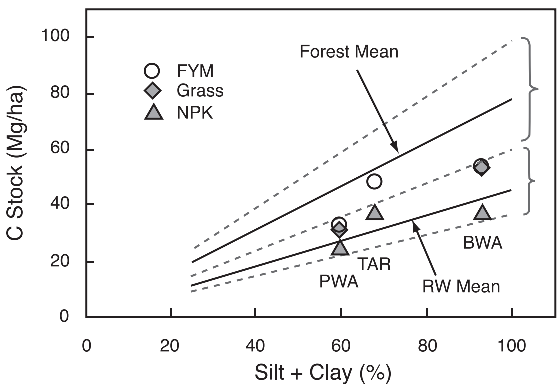


Figure 34. Measured effect of soil texture on SOC stocks (0-60cm) for forest and rice-wheat soils in Nepal and Bangladesh. Point data are for long term soil fertility experiments at Parwanipur (PWA), Tarahara (TAR) and Bhairahawa (BWA), Nepal. Solid and dashed red lines represent the data envelope observed for RW and forest soils, respectively.

soils. While our analysis of C sequestration potential is representative of the current situation at the landscape scale, characterization of C sequestration potential at an individual site is a challenging task.

Table 31. Effect of soil texture on mean carbon sequestration potential (0-60 cm) for rice-wheat soils in Nepal and Bangladesh.

Silt + Clay	Soil C Sequestration Potential
%	Mg/ha
25	8.2
50	16.4
75	24.6
100	32.8

Measured SOC stocks for FYM and NPK treatments in 25 year long term experiments at Parwanipur, Tarahara and Bhairahawa, Nepal and for uncultivated, unfertilized fallow (grassland) strips at two of the three sites are included for reference. Soil C stocks in the recommended NPK treatments were close to the RW minimum (from farmer sites) at Parwanipur and Bhairahawa, but close to the maximum at Tarahara. The input of 10 Mg/ha FYM/crop (20 or 30 Mg/ha/yr) or a switch to no-tillage (represented by the fallow grassland) at Parwanipur and Bhairahawa increased SOC stocks to the minimum value line observed for forest sites (also the maximum line for RW sites), suggesting that there is still additional potential to sequester C in these soils. The SOC stocks at Tarahara appear to be unusually elevated compared to the other two sites, which may be due to:

1. The site is more recently cleared from forest so that SOC levels are still declining;
2. The site contains charcoal, possibly from forest clearing operations (discussed more under modeling section)

Mean SOC stock declined with soil depth but differences between forest and RW sites were observed in both the 0-15 and 15-30 cm depth, consistent with a greater input of C associated with deeper rooting in the forest (Figure 35). In general the texture of the forest sites was slightly coarser than that of the rice-wheat sites. When adjusted to comparable soil textures the mean SOC stocks under forest and rice-wheat cropping were 52.8 and 32.1 Mg C/ha, respectively. Thus 20.7 Mg C/ha, or 39 percent of the original SOC was lost from soils under rice wheat cropping. Losses were 54, 35, 18 and 10 percent from the 0-15, 15-30, 30-45 and 45-60 cm depth increments, respectively. In general, treatment effects on SOC stocks in RW soils are observed to a depth of 30 cm so sampling should be at least to that depth.

Effect of Flooding Time on SOC Stocks in RW Soils

Soil samples were collected from farm sites in Bangladesh where two (6 farms) or three (5 farms) flooded rice crops are grown in a year to test the hypothesis that soil C stocks would be higher under these cropping systems compared to the RW rotation, with only a single flooded rice crop in a year. A long-term triple-cropped rice experiment at BRRI Joydebpur headquarters was also sampled. Samples have only been partially analyzed to date.

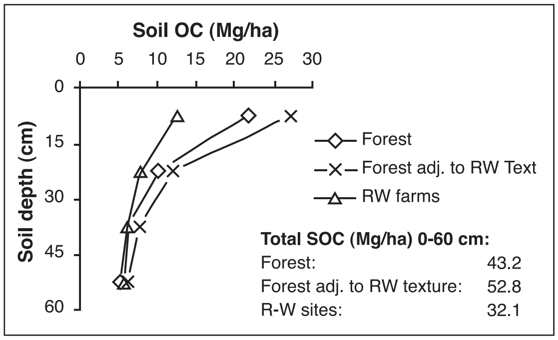


Figure 35. Depth distribution of mean SOC stocks for forest and rice-wheat farms.

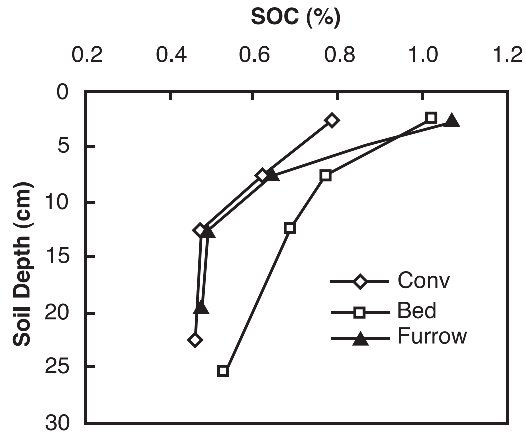


Figure 36. Comparison of SOC concentrations in the permanent bed and conventional ('Conv') tillage treatments without residue return for the R-W-maize/mungbean experiment at Nashipur, Bangladesh.

Objective 1, Output 2: Effects of Tillage, Residue Management and Nutrient Inputs on SOC Stocks

Tillage Experiments

A second set of soil samples were collected for measurement of SOC stock assessment after rice in 2006 from the following tillage and residue management experiments:

Nepal: RW Tillage and Crop Establishment, Bhairahawa
RW Crop residue management, Bhairahawa
No-tillage R-W-mungbean, IAAS, Rampur
No-tillage R-W-mungbean, Baireni, Chitwan
Bangladesh: R-W-maize/mungbean permanent beds*, Nashipur
R-W-mungbean permanent beds, Nashipur
* first time this experiment was sampled

Analysis of these soil samples is incomplete, except for the R-W-maize/mungbean permanent bed experiment at Nashipur. This experiment with three replications was initiated with maize in 2002, and had been through 4.66 cycles and 14 successive crops at the time of sampling. It included crop residue return at different rates, which is likely critical for sustainability of the almost no-tillage permanent bed approach. Soil OC concentrations were substantially elevated on the bed and in the 0-5 cm depth of the furrow compared to conventional practice (Figure 36).

Soil OC stocks were increased by 2.7 to 6.45 Mg/ha by the permanent beds (description of calculation methodology in *SM CRSP Annual Progress Report, 2005 - 2006*), but were not measurably affected by residue return rate (Table 32). The mean difference between the bed and conventional practice of 4.95 Mg/ha corresponds to an annual rate of gain of 1.06 Mg C/ha/yr. This value is higher than the 0.78 Mg C/ha/yr that we previously measured for a R-W-mungbean experiment at the same location. Both values are high and illustrate the potential for the permanent bed system to sequester C.

Table 32. Soil OC stocks (0-30cm) in R-W-Maize/mungbean experiment at Nashipur, Bangladesh; data adjusted to same soil mass for conventional ('Conv.'). and P. Beds.

Treatment (Res. Ret'n Rate - %)	SOC Stock Mg/ha
Conv. (0)	26.36
P. Bed (0)	32.08
P. Bed (50)	29.06
P. Bed (100)	32.81

Impacts of Tillage and Organic Inputs on Rate of SOC Gains

A summary of the SOC sequestration gains that we have measured for different management practices in rice-wheat cropping systems is given in Table 33. In general, larger gains in C are seen with reduced or no-tillage practices than with return of crop residues. The hypothesis that the combination of residue return with no-tillage accelerates C sequestration appeared to hold in the IAAS experiment but not with the permanent bed experiment at Nashipur. Manure addition rates used in the Nepal LTFEs are typical of research experiments but could not be scaled up to the landscape level as they are much higher than the maximum potential production rates. There was only a small effect of soil texture on the rate of accumulation of SOC in the LTFE experiments. SOC accumulation rate under the natural grass fallows at two LTFE experiments was approximately equivalent to that achieved with addition of 10 Mg manure/ha/crop (20-30Mg/ha/yr), again indicating the potential gain with no-tillage agriculture.

Assessment of Tillage Effects on Residue Decomposition Using the ^{13}C Tracer Method

Decomposition of rice and wheat roots and straws under no-tillage and conventional tillage practices was studied by PhD student Sanjay Gami in micro-plots using ^{13}C labeled residues at two sites in Nepal.

Results from these experiments were:

- Straw decomposition was initially slower in the NT treatment, where straw was placed as mulch, than in the CT treatment, but after 16.5 months and three crops, straw C remaining in the NT treatment (7-13%) was significantly less than that in the CT treatments (13-17%) for both rice and wheat residue types;
- Root C decomposed more slowly than straw C for both rice and wheat;
- A tillage effect on residue decomposition was observed for rice roots, but not wheat roots, where higher amounts of root derived C remained under NT than CT (43-50% versus 37-38% after 16.5 months)

While plant root residues are generally recognized to decompose more slowly than shoot residues, the differences observed in the present experiment are accentuated because the root C has already undergone some decomposition and transformation by the time of the first measurement at crop harvest following field ^{13}C labeling. In contrast a defined amount ^{13}C labeled straw is added at the beginning of the decomposition experiment. The results of the residue decomposition studies do not entirely support the hypothesis that NT leads to C sequestration in soils, in that decomposition of straws of rice and wheat was faster under NT compared to CT, and only the decomposition of rice roots was slower under NT. Possibly, the change to NT in these carbon degraded soils leads first to an improved soil biological capacity and accelerated decomposition of residues, before later building aggregates that

Table 33. Impact of carbon sequestration practices on the rate of soil carbon gain in rice-wheat systems and grass fallow.

Carbon Sequestration Practice	Rate of C Gain Mg C/ha/yr	Location and Duration of Experiment[1]	Soil Texture
A. Reduced Tillage			
No puddling for rice	0.38	Bhairahawa[3]; TCE; 7 yr	Silty Clay
No tillage w/o mulch	0.22	IAAS[3] ; tillage & mulch; 5 yr	Silt Loam
plus mulch	0.58		
No tillage ± mulch	ND[2]	Baireni[3]; 2 yr	Clay loam
Permanent Bed RWM	0.78	Nashipur[3]; 4 yr	Sandy loam
Permanent Bed ± mulch RWMz+M	1.06	Nashipur; 4.67 yr	Sandy loam
B. Organic Inputs (CT)[4]			
Straw return 8 Mg/ha/yr	0.21	Bhairahawa[3] Crop residue; 7 yr	Silty Clay
Straw return 10 Mg/ha/yr	0.16	Parwanipur LTFE; 23 yr	Silt Loam
Manure 20 Mg/ha/yr	0.37-0.43	3 LTFE's; 23-25 yr	Silt to silty clay loam
C. No-Tillage Grassland	0.28-0.60	2 LTFE's; 23-25 yr	

[1]All locations are in the terai of Nepal except for the permanent beds, which are in NW Banglades. LTFEs are located at NARX Research Centers at Bhairahawa, Parwanipur and Tarahara;
[2]ND = not detectable;
[3]These sites were sampled again in Nov., 2006;
[4]CT = Conventional tillage; organic inputs are on fresh weight basis; straw was mature and dry. FYM was estimated to contain 8 Mg/ha dry wt.

protect organic matter from decomposition. It is expected that root derived C will be the most important contributor to C sequestration under long-term NT in the rice-wheat system.

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)

Studies continue to assess the watershed level effects of the soil and water conservation technology ACN (*aménagement en courbe de niveau* or ridge tillage, *see* Carbon Sequestration in *SM CRSP Annual Progress Report, 2005 - 2006*). Further analysis of soil water measurement data confirm preliminary results that the low efficiency of rainfall use is related to the unusually low infiltration rate of the soils of the Sahel as well as to the unusually high intensity rainfall. This is currently being documented in publications. Evaluation of the C sequestration potential of this technology now indicates that studies of tree biodiversity and growth increase are needed to better quantify effects on these components of the watershed. While studies of the field water balance continue, the results suggest that deep drainage may be increased by upward of 150 percent. The consequence of such inputs of water into the groundwater appear to be increased drinking water availability and in some cases, potential for irrigation in the dry season. A survey of the village of Siguidolo, Mali, where ACN has been implemented for 12 years and has been adopted by approximately 90 percent of the households, about 80 percent now have vegetable gardens irrigated by village women. Approximately 80 hectares of new ACN fields have been surveyed in new villages, some of which are part of the USAID Mission, Prodepam project.

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)

Changes in the Biodiversity of Microbial Populations in Soils under Varying Fallow Treatments

This study was added after seeing such major differences in crop growth and yield among the treatments in the experiment in Kpeve conducted by S. Adiku and others. Large differences in soil C among the treatments were found after only three years into the rotation study. Experiments were conducted to test the hypothesis that carbon stored in soils of different management practices is affected more by the microbial biomass carbon and activity than microbial community structure and that the distribution of the major microbial grouping in soil is influenced by how much carbon is sequestered in soil.

Soils were sampled from the Kpeve Agricultural Experimental Station (KAES) in the Volta Region in Ghana. The treatments involved T1 - Maize followed by fallow elephant grass that was burnt before planting, T3 - Maize followed by pigeon pea fallow, T4 - Maize followed by bare fallow, T7 - fertilized Maize followed by elephant grass fallow, FR - forest reserve (never farmed native land). Microbial biomass carbon was determination by chloroform fumigation method whilst the dehydrogenase activity was determined by the triphenyl tetrazolium formazon (TPF) method. Phospholipid fatty acid analyses (PLFA) were performed on part of the soil sample. Under treatments favoring higher soil carbon sequestration, there was a corresponding increase in the microbial biomass carbon. The treatment effects were significantly different ($p<0.007$).

Correlation between microbial biomass carbon and soil organic carbon was significant ($r= 0.63^*$). Treatments with the least amount of carbon showed the least microbial activity. A significant relationship existed between dehydrogenase activity and the soil organic carbon= 0.63*). The effects of different soil management practices on biodiversity of soil organisms was assessed by using the PLFA signature profiles for the eukaryotes, generally representing the normal saturates, actinomtycetes, anaerobic metal reducers, proteobacteria and the terminally branched saturates that mostly represent the Gram positive forms. Differences in soil carbon in the treatments did not cause the extinction of a particular PLFA signature but affected the percentage compositions of the various treatments, thus affecting the distribution. The amount of carbon in soil significantly influenced the porteobacteria ($P<0.001$) and actinomycetes populations ($p<0.028$).

We conclude from this study that carbon stored in soil had more influence on the microbial biomass carbon and microbial activity than on the microbial community structure. Secondly, the distribution of the major microbial grouping in soil was influenced by how much carbon was stored in soil. Thirdly the changes in the population of the proteobacterial population can be used to indicate changes in level of carbon sequestered in soil.

Wide Area Soil Sampling for Characterizing the Wa, Ghana Study Area

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). Additional samples were collected In 2006 in the Wa area. 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. Work done this year focused mostly on the Wa, Ghana study area.

The study site was located south of Wa in the Upper West Region of Ghana. In July 2004 and April 2006, *in situ* soil samples and farm management surveys were obtained in four villages in the area: Nakor, Kparisaga, Kumfabiala, and Bamahu. A total of 132 farmers' fields were identified within an about 18 km^2 (6 km in North-South and 3 km in East-West direction). In each field, a composite soil sample consisting of 5-6 subsamples to 20 cm depth was taken in 2004-2006, and soil organic carbon contents and soil texture were analyzed by Savannah Agricultural Research Institute. Other information collected at each sampled field included field boundary, GPS location, cropping history, residue management, and fertilizer applications. A database of 132 fields was created to organize all of these data for subsequent analyses.

In the absence of inorganic fertilizer applications, most farmers relied on the native soil fertility. However, overall quality of soils in the area is not ideal for low-input agricultural production. Brady and Weil (2002) listed the factors of an agricultural system that lead to losses of soil organic matter, and this study showed that many of such factors occurred in the study area, including intensive tillage, residue removal, high temperature, low soil moisture, fire, and low plant productivity. Low levels of SOC may thus be related to continuous cultivation alternated with an ineffective (overly short) fallow. Soil texture was mostly sandy, which has poor water and nutrient retention capacities. In addition, a dry winter season which hampers mineralization prior to residue burning practices also greatly increases SOM losses. Shifting cultivation to new land was becoming more limited due to rapidly increasing population pressure. This is shown in Figure 37 by the decreasing trend in fallow fields from 2001 through 2005 in the Wa study area. In order to sustain the cropping system under this low-input management condition, strategies that can effectively increase soil organic matter, such as no-till agriculture (Lal *et al*., 2004) and increased use of supplemental fertilizers and/or irrigation should be considered.

Koo (2007) presented these data and relationships. A few of the most interesting findings were: 1) soil carbon in the fields was not correlated with field slope, 2) soil C was positively correlated with the number of times that cereals were grown in the field during the last five years (Table 34) and negatively correlated with the number of years legumes or tuber crops were grown, and 3) high correlations were found between soil C and texture.

Correlation analysis showed good potential for estimating the soil organic carbon content by using soil texture analysis. This approach may be useful, especially where SOC measurements are not readily available. However, not surprisingly, we found that the soil C estimation variability was too high to have practical significance for assessing soil carbon sequestration over just a two-year time period.

Maize Production and Soil C Changes in 2006 under Different Maize-based Cropping Systems, Native Fallow and Bare Fallow in Kpeve, Ghana

The final field maize-fallow trial was conducted from May to September 2006 at Kpeve, Ghana. This concluded a four-year study with data collected on maize growth (biomass), yield and soil carbon measurements. A total of 700 mm rainfall was received during the season, which was comparable to the long-term seasonal average. The average temperature was between 25 to 27^{0}C and the average daily solar radiation was 15 $MJ/m^2/d$.

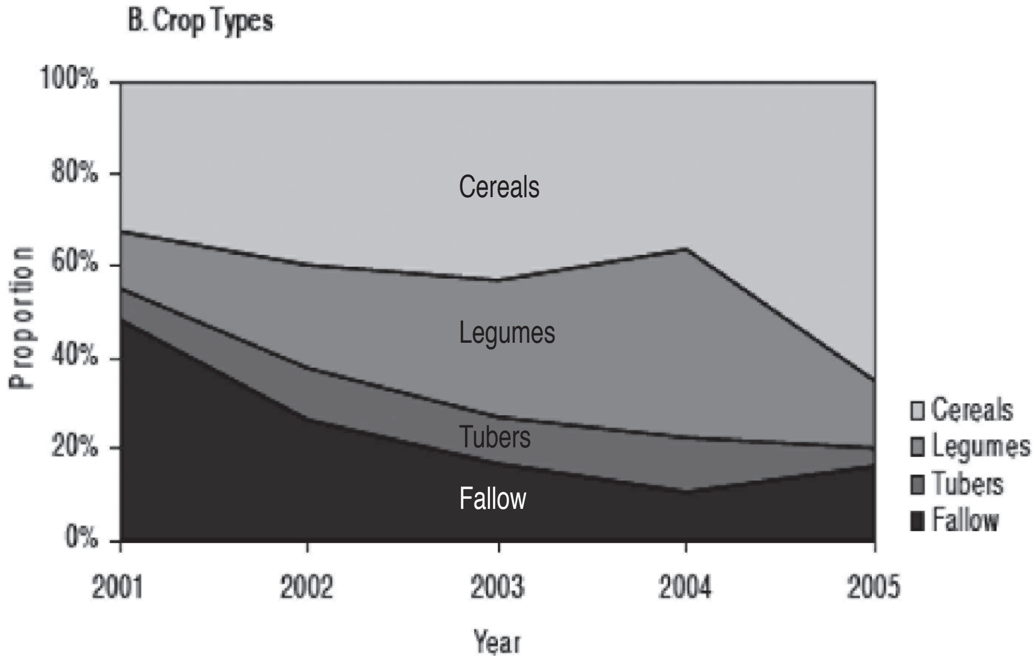


Figure 37. Proportions of land used for different types of crops and fallow in 132 farmers' fields in Wa, Ghana, during 2001-2005 (J. Koo, 2007).

The trial involved seven treatments of maize planted on May 23, 2006, following different previous fallow treatments (Table 35). Treatment T7 received 250 kg/ha compound NPK fertilizer (15-15-15) at planting, followed by an application of 125 kg/ha sulphate of ammonia $(NH_4)_2SO_4$) at six weeks after planting (WAP) following the recommendations of the Agricultural Extension Handbook (S. Adiku, personal communication, July 2007). Upon emergence, the seedlings were thinned to two per hill on June 6, 2008. Only one final harvest was carried out at maturity for growth and yield analysis on September 12, 2006. The trials were terminated thereafter.

The growth and yield of maize during the last trial is also shown in Table 35. Even though rainfall was adequate, the previous fallow treatment significantly affected maize growth and yield. The treatments T2, T3 T6 and T7 produced more than 7.9 tons/ha, which were significantly higher than T5 and T1 growth (6 to 7 tons/ha). The least growth was for T4 (0.87 ton/a). The maize yield also differed among treatments. The T7 maize produced 2.4 ton/ha, which was significantly higher than all the others, resulting also in the highest harvest index of 0.24. T4 maize produced only 0.005 ton/ha with harvest index of 0.05.

Table 34. Correlation matrix of SOC measured in 2004 and 2006 and the cropping history (number of years that specific crop type was cultivated) in the 132 fields in the study area from 2001 through 2005 (n=132, α=0.05, *=90% significance level, **=95% significance level, ***=99% significance level, ns=not significant) (J. Koo, 2007).

	SOC 2004	SOC 2006	Cereals	Legumes	Tubers	Fallow
SOC 2004	-					
SOC 2006	0.83***	-				
Cereals	0.40***	0.31***	-			
Legumes	-0.40***	-0.38***	-0.52***	-		
Tubers	-0.22**	-0.20**	-0.29***	-0.06^{ns}	-	
Fallow	0.00^{ns}	0.08^{ns}	-0.58***	-0.22**	-0.16*	-

Table 35. Treatment description, maize grain yield (kg/ha), grain harvest index, and soil carbon (%) for the last field trial, conducted in 2006 in Kpeve, Ghana.

Trt	Description	Biomass	Yield	HI	SOC
T1	Bush fallow with burning	6180b	1022b	0.16	1.17
T2	Bush fallow incorporated	7962a	1277b	0.16	1.19
T3	Pigeon pea fallow, no-till	8120a	1481b	0.18	1.62
T4	Bare fallow	872c	45c	0.05	0.70
T5	Cowpea fallow, no-till	7064b	972b	0.14	1.16
T6	Mucuna fallow, no-till	8549a	1781ab	0.20	1.12
T7	Bare fallow, no-till	9759a	2358a	0.24	1.66

At the end of the trial, soil carbon was generally higher in the treatments with residue retention and no-till (e.g., T3, T7) than those with residue removal (T1, T4). The highest value of 1.66 percent for soil carbon was observed for treatment T7 and the least was observed for T4 (0.70 percent). Considering that the initial soil carbon prior to the commencement of the project was 2.4 percent, it is evident that all the maize-fallow rotation treatments showed a decline in soil carbon. However, the decline was fastest for T4 where all residues were continually removed over a four-year period. Maize yield increased with soil carbon (Figure 38) and the relation was significant (R2 = 0.70*). The trend line suggests that no yields are attainable without external inputs when the SOC falls below about 0.5 percent. This implies that mineralization of nutrients decreases to a very low level that is not sufficient for maize crop production. A minimum of about 1.4 percent soil carbon was required in this soil to attain maize yield of 1.5 ton/ha. For higher yields above 2 ton/ha, the soil carbon should not fall below 1.6 percent. Although these results are specific to this soil, they highlight the importance of maintaining soil organic matter.

The general conclusion was that fallow management is important for sustainable soil and crop productivity. High returns of residue combined with no tillage and modest fertilizer application provide a technology that maintains high soil carbon and also appreciable maize yields of 2 tons/ha, which is more than double the average yields of farmers in the Kpeve District of Ghana.

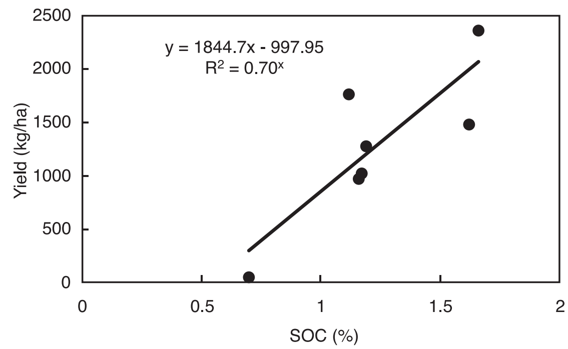


Figure 38. Relationship between maize grain yield and soil carbon measured during the last year (2006)of the field trial in Kpeve, Ghana.

Nitrogen and Phosphorus Fertilization Effects on Maize Yield and SOC Dynamics in the Northern Savanna Zone of Ghana

Sustainable management practices are needed to enhance soil organic carbon (SOC) in degraded soils in semi-arid West Africa. Practices are needed that leave plant residue in the field to replenish SOC that decomposes when soils are cropped. However, residue production is very low in many of the cropping systems in this region and fields must be taken out of production to allow SOC to build up again after crops are produced for only a few years.

J. B. Naab conducted an experiment for five years in Wa, Ghana to provide information needed to characterize the interactions of soil and crop management and SOC. Treatments in that five-year experiment were: three nitrogen (N) levels, three phosphorus (P) levels and fertilization rates using a replicated factorial design. The field was only minimally tilled (hand hoeing to cover residue before each season started). A continuous maize cropping system was studied to determine effects of N and P treatments on crop biomass production, residue C, N and P concentration, and their impact on SOC, total soil nitrogen (TSN) and phosphorus (TSP) in the 0-20 cm soil depth. The experiment was conducted in a soil with very low initial SOC (3.74 g/kg). Data from one year in this study (2004) were used to help complete and initially evaluate the phosphorus module in the DSSAT-CENTURY model (see above in this report).

Results analyzed thus far indicate that biomass production, the resulting amount of residue returned to the soil, was significantly increased by about

60 – 70 percent when N and P fertilizers were applied compared with no N fertilization. Averaged over P levels, mean annual maize crop residue returned to the soil from 2003 to 2006 was greater under high fertility levels than under low fertility levels. Averaged across years, N and P fertilization resulted in higher residue C, N and P returned to the soil, than without N or P fertilizer.

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 continued to extend ACNs *(aménagements en courbe de niveau)*, still free of charge. Requests for implementing the 'ados' have been strongly increasing, as the program registered 872 demands from farmers at 174 locations. Only a total of 194 ha were surveyed and marked for the 'ados' (Table 36). Unfortunately the rate to bring these 'marked' hectares into effective ACNs can be as low as 52 percent.

Table 36. Sites, farms and areas surveyed for installing 'ados' for ACN implementation.

Sites	Farms	Total areas (ha)
Fansirakoro	2	3
Oumarbougou	5	10
Konobougou	11	21
Bamako (periurban farms)	9	31
Koniobla	8	14
Cinzana	5	9
Niessoumana	4	10
Diou	7	9
Samanko	5	20
Karangasso	11	24
Sanakoroba	4	6
Kita	11	23
Bougouni	7	14
Total	**89**	**194**

Clearly a need exists to train farmers and farmers' organization of a given commune (e.g., The Commune Rurale of Konobougou). The commune could then organize a local 'ACN Committee' to manage an implementation program on a 'pay per use' basis. Follow-up programs also need to be developed to improve the above 52 percent rate of implementation.

Impact of ACN on Soil Organic Carbon

Four methods were proposed to test the hypothesis that ACN may lead to increases in soil organic C: 1) comparison of SOC in adjacent fields, 2) comparing estimates of SOC over time, 3) testing the ACN management in a replicated experiment – carried out at the Yundum site in The Gambia, and 4) monitoring change over time in SOC.

The first method results indicated no significant differences between percent SOC in fields where ACN had been in place and where no ACN had been in place. While there was a tendency for soil C levels to be higher under ACN management, the differences were not significant. There was also a tendency for the variance in SOC to be higher under ACN management. Overall, this approach to assess the ACN effect on soil organic C appears to be the least defensible of the four methods. Even if a significant difference exists, such an effect would be confounded with farmer management, which included different crops, varieties and fertilization.

The results for Method 2, shown in Figure 39, clearly suggest a strong effect of ACN in increasing soil organic carbon (SOC). Several cautions are needed in interpreting these data, however. Two assumptions were made to implement Method 1. Firstly, the fields initially placed under ACN management were identical to the most recently planted fields, and secondly, we assumed the density of trees and their proximity to the sample sites were the same for both fields. The latter assumption is complicated by the observation that ACN tends to lead to increased tree density.

The third method results showed a significant increase in SOC. Maize yields increased with ACN management, but only during the third year of the experiment. We suspect that the growth of the local shrub *Icarina senegalensis* contributed to the ACN effect through increased growth from the greater capture of rainfall and storage in subsoil.

As for Method 4, soil C also did not conclusively indicate that ACN increased SOC. While the soil C percentages did appear to increase in the case

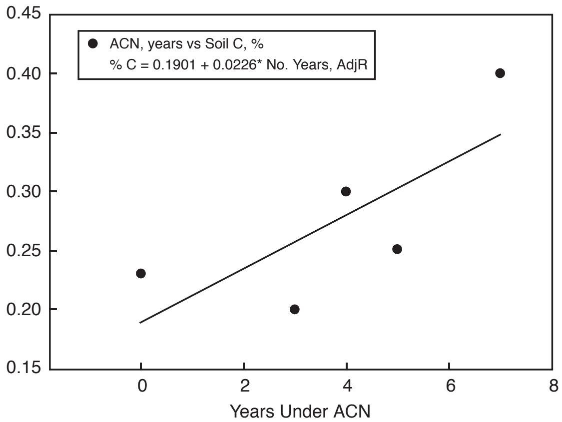


Figure 39. Change in soil C with time, Zan Diarra's farm, Konobougou, Siguidolo, Mali.

of Mory Konaté's farm but not significantly, this method does not provide a control and as a result we have no way to assure that the outcome was due exclusively to ACN and not a regional phenomena.

In summary then, field experiments in Mali and The Gambia indicate that the amenagement en courbes de niveau (ACN) increased soil organic C based on results obtained with Methods 2 and 3 and suggest a possible effect using the other two methods. The increase in soil organic C appears to be related to at least three factors: a) Increased crop growth, often at 30-50 percent, b) Increased growth of trees and shrubs and their input of litter and soil C, and b) the reduction in soil erosion losses of soil C. These components remain to be quantified as studies continue. Data from these experiments are also being analyzed by geospatial methods, which are expected to provide quantification of some of the effects proposed herein as well as recommendations for optimal sampling distance, frequency of sampling, and estimates of uncertainty related to the C tonnage calculations.

Impact of ACNs on Groundwater Recharge

Based on field water balance calculations (Brannan *et al.*, *in progress*) it was apparent that very large increases in deep drainage occurred when ACN in Mali was implemented. This was noted especially in the village of Siguidolo where families, with NGO assistance, began off-season irrigation of vegetable gardens – an activity recognized by the village to be women's responsibility and to whom the sales returned. Beginning in 2006, a series of four wells were installed in Drissa Traore's fields at Fansirakouro, Mali. In addition, measurements at associated village wells in both Fansirakouro and at Siguidolo were instituted with the purchase and delivery of well-measuring devices. The hypothesis for measurements at Drissa Traore's field was that wells in the ACN zone might have higher water tables than those in the non-ACN zone. One of the first results was that the wells needed to be much deeper than first thought. Initially, the depth was in the 10 to 12 meter range. The field wells were drilled into base rock beginning about 10 meters and continuing until about 25. The first results indicated nearly the same level of water in the village wells as in the ACN wells at Fansirakouro. An interesting preliminary observation, however, is that the ACN wells contained substantial amounts of water even during the dry season, while the neighboring village drinking water wells went dry, some beginning in February, and remaining dry until the July rains (Figure 40). Monitoring of the wells is anticipated for several years to assess trends either positive or negative both at Fansirakouro and at Siguidolo.

We note that the village well ("Puits Villagois" or "Well Village") has a lower water table than wells in the ACN (Figure 40). The most critical parts of the year are not yet recorded and we do not know the level of water in the village well prior to June 2006. It may have been "dry" or perhaps that was the first date of measurement. Well measurements so far are quite interesting and document the status of this critically important resource for both seasonal and long-term trends of drinking water supplies.

Wells were also monitored in the village of Siguidolo, much farther north and in a much drier environment, but where ACN had been installed for some 13 years and where the village now has approximately 80 to 90 percent of the land under ACN. The legend in Figure 41 reads, in English, from top to bottom:

1. Village Well,
2. Well near Mosque,
3. Well outside Siguidolo,
4. Bouba Togola's vegetable garden well (former ACN site),
5. Moussa Djan's family well,
6. Well no. 1 in the Main garden,
7. Moussa Djan's vegetable garden well,
8. Well no. 2 in the community garden,
9. Well no. 3 in the community garden, and
10. Well just west of the community garden.

The data record for these wells is much longer than that of Fansirakouro and is beginning to tell an interesting story, and possibly one of decreasing water levels. Though this might be expected since it occurred during the dry season, it is interesting to note that the well water levels began a sharp increase in late June 2007 and at the second sampling during the dry season the water levels were much higher. What is also interesting is the great variation in water table over relatively short distances in Siguidolo. This likely suggests considerable variability in the aquifer and may suggest, to those experienced in ground water hydrology, other implications.

Conclusions

From the results of soil moisture data obtained at Siguidolo, it can be concluded that soil conservation practices affect many aspects of the water cycle. As well as reducing soil erosion, proper soil management such as *aménagement en courbes de niveau* (ACN) can increase soil moisture reserves by capturing rainfall and transporting it into deeper soil depths where it can be stored or further moved through the soil profile to recharge groundwater. It was evident that at the 20–40 cm depth of the profiles the soil water content was probably near field capacity (Figure 41) and even exceeded it at 30 cm below the ACN plots early in the cropping season. In contrast, the 'no ACN' treatments did not exhibit any increased moisture at the 20–40 cm depth that was observed in the ACN treatment. Compared with the remainder of the soil profile, most of the soil moisture was stored at the 20–40 cm depth in July during the early stages of the rainy season. The higher clay content of the soil layer in the lower horizons notably retained more water throughout the season and even into the post season. In Siguidolo, many crops are planted most years in the early part of June. Farmers prefer to plant as soon as possible at the onset of the rainy season. Farmers report that with ACN management, earlier planting is possible (Roncoli, 2002, personal communication). Local cultivars of sorghum and millet are photoperiod-sensitive, which means that the plants grow and accumulate photosynthate until the day length is sufficiently short as to trigger reproductive growth. Consequently, with photo period-sensitive cultivars, early planting directly translates into increased biomass and thus the greater yields with ACN are to be expected.

The ACN practices clearly led to increased water storage in the soil profile. One reason for increased infiltration is the greater retention of rainfall on the soil surface over a longer period of time. The increased rates of infiltration in fields where ACN was practiced suggest a reduction in runoff from the surface of the field and deep percolation of water into the soil, both of which were anticipated. Reduced runoff and greater infiltration have several implications: 1) reduced soil surface erosion; 2) reduced downstream flooding from runoff; 3) improved growth of deep-rooted crops such as tree species (shea butter trees) and shrubs as they take advantage of the extra reserves of deep moisture; and 4) improved availability of drinking water supplies and water for irrigation in the off-season for village residents (Siguidolo villagers, 2006, personal communication). It is likely that the higher yields reported from village production systems can be attributed to the additional rainwater captured and the subsequent increase in available soil water stored during the growing season with implementation of the ACN system. The frequently observed greater yield, however, may be due simply to the earlier planting of a photoperiod-sensitive crop, made possible by more efficient capture and harvest of the earliest rains. These results point out the need to evaluate the larger scale effects of ACN when several farms or villages together place their land under ACN. Such effects may explain the anecdotal effects offered by farmers of increased groundwater supplies, reduced flood frequency, and reduced flood damage, which occur at the watershed scale.

Impact of C-4-T on Millet Yield and Soil Carbon

An experiment was designed and implemented to evaluate the impact of selected management practices on soil carbon and crop yields. These management practices, referred to as C-4-technologies (C-4-T), include: ACN, NuMaSS, reduced tillage and residues management in a 2x2x2x2 factorial experiment. This experiment of 16 treatments were implemented in a single replication, on-farm at Fansirakoro, Konobougou and Oumarbougou. The same experiment was replicated three times at the Sotuba research station. Data collected were those for the fifth year of implementation on the same plots. The crop was millet this project year. Plant growth and yield were recorded. Soil samples were collected for laboratory analyses, for the C (Walkey-Black) method. As previously documented (Gigou *et al*., 1997; Gigou *et al*., 2006), there were significant effects of both ACN and fertilizer application. In fact, cultivating on ACNs has significantly increased

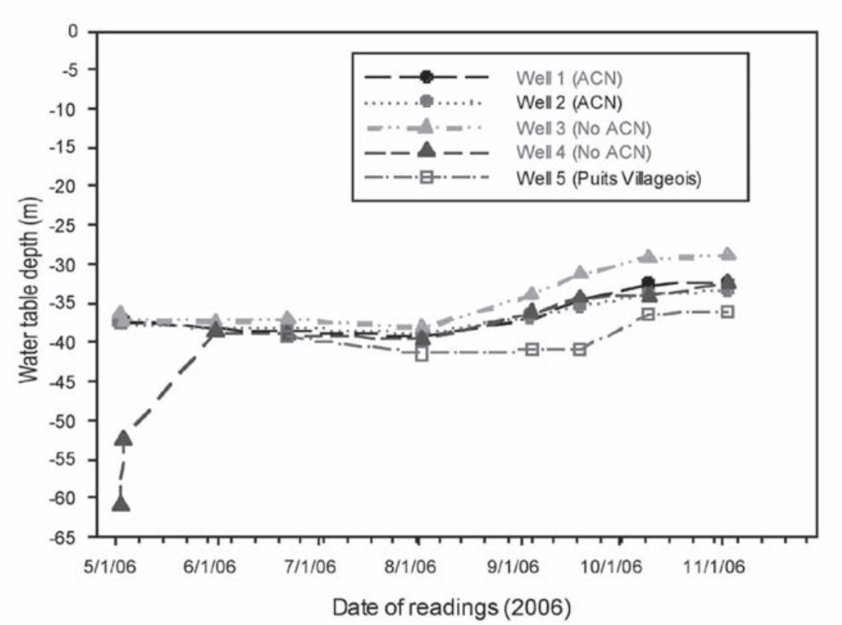


Figure 40. Well water depth 2006, Drissa Traore's field (4 wells) and one village well ('Puits Vilageois'), Fansirakouro, Mali.

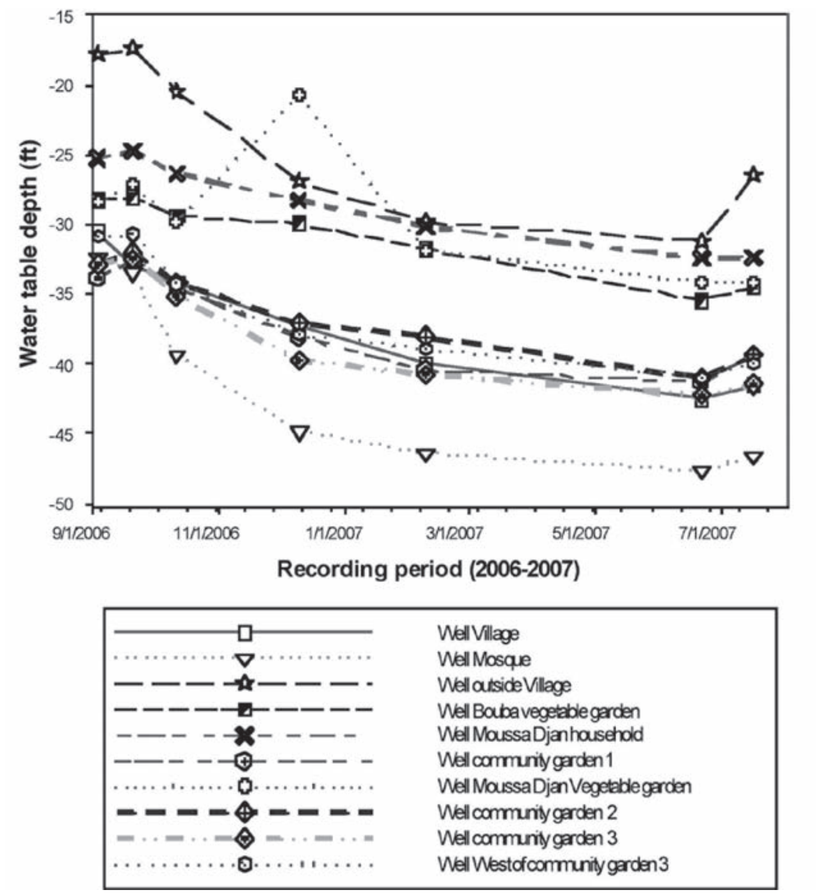


Figure 41. Decrease in water level in wells at Siguidolo during the 2006 and early 2007 dry seasons. Rains typically begin in late June and July. This seems to be apparent in the sharp upturn in the water table in early July.

grain yield by 53 percent. Gigou *et al*. (2006) reported yield and average increases of 30 percent. Applying N and P according to NuMaSS has provided 44 percent more millet grain yield than the check (Table 37).

The interaction effect between ACNs and NuMaSS provided a 72 percent yield increase over check, which is far above the 50 percent reported by Gigou *et al*. (2006). The increase may be attributed to the relatively low yield results reported in 2006 (*see* Carbon Sequestration in *SM CRSP Annual Progress Report, 2005 - 2006)*. Using NuMaSS fertilizer recommendations on the "poor soils" and with better water conservation with ACN and the use of crop residues, crop yields improved. Leaving crop residues on the field has increased grain yield (22 percent) for the first time during combined five years of experimentation. This treatment had failed to do so before because only eight crop residues were cultivated within the soil at the onset of the rainy season (left over after grazing by livestock). Collaborating farmers, however, reported that the residue issue is critical because they have other uses for it (construction material, potash for cooking, forage, etc.). In addition, they say, keeping residues on the field may reduce germination, favor termite attacks on seedlings and wound 'bare foot' workers. Combining ACNs, NuMaSS and crop residues increased yield by 75 percent.

Cultivating in ACNs and using fertilizer applications recommended by NuMaSS has increased (over a period of five years continuous cotton/cereal rotation) soil C by 35 and 32 percent, respectively (Table 37). Increased biomass production by these technologies may have contributed to 'sequestering' more C into these soils.

ACN in Senegal

The ACN technology, developed in Mali where crop planting takes place on ridges continues to be adapted to the flat-planted peanut cropping systems of Senegal. Methods of measuring and quantifying soil C developed in Mali are being tested in Senegal. Soil analyses performed in 2006 indicated an increase in soil organic C associated with ACN, with some increases reaching 14 percent greater soil organic C where ACN was implemented. Post-graduate student R. Bayala from the University of Cote D'Ivoire continues this work.

The ACN technology has been adapted to the flat-planted peanut production systems of Senegal and The Gambia. In this system, in contrast to the Malian system, the peanut is planted on the contour as defined and outlined by the 'ados' (permanent ridges). In 2003 the adapted technology was applied on eight peanut farmers in Southern Senegal. Yields tend to be greater on ACN than on no-ACN. Soils in the ACN and no ACN were sampled in 2004 and 2006. The results of the 2006 analyses indicate a significant increase in soil organic carbon occurred. The amount of the increase appears relatively small, but ranges as high as 14 percent on certain farms (Table 38). These results replicate increases in soil organic C observed in earlier studies and measurements in Mali (Doumbia *et al.,* 2007).

ACN in The Gambia

Field studies of ACN used in The Gambia have resulted in contradictory results that dramatically differ from previous results. Soil organic C increased where ACN was applied for several years. However, recent results do not confirm these results. It is unclear what

Table 37. Impacts of C-4-T on millet yield and soil carbon in Fansirakoro, Sotuba, Konobougou and Oumarbougou.

Technologies	Treatments	Millet yield (kg/ha)	C in soil (%)
ACN	Check	772 b	0.20 b
ACN	1182 a	0.27 a	
Fertilizer	Check	774 b	0.19 b
NuMaSS	1116 a	0.25 a	
Residue Management	Left	1327 a	0.31 a
Removal	1084 b	0.23 a	
Tillage	Full tillage	1208 a	0.24a
	Reduced tillage	1187a	0.27a
	CV(%)	43	19

Table 38. The effects of ACN technology on soil organic carbon on peanut production systems in Southern Senegal. Measurements taken three years after implementation. Measured in November 2006.

Farmer	no ACN - - % C - -	ACN - - % C - -	
A.C. Toure	0.360 q	0.411	
A.N.Diaye	0.329	0.349	
C. Ba	0.294	0.264	
I. Diane	0.296	0.314	
C.H.Kane	0.365	0.389	
O. Kane	0.292	0.283	
M. Diabo	0.298	0.329	
Overall	0.321(n=183)	0.339(n=133)	(P=0.01)

is the reason for the reversal. A short term study by Mr. Ansumana Jarju at the University of Hawaii was made possible with NARI (National Agricultural Research Institute, The Gambia) funds. The results of the short term study are still in the process of documentation. One important result, however, was that a variant of the Mali version of the water and soil conservation treatment (ACN) was proposed and will be tested this year in The Gambia.

Virginia Tech (Sub-contract)

Analysis of the Diviner data from 2003 to 2006 shows that there was an approximately 280 percent increase in deep drainage predicted from field-based water balance calculations. These results provide a quantitative basis for the frequently observed improved water status of drinking water wells where ACN has been implemented and the greater availability of water both for drinking and possible off-season irrigation.

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)

Carbon Sequestration and Farm Income: Identifying Best Management Practices for Smallholder Agricultural Systems in Northern Ghana

This study evaluated different crop management strategies both by their capacity to sequester carbon in agricultural soils and by their contribution to household income. A case study in Wa, Upper West Region of Ghana was used to test 48 different cropping strategies by means of the DSSAT-CENTURY crop simulation model and a household-level multiple-criteria optimisation model. Each cropping strategy was evaluated after a 20-year simulation period by its capacity to accrue carbon in the soil, by its economic performance at the plot level, and by its contribution to the farm income with and without carbon payments. A set of best management practices that concomitantly increase soil carbon and farm income are identified and classified by their cost of investment.

Figure 42 shows a comparison of the economics of each management strategy evaluated, relative to baseline conditions. In general terms, as the management was intensified with higher levels of fertilizer and pesticide applied to the crops and higher proportion of residue returned to the soil, the levels of soil organic carbon increased while concomitantly yielding higher economic returns than the baseline levels, even in the absence of carbon payments. Furthermore, when payments for carbon sequestration were included in the simulations, the contribution of carbon to household income was significant and a set of best management practices was identified. However, those management practices that generated higher profits are not prevalent among the farmers suggesting the existence of entry barriers due to the higher costs of the inputs and the intensity of management. Financial entry barriers to diversification and adoption of farming technologies is a well described phenomena across Africa limiting the capacity of the poor to be involved in certain activities. In that context, it is evident that the adoption of a single pro-carbon strategy by a whole farming community might be difficult, since the financial capacity to meet the investment cost of new practices varies from farmer to farmer. Gonzalez-Estrada (*submitted*) describes this study in more detail and discusses additional considerations relative to their adoption by farmers.

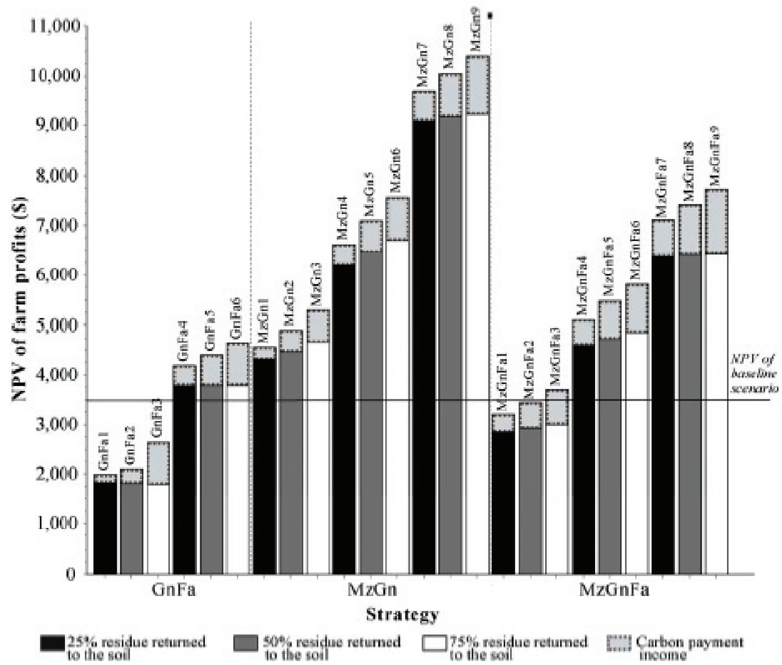


Figure 42. Net present value of farm profits showing the contribution of carbon payments for each management strategy in the Wa, Ghana region over a 20-year period. Gn, Fa and Mz are for groundnut, fallow and maize, respectively (Gonzalez-Estrada *et al*., *submitted*).

Scale-up Predictions of Soil C Changes over Large Areas

The objective of this study was to estimate aggregate regional soil carbon sequestration potential for areas with predominant smallholders' cropping systems in northern Ghana using DSSAT-CENTURY cropping systems model and scenario analyses. This is a summary of the study by J. Koo (2007). Scenarios describing the adoption of various management practices were defined and used to simulate cropping systems for estimating soil carbon sequestration potential relative to that of the "business as usual" cropping systems determined in this project. Although yield changes were also simulated in this study, only results of soil C changes, aggregated over the area annually during a 20-year period, are summarized here.

Simulations were made for the 132 fields managed by smallholder farmers in the Wa, Ghana area. Field data were collected from each of these fields in 2004 and 2006 as reported earlier. We assumed that the area of each field was 1 ha, which was the average field area in this region (Braimoh and Vlek, 2004). The majority of soils are classified as Alfisols (J.B. Naab, Savannah Agricultural Research Institute, personal communication, August 2006). The DSSAT-CENTURY model was used to simulate crop yield and SOC dynamics under several different management scenarios and these were evaluated relative to their potential for sequestering SOC. Each scenario was simulated for 20 years of weather data for Wa generated using the WeatherMan software in DSSAT. Initial soil C for each field was set to values measured in 2006. The simulation time period was 20 years; 2006 was the initial year.

For each of 132 fields, a soil profile was generated using the *SBuild* program based on the soil organic carbon and soil texture measured at 20 cm depth in 2006. Each soil profile included estimated soil properties related to water holding characteristics (e.g., lower limit, drained upper limit, saturated upper limit, and saturated hydraulic conductivity), root growth factor, bulk density, and soil pH in each of seven soil layers to 1 m depth. Initial pool fractions of SOC were based on results from Bostick *et al*. (2006).

Five scenarios were studied containing different management practices that potentially influence crop growth and soil carbon dynamics (e.g., tillage, fertilization, and residue removal). First, the business-as-usual (BAU) scenario was implemented to

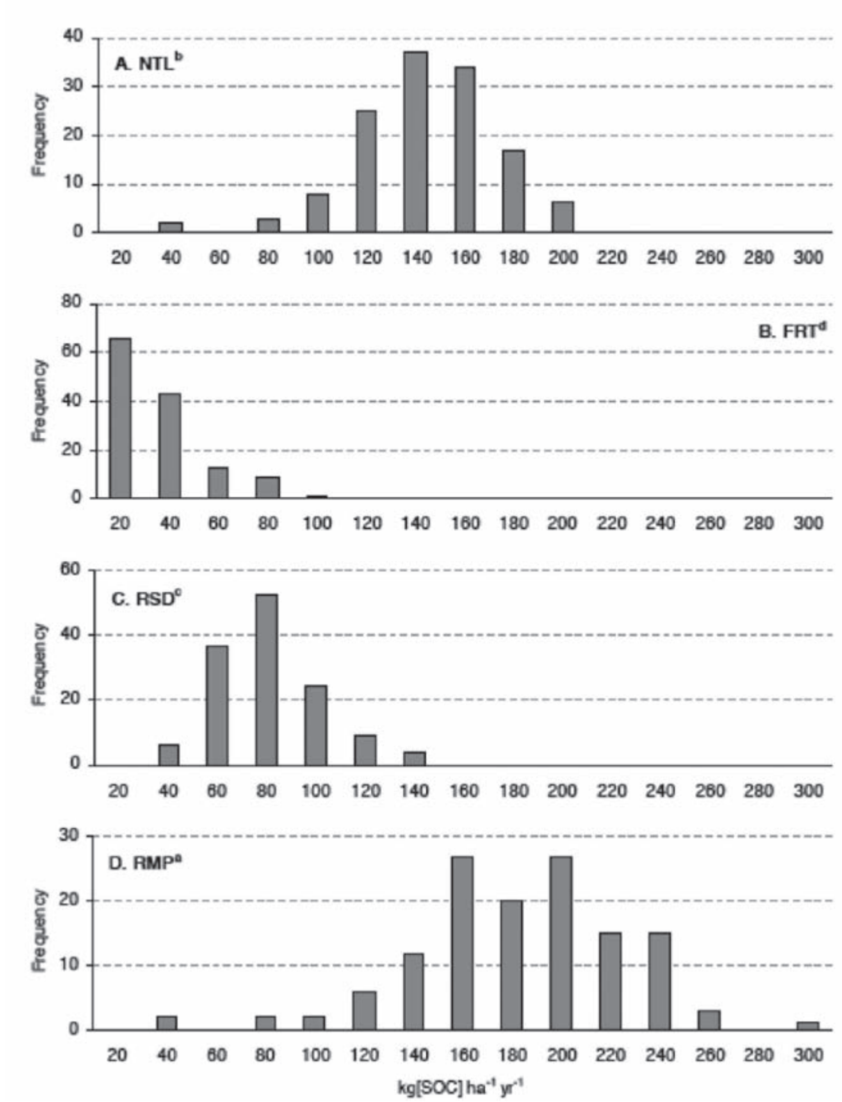


Figure 43. Histogram of simulated soil carbon sequestration rates in 132 farmers' fields in Wa, Ghana, for each management scenario relative to BAU (J. Koo, 2007).

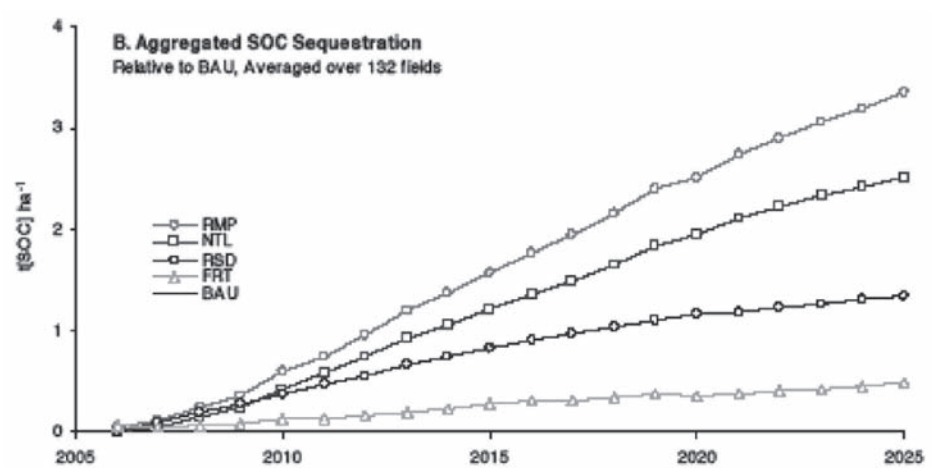


Figure 44. Simulated soil carbon sequestration relative to BAU, aggregated over 132 farmers' fields in the study area in Wa, Ghana, for 20 years (J. Koo, 2007).

reflect farmers' current field management practices, including tilling the field before planting with hand-hoes to a soil depth of 20 cm, no fertilization, and removal of most crop residues after harvest (see Table 39 for a summary of those practices in each of five scenarios).

For each management scenario, a cropping sequence was created in each field and for each year of the simulation time period. A one-step transition probability matrix of crop types was calculated from the surveyed cropping history and used to stochastically create cropping sequences for all fields using the Markov Chain Monte Carlo (MCMC) method. This stochastic method was used to mimic the spontaneous nature of smallholder farmers' crop selection in each season. Values in the transition probability matrix represent the probability that a particular crop in the sequence (in columns) follows a particular crop that is found in a field (in rows). The yearly soil carbon sequestration rate for each scenario in each field was calculated relative to soil carbon changes under the BAU scenario.

Because of the variability among the 132 fields in terms of soil properties, initial conditions, and management sequencies, not all fields performed at the same level for a given scenario. For example, some fields that were not tilled sequestered about 200 kg/ha/yr (Figure 43), but average annual rate across all fields was about 140 kg/ha/yr. The scenario that resulted in the highest C sequestration rate (about 175 kg C/ha/ yr) was the RMP strategy that combined small amounts of fertilizer with no-till.

Figure 44 shows cumulative, aggregate soil C sequestration over the 20-year period. These results highlight the importance of spatial variability in determining the potential sequestration rate; not all fields can perform at a maximum rate.

Objective 2. Apply Methods to Assess the Potential for Soil C Sequestration for Selected Sites in South Asia (Cornell)

Objective 2, Output 1: Modeling of SOC Dynamics and Stocks

Long-term Soil Fertility Experiments

After much effort we abandoned the CENTURY model because of its inability to simulate observed results from the long-term soil fertility experiment (LTFE) at Bhairahawa, its requirement for a large number of input parameters, and because we really do not need a crop growth model for agricultural soils where we already have crop productivity information. The RothC model is also unsatisfactory as its prediction of very long time periods for soil C to reach equilibrium in the sub-tropical environment seems unreasonable, the input of important parameters is not explicit, and it does not include tillage as a variable affecting SOC content. Overall, we felt that CENTURY predicted C trajectories better than RothC, but RothC did better at predicting actual SOC stocks. Because of these limitations to the two

Table 39. Summary of production practices used for the different management scenario simulations (J. Koo, 2007).

Scenario (Abbreviation)	Tillage	Fertilization	Residue Removal: Cereals	Residue Removal: Legumes	Residue Removal: Bush Fallow[1]
Business-As-Usual (BAU)	Hand-hoeing at 20 cm	No fertilization	100%	75%	100%
No-Till (NTL)	No-Till	No fertilization	25%	25%	25%
Fertilization (FRT)	Hand-hoeing at 20 cm	Sorghum: 20 kg[N]/ha/yr Maize: 40 kg[N]/ha/yr Millet: 20 kg[N]/ha/yr Peanut: No fertilization Bush Fallow: No fertilization	100%	75%	100%
Leaving Residues (RSD)	Hand-hoeing at 20 cm	No fertilization	25%	25%	25%
Recommended Management Practice (RMP)	No-Till	Maize: 40 kg[N]/ha/yr Sorghum: 20 kg[N]/ha/yr Millet: 20 kg[N]/ha/yr Bush Fallow: No fertilization	25%	25%	25%

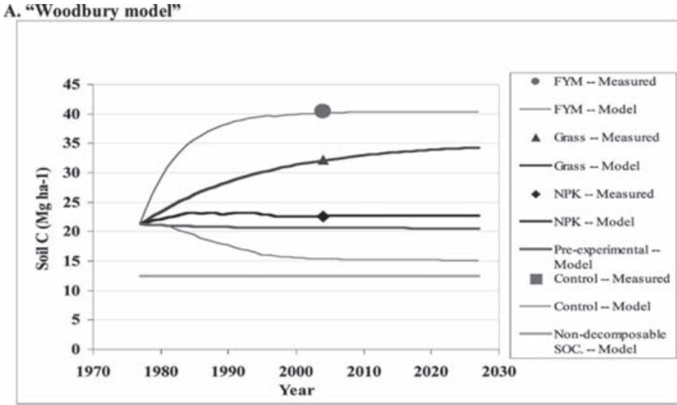
existing models, we (Peter Woodbury) developed a simple Excel spreadsheet-based C model utilizing much of the RothC approach and including tillage as a variable. The model uses the following six carbon pools:

1. Non-decomposable SOC (that is, SOC that will not decompose during the simulation period of 50 years).
2. Initial decomposable SOC present at the beginning of the simulation.
3. Root C inputs.
4. Top residues incorporated into soil.
5. Top residue placed on the soil surface.
6. Manure (subsequently referred to as FYM for farmyard manure).

The non-decomposable pool (equivalent to the inert pool in RothC and the passive pool in CENTURY) is not affected by the model. Root inputs for cereals are described as a function of grain yield and plateau at yields above 2-4 t/ha. For each of the other carbon pools, decomposition is modeled using a rate specific to the first year, and subsequently a first-order decay rate that applies to all other years. Tillage, soil texture and temperature are parameters that affect C decomposition rates of the decomposable C pools. The model allows up to five different crops and five different treatments for a single simulation. Each simulation is for 50 years. A comparison of the results of our model with RothC for the Bhairahawa LTFE is shown in Figure 45. This site was used for parametization of the Woodbury model. The main difference between the two models is in the pattern of SOC change over time, with the Woodbury model showing that equilibrium SOC stocks are reached within the 25 year experimental period, except for the grass fallow that was not part of the experiment. A similar result is obtained for the Parwanipur LTFE (Figure 46), with both models predicting the measured soil SOC levels reasonably well, but showing different SOC trajectories over time.

In contrast to model results for Parwanipur, neither the Woodbury nor Roth C models predicted measured SOC stocks well at the Tarahara site (Figure 47), with measured values being greater than modeled values for the Woodbury model and less than the modeled values with RothC.

A. “Woodbury model”



B. “RothC model”

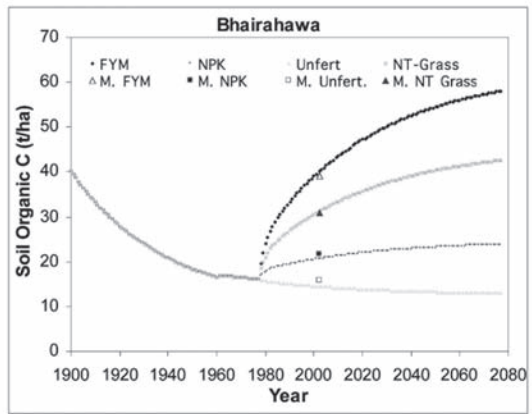
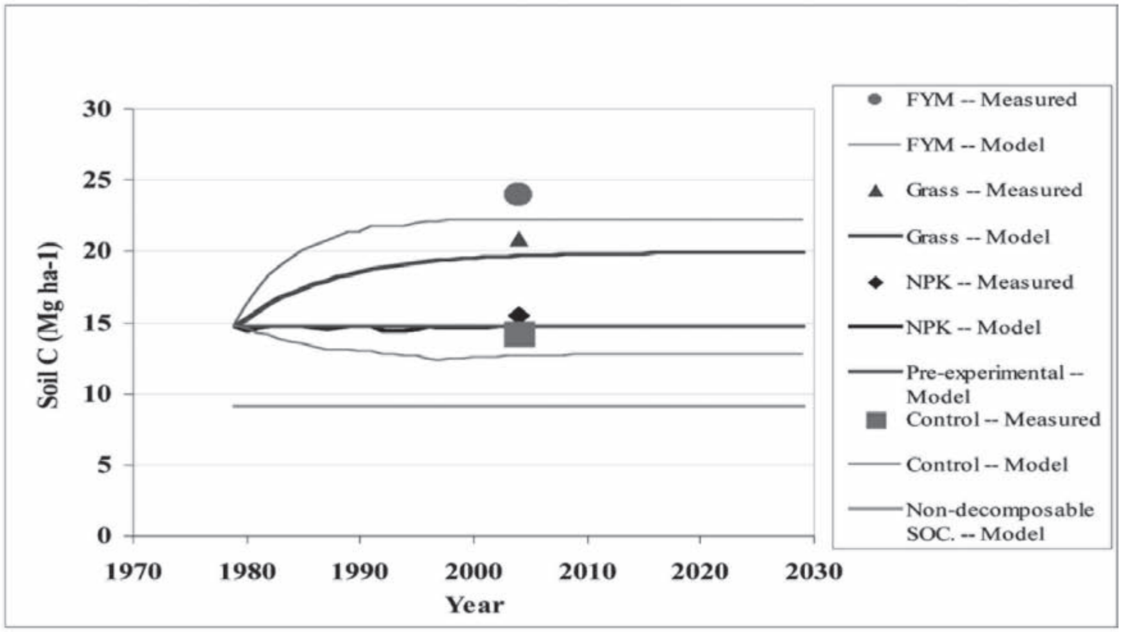


Figure 45. Comparison of Woodbury (A) and RothC (B) model results for C stocks in the 0-15 cm soil layer of the Bhairahawa LTFE.

However, the Woodbury model predicted treatment differences well (Figure 48), suggesting that the model is robust in this regard. This raises the question of whether the input value for the inert SOC pool is correct at Tarahara. The value of the inert SOC pool is based on the linear regression of regional texture and SOC data from farmer RW fields, (i.e., it is texture dependent and increases with increasing silt + clay content). A similar approach is also used in the CENTURY model. The Woodbury model would fit the data if the size of the inert SOC pool were increased by 5 Mg C/ha. This, however, would bring it to more than the value used for the finer textured soil at the Bhairahawa site. Another factor that could alter the size of the inert pool is the amount of charcoal in soil - this is relatively inert due to its structure, whereas “resistant” humic substances are so largely due to protective interactions within soil. We do not know whether or not there was a difference in clearing practice from the forest. Note that it can also be seen that the model

A. "Woodbury model"



B. "RothC model"

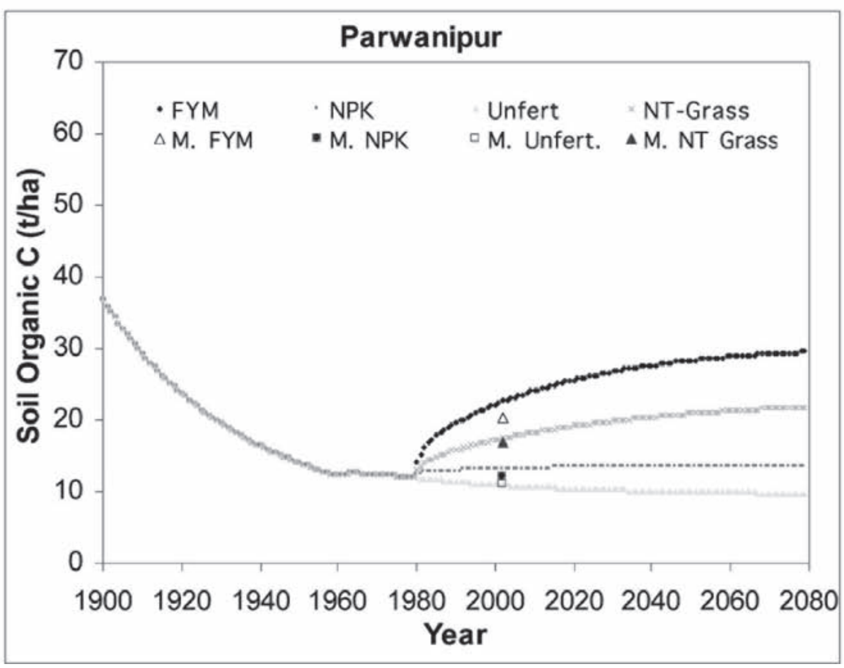
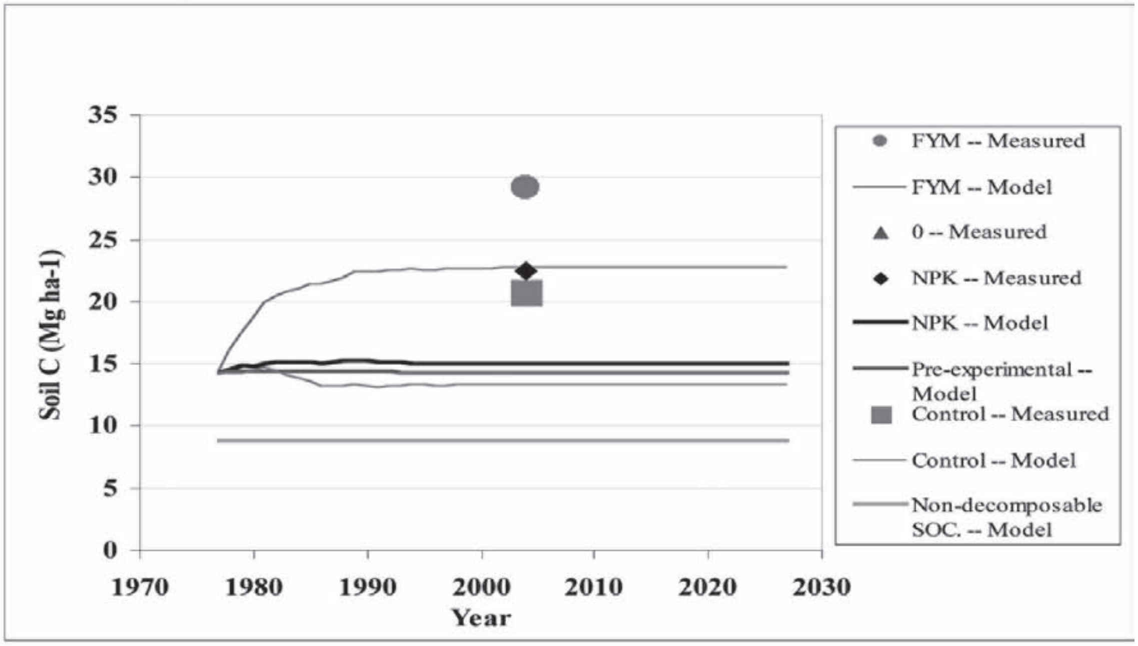


Figure 46. Comparison of Woodbury (A) and RothC (B) model results for C stocks in the 0-15 cm soil layer of the Parwanipur LTFE.

A. "Woodbury model"



B. "RothC model"

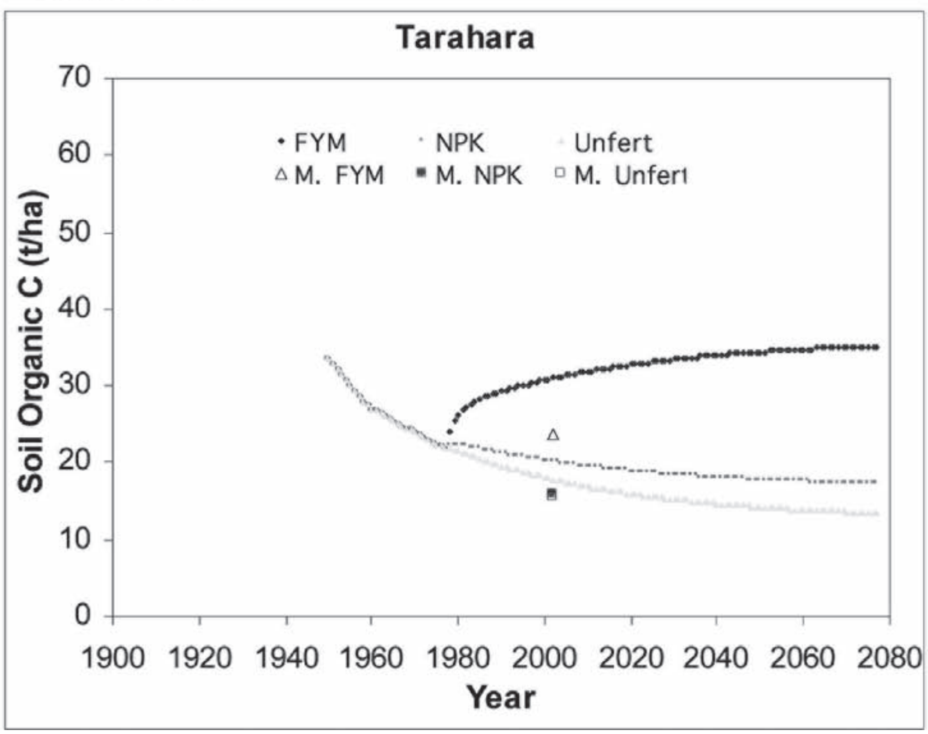


Figure 47. Comparison of Woodbury (A) and RothC (B) model results for C stocks in the 0-15 cm soil layer of the Tarahara LTFE.

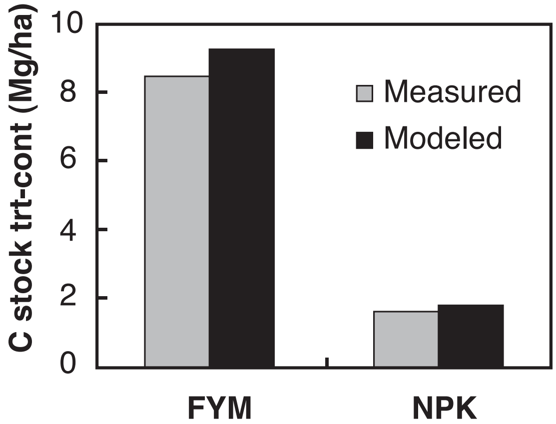


Figure 48. Comparison of measured and modeled differences in SOC stock (0-20 cm) between control and nutrient input treatments.

fit to data at Parwanipur would be improved by a small increase in the size of the inert SOC pool. We will attempt to measure charcoal content in soils of the three LTFE experiments although, unfortunately there are not good methods for doing so.

It is also possible that differences in charcoal content contribute to the variability in SOC stocks in both forest and farmer RW sites. In the latter case, farm households mostly use manure and/or wood as cooking fuel and ash is returned to the compost pit, which eventually is returned to fields. It is very likely that charcoal is included in the compost because of the inefficient design of local clay cooking stoves.

Predicting C Gains with SOC Sequestration Management Practices

The Woodbury model is now being applied to the various data sets we have generated for the different C sequestration practices (Table 33). The objective of this work, which will be largely accomplished under the no-cost extension, is to predict timelines of SOC sequestration and final equilibrium SOC stocks for each of these practices. The models will then be coupled with GIS databases on current SOC levels and soil texture to refine our earlier predictions of C sequestration potential following adoption of various practices. Our ultimate output will be scenario maps for Rupandehi district in the Nepal terai where we have the most reliable and detailed information and for the country of Bangladesh, representing a large scaling up example.

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, John Duxbury, Cornell University

Summary

Field studies have been carried out for four consecutive years (2004-2007) in New York (corn) and China (rice) and two consecutive years (2004-2005) in Colombia (cotton). Project activities in Colombia ended in 2006, when Dr. Barrios and his team departed from CIAT. Soil samples were collected at planting, anthesis and harvest in the corn trial and at the seedling, heading and physiological maturity stages in rice. A three-year litterbag study was initiated with corn and rice residue at each field-site. Litterbags were retrieved from the field at physiological maturity every growing season for each crop. DNA was extracted from the corn litterbag samples and bacterial and fungal residue colonizers analyzed by terminal restriction fragment length polymorphism (TRFLP) fingerprinting. Molecular methods used to analyze the community structure of arbuscular mycorrhizal fungi (AMF) reported in the literature did not provide either the coverage or specificity needed for our studies, so several primer sets were designed and tested. Of these, one primer pair, used in a nested PCR protocol with general fungal primers, was found to be sufficiently robust for use in the AMF biodiversity studies, and was used to assess the AMF community composition in samples from the Bt corn trials in New York. Glomalin, as an indicator of the abundance of AMF, was measured in rice soil samples. Chambers for $^{13}CO_2$ pulse-labeling of corn were constructed and a greenhouse trial conducted in which Bt (MON863) and non-Bt corn were grown with and without corn rootworm pressure and labeled with ^{13}C at various phenological stages. Our findings suggest that the two isolines differ in some growth characteristics (e.g., plant height), but not in their patterns of C accumulation or proportion of lignin C in the different plant parts. At Cornell University, doctoral candidate Kai Xue is conducting the corn litterbag study and $^{13}CO_2$ pulse-labeling work, while doctoral candidate Tarah Sullivan is analyzing microbial diversity in DNA extracted from rhizosphere samples from Bt and non-Bt cotton in Colombia. Graduate student and technical officer Luz Marina Londoño conducted research on AMF abundance and community structure and graduated in December 2006 with her MSc degree. At Zhejiang University in Hangzhou, China, doctoral candidate Liu Wei is conducting the C allocation and decomposition studies, while graduate student Hao Hao Lu is conducting the AMF studies.

Field Trials and Objectives

Corn – M. Devare, J.E. Thies, J. Duxbury, L. Allee, and J.E. Losey (Cornell Univ., USA).
Field trials were established at the Musgrave Research Farm in Aurora, NY, in May 2004, 2005 and 2006, but were not replanted in 2007. Treatments in the field trials were replicated three times in a randomized complete block design (RCBD): "YieldGard" (MON863) transgenic corn (Bt), which produces the Cry3Bb1 protein conferring resistance to the corn rootworm (CRW); and the non-Bt isoline with (non-Bt+I) and without (non-Bt) the pre-emergent insecticide tefluthrin applied at planting to control the CRW. These treatments were established in two fields with varying field histories: one was previously planted with continuous corn and the other with alfalfa. The former had preexisting rootworm pressure and the latter did not. Litterbags placed on the soil surface or buried at 10 cm depth were collected after 25 months in the field to assess litter decomposition rates.

Rice – W. Wu (Zhejiang University, Hangzhou, China)
Three replicates of KMD1 transgenic rice (Bt), which produces the Cry1Ab protein active against lepidopteran pests and two non-transgenic varieties (Xiushui 11 and Jiazao 935) were transplanted in a 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. The experiment was not replanted in 2007. 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 taken across a transect of each plot was collected at the seedling, booting, heading and maturing stages of the rice. Samples were immediately transported to the laboratory and processed

in less than 6 h after being removed 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 thoroughly prior to analysis.

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.

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 the extent of the symbiosis with arbuscular mycorrhizal fungi (AMF). AMF abundance was evaluated by counting spores extracted from soils sampled from corn and rice plots. Glomalin content in rice soils was also determined. AMF infectivity was assessed by measuring the extent of roots colonized by hyphae, arbuscules, and vesicles in corn. No AMF root colonization could be detected in rice roots at any of the tested stages of rice development in 2006. Diversity of bacteria and fungi colonizing rice residues and persisting in rice soil was also determined. Data from all trials indicate no adverse effects of the Bt genotype on AMF or residue-colonizing bacteria or fungi over the period of the experiments for either corn or rice.

Abundance of AMF – Spore Density, Root Colonization and Glomalin

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. 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 (Figures 49-51).

AMF Spore Density – Corn

Results from corn plots in NY indicate that there was no significant effect of corn genotype on counts of AMF spores in soil (Figure 49). There was a highly significant effect of sampling time ($p=<.0001$) and a significant effect of field history ($p= 0.006$).

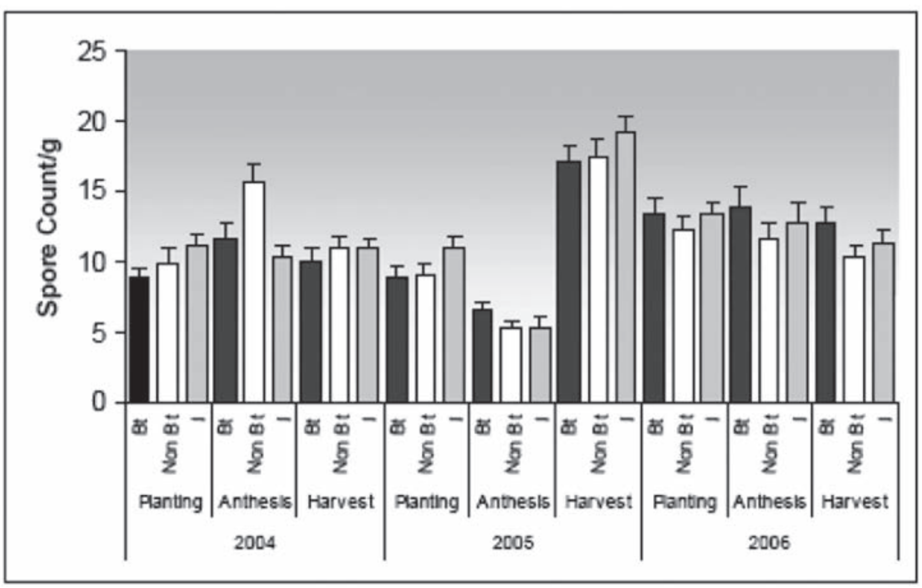


Figure 49. AMF spores per gram of soil at planting, anthesis, and harvest in Bt, non-Bt, and non-Bt+I corn plots over the 2004, 2005 and 2006 growing seasons in New York.

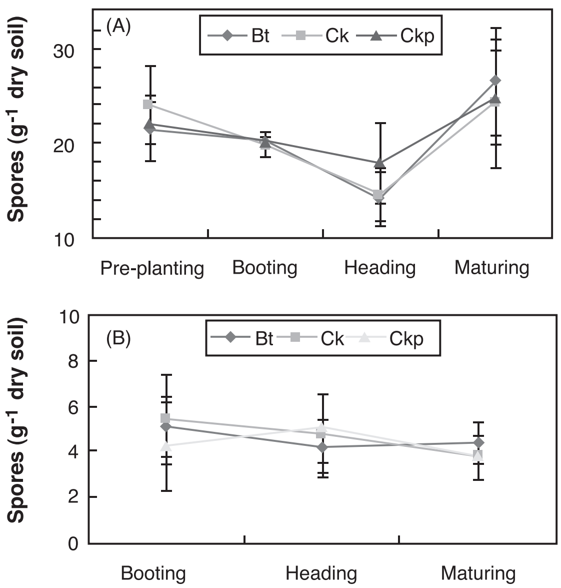


Figure 50. AMF spore density in Bt, non-Bt (Ck), and non-Bt+insecticide (Ckp) rice rhizospheres in (A) 2005 and (B) 2006 growing seasons (China). Error bars represent the standard deviation of the mean.

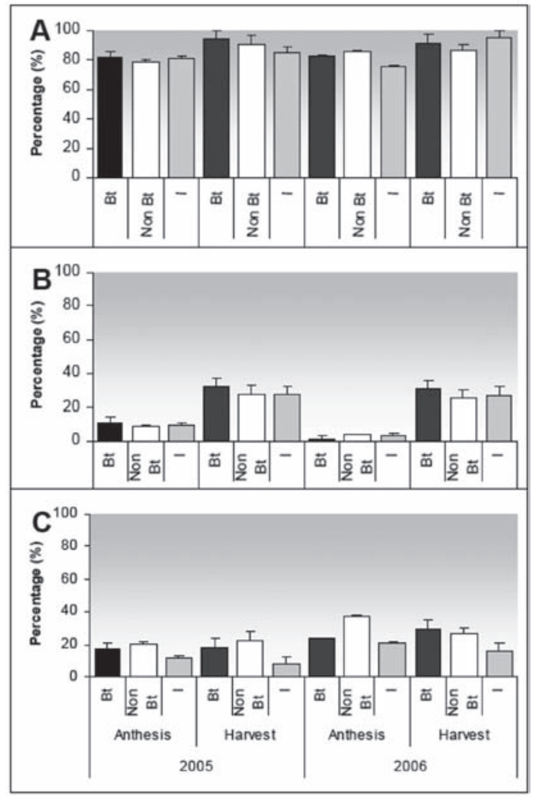


Figure 51. Extent of root colonization by: (A) AMF hyphae, (B), vesicles, and (C) and arbuscules in Bt, non-Bt, and non-Bt+I corn at anthesis and harvest in 2005 and 2006.

AMF Spore Density – Rice

The number of spores in rhizosphere soil varied over the course of rice development in 2005 in China (Figure 50A), and to a lesser extent in 2006 (Figure 50B). However, there were no significant differences between rice treatments in the number of spores per gram of rice rhizosphere soil.

AMF Root Colonization – Corn

Corn root colonization by AMF was determined by measuring the percent of corn roots containing hyphae, vesicles, and arbuscules (Figure 51).

There were no significant differences in corn root colonization by AMF hyphae between genotype treatments, field histories, or years, but hyphal colonization of corn roots did differ significantly between sampling times within each year ($p<0.0001$; Figure 51A). AMF vesicle colonization differed significantly within ($p<0.0001$) and between years ($p<0.002$), but not between genotype treatments or field histories (Figure 51B). Arbuscule colonization differed significantly between years ($p<0.0003$) but not within years, Arbuscule colonization also differed between treatments ($p=0.0005$), where the percent of roots containing arbuscules was significantly lower in the non-Bt+I treatment as compared to the Bt and non-Bt treatments (Figure 51C).

AMF Root Colonization – Rice

AMF colonization was only observed at harvest in 2005, but the extent was low. There was no significant effect of rice genotype on percent root length colonized by AMF. No AMF colonization was observed in rice roots in 2006.

Glomalin – Corn

Glomalin is a purported biochemical surrogate for AMF abundance (Wright and Upadhyaya, 1996). One pool, “easily extractable glomalin” (EEG), quantified using the Bradford total protein assay (Bradford, 1976; Wright and Upadhyaya 1996), was tested and applied to soil samples from corn and rice plots in New York and China in 2005 and in the China trials only in 2006. EEG varied by crop

Table 40. Glomeromycete species identified in soil and root samples at anthesis and harvest, 2005, in corn trials in New York.

	Sampling Time	
Sample	**Anthesis**	**Harvest**
Soil	*Glomus claroideum*	*Paraglomus occultum*
	Glomus intraradices	*Glomus mosseae*
	Glomus mosseae	
Root	*Glomus microaggregatum*	*Glomus intraradices*
	Glomus deserticola	*Glomus manihotis*

growth stage in corn and rice, and was significantly reduced by insecticide applied in corn in 2005, but not affected by genotype in either trial.

The variability in glomalin measurements made by this method is high, and recent findings in the Thies Laboratory (Clune, 2007, MSc thesis, Cornell University) suggest that the method is not specific for glomalin, but also extracts other proteins from soil. We considered developing an ELISA protocol, which may have allowed a quantitative but less variable means to determine glomalin concentrations in soil, but the high cost and time involved and ambiguity of the data did not justify continuing with these measurements.

Glomalin – Rice

There were no significant differences due to rice genotype in glomalin extracted from rice soils in China (Figure 52). However, glomalin content varied significantly between sampling times in 2005, and between years.

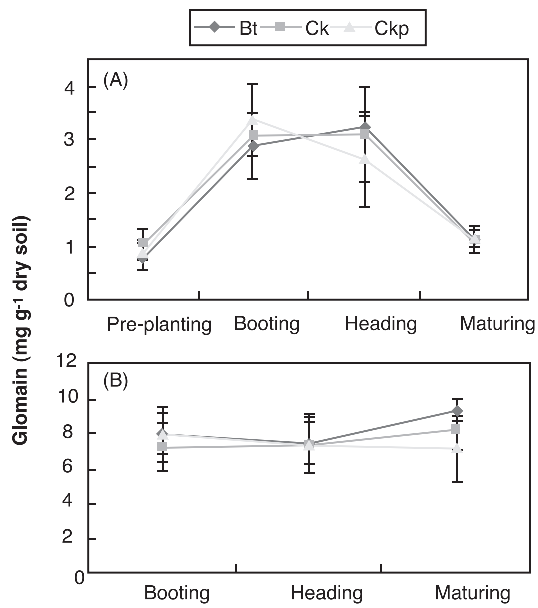


Figure 52. Easily extractable glomalin (mg g-1) in soil from Bt, non-Bt (Ck), and non-Bt+I (Ckp) rice soil in (A) 2005 and (B) 2006 (China).

AMF Community Structure

Almost all primers tested for use in evaluating AMF diversity published in the literature lacked specificity and/or excluded important AM fungal genera from the analysis. The primer pair developed by Van Tuinen *et al*. (1998), FLR3-FLR4, proved to be the most specific, gave good results and was used to analyze soils sampled from corn trials and DNA extracted from spores.

DNA from soil samples collected in the Colombia cotton experiments has been extracted and is being analyzed in the Thies Laboratory.

Corn

Cloning and sequencing of DNA from soils and roots yielded sequences mostly confined to the genera *Glomus* and *Paraglomus* in the division Glomeromycota (Table 40). No selection for particular genera was observed between the corn genotypes

Rice

Low spore density in Bt, non-Bt, and non-Bt+I rice plots precluded the extraction of DNA and application of molecular techniques to analyze AMF community structure in China.

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 time-point. 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.

Detritivore Arthropod Abundance and Community Structure

Corn

Corn litterbag residues were retrieved from the field at harvest in 2006 to determine detritivore arthropod abundance and community structure. Detritivore arthropods on corn residues are still being enumerated and identified in the Peck Laboratory at the Cornell University Geneva Research Station, Geneva, NY.

Rice

Detritivore arthropod populations in rice litterbags that were in the field for almost 24 months were determined according to the Berlese funnel method at harvest in 2006 (Tables 41 and 42). Detritivore arthropod populations differed significantly in litterbags, which were at the soil surface and those that had been buried ($p<0.05$). However GLM (General Linear Model) analysis showed that there were no significant differences between Bt and non-Bt rice. The data suggest that the detritivore arthropod community is both less abundant and less diverse in rice residue samples placed at depth in the field compared to those that are retrieved from the surface. Straw vs. root residue did not appear to cause differences in either abundance or community structure of detritivore arthropods.

Table 41. The abundance and community structure of detritivore arthropod populations on Bt and non-Bt (Ck) rice straw (S) and roots (R), left on the surface (S) or buried (U; shaded). * Ck: non-Bt parental rice variety; Ck 1-S-S-1: non-Bt rice straw litterbag sample placed on the surface of #1 field plot.

Treatment*	Bdellidae Bdella	*Poduridae podura*	Amphientomidae
Bt 1-S-R-1			
Bt 1-S-R-2			
Bt 2-S-R-1		3	
Bt 2-S-R-2			
Bt 3-S-R-1			
Bt 3-S-R-2			
Ck 1-S-R-1		1	
Ck 1-S-R-2	2	1	1
Ck 2-S-R-1	6		
Ck 2-S-R-2	7	6	2
Ck 3-S-R-1			
Ck 3-S-R-2			
Bt 1-U-R-1			
Bt 1-U-R-2			
Bt 2-U-R-1		2	
Bt 2-U-R-2		1	
Bt 3-U-R-1			
Bt 3-U-R-2			
Ck 1-U-R-1			
Ck 1-U-R-2			
Ck 2-U-R-1		2	
Ck 2-U-R-2		2	
Ck 3-U-R-1			
Ck 3-U-R-2			
Bt 1-S-S-1			
Bt 1-S-S-2		1	3
Bt 2-S-S-1			
Bt 2-S-S-2			
Bt 3-S-S-1			
Bt 3-S-S-2	1	6	
Ck 1-S-S-1			2
Ck 1-S-S-2			
Ck 2-S-S-1			
Ck 2-S-S-2	2	9	
Ck 3-S-S-1			
Ck 3-S-S-2	1	2	1
Bt 1-U-S-1			
Bt 1-U-S-2			
Bt 2-U-S-1			
Bt 2-U-S-2			
Bt 3-U-S-1			
Bt 3-U-S-2	1	2	1
Ck 1-U-S-1			
Ck 1-U-S-2			
Ck 2-U-S-1			
Ck 2-U-S-2	1	4	
Ck 3-U-S-1			
Ck 3-U-S-2.			

Table 42. Detritivore arthropod population analysis by rice genotype (Bt and non-Bt), litterbag placement (surface or buried) and plant component (rice straw and roots), in 2005 and 2006.

Source	DF	F Value	P Value
Genotype	1	3.78	0.054
Placement	1	6.61	0.011
Plant component	1	0.00	0.950

Community Structure of Bacteria and Fungi Colonizing Corn Residues

Corn

Fungal and bacterial community DNA was amplified with fluorescently labeled primers to the internal transcribed spacer (ITS) and 16S rRNA genes, respectively. PCR products were digested in separate reactions using the restriction enzymes *Hha*I and *Msp*I for fungi, and *Hha*I and *Sau*96I for bacteria. Terminal restriction fragments were sized, and the resulting data analyzed by use of multivariate statistical approaches (Figure 53).

There was no detectable difference in either the bacterial or fungal (data not shown) communities colonizing residues from Bt, non-Bt or non-Bt+I corn plants. However, as the combined data for bacteria over two years shows, communities clearly separated between the two growing seasons, 2005 and 2006 (Figure 53). Within samples of each season, bacterial communities colonizing residues placed on the soil surface separated clearly from those colonizing residues placed at 10 cm depth. The location (cropping history of plots) also had a marked effect on communities, especially for bacterial communities colonizing buried residues in 2005 and surface-placed residues in 2006.

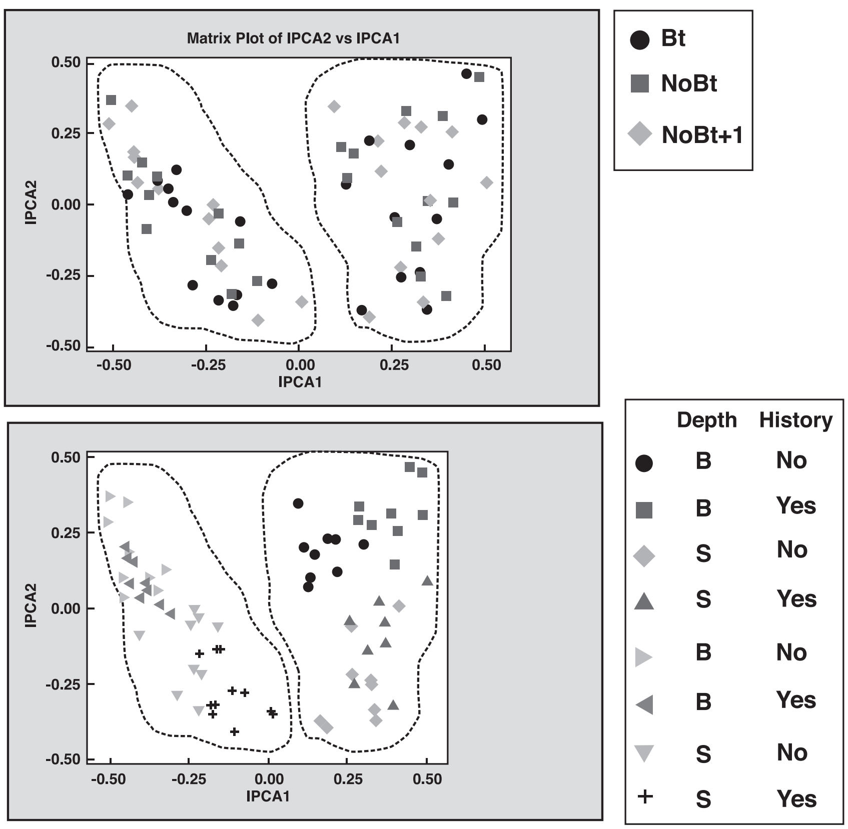


Figure 53. Additive Main effects and Multiplicative Interactions (AMMI) analysis to compare relative abundance of terminal restriction fragments (T-RFs) in soil from Bt, non-Bt, and non-Bt+I plots in 2005 and 2006 after digestion of bacterial PCR products with *Hha***I. Top:** samples do not separate by treatments; **bottom:** samples separate by year and placement. B=buried; S=surface; yes=with corn cropping history; no=without corn cropping history.

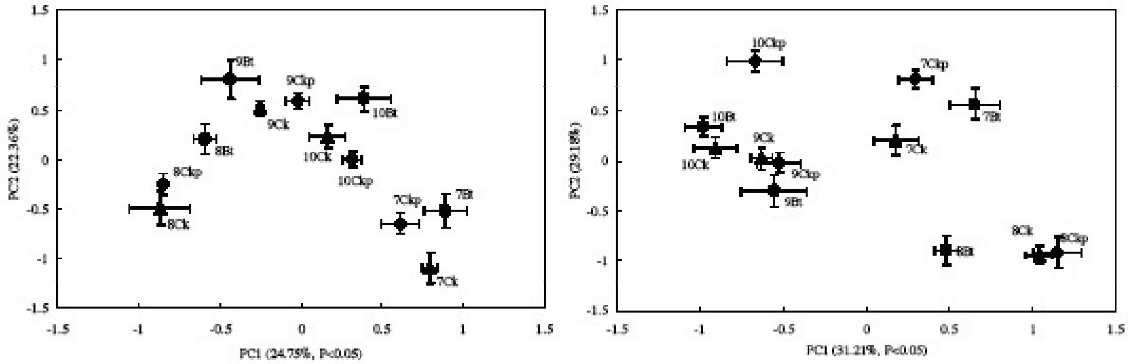


Figure 54. PCA analysis of T-RFLP patterns of bacterial 16S rRNA (left), and fungal ITS region gene fragments (right) amplified from DNA extracted from the rhizosphere soil of Bt, Ck and Ckp at different stages of rice development in the field in 2005. 7 = seedling; 8 = booting; 9 = heading; 10 = maturing. Each symbol indicates the average for three replicates of each treatment (n=3). The error bars represent the standard error of the means. The level of variation explained by each principal component is indicated in parentheses along the x and y axes. P values are indicated when there was a significant variety effect, as determined by ANOVA.

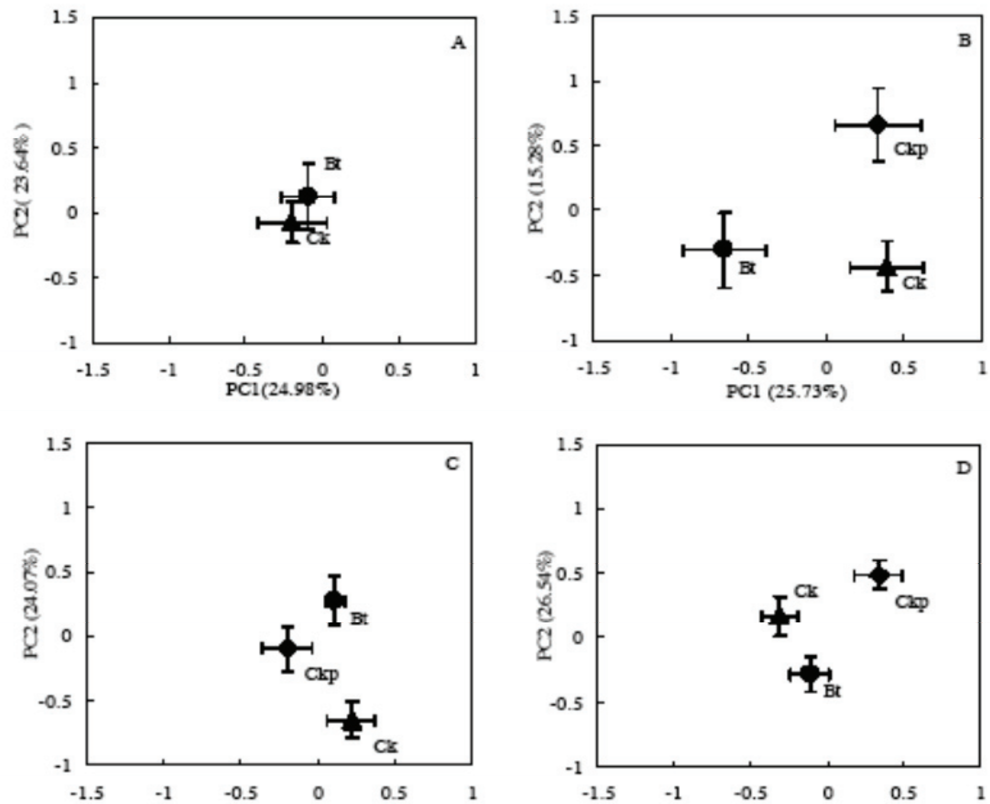


Figure 55. PCA analysis of T-RFLP patterns of ITS regions of fungi amplified from DNA extracted from rhizosphere soil of Bt, Ck (non-Bt) and Ckp (non-Bt) at different stages of rice development in the field, A: seedling; B: booting; C: heading; D: maturing. Each symbol indicates the average of three replicates of each treatment (n=3). The error bars indicate the standard error of the means. The level of variation explained by each principal component is indicated in parentheses along the x and y axes. P values are indicated when there was a significant variety effect, as determined by ANOVA.

Rice

Microbial community composition in rhizosphere soil samples of Bt, Ck (non-Bt) and Ckp (non-Bt+I) rice plants collected in 2005 were analyzed using principal component analysis (PCA) of T-RFLP fingerprints. The PCA analysis performed on the T-RFLP data revealed distinct temporal shifts in bacterial and fungal community composition in rhizosphere soils of Bt, Ck and Ckp rice plants over the rice development stages. This is reflected by the clockwise change in the bacterial and fungal communities in PCA plots according to sampling time (Figure 54). However, there were no statistically significant differences (P>0.05) in bacterial or fungal (Figure 55) community structure in the rhizosphere soil between Bt, Ck and Ckp rice plants at any sampling time, except for bacteria at the booting stage in 2005 (Figure 55). The bacterial community composition of non-Bt rice with triazophos applied was significantly different from samples of Ck and Bt rice along PC2 (Figure 55B).

The results indicate that there were strong seasonal changes in microbial community composition in the rhizosphere soil of all treatments. Some occasional and inconsistent effects of the application of triazophos on the bacterial composition in the rhizosphere soil of rice plants were detected as compared with that of Bt rice. In general, Bt rice had little effect on the dominant amplifiable rhizosphere bacterial and fungal communities in the field.

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

As reported in the 2005-06 progress report, $^{13}CO_2$ pulse-labeling experiments with Bt and non-Bt corn with and without corn rootworm pressure conducted in 2005-06 showed that at V7 (kneehigh), non-Bt corn allocated more ^{13}C into leaves and stalks than Bt corn. 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 compared to non-Bt plants. Non-Bt plants were taller than Bt plants. Rootworm pressure had an effect on both genotypes, causing an increase in plant height compared to controls without rootworms. In keeping with our findings on height differences between corn genotypes, the dry weight of non-Bt plant parts was higher than that of Bt plant parts. 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 the Bt and non-Bt genotypes was similar, except that Bt cobs accumulated more C than leaves, while the reverse was true for non-Bt corn. The findings on total C content may be summarized as follows:
Bt: Roots > Stalks > Cobs > Leaves > Husks
Non-Bt: Roots > Stalks > Leaves > Cobs > Husks

Lignin concentration and content in Bt and non-Bt corn plant parts did not vary significantly as measured by the acid detergent lignin method. Although lignin content in the plant parts was significantly different as follows: root lignin > cob > stalk > leaf > husk lignin.

In 2006 summer, a pre-experiment was conducted to test how different potting media affect the survival of corn rootworm larvae. A modified Cornell mix and a mixture of modified Cornell mix and top soil (1:2 v/v) were compared. The modified Cornell mix contains peat, vermiculite, and perlite (1:1:1 by vol.) with 6 g of pulverized limestone, 35 g of CaSO4, 42 g of powdered FeSO4, 1 g of fritted trace elements (Peters FTE 555, Scotts Co., Marysville OH), and 3 g of wetting agent (AquaGro G, Aquatrols, Pennauken, NJ). At the V10 stage (about 41 days after germination), 30 larvae were transferred to each pot. After seven days, Berlese funnels were used to extract larvae from pots over the following 24 days. For non-Bt corn, the cumulative survival rate of larvae for modified Cornell mix and the mixture of modified Cornell mix and top soil were 20 and 40 percent, respectively. Based on these results, the mixture of modified Cornell mix and topsoil was selected for use in the greenhouse trial.

In September 2007, a new greenhouse trial was initiated to test whether C partitioned above and belowground, and acid detergent lignin content differs between Bt corn and its closest non-Bt isolines, with and without corn rootworm feeding pressure. Three Bt hybrids with both the YieldGard® rootworm and RoundupReady® event (DKC 51-41, DKC 46-24 and DKC 61-68) and their closest non-Bt isolines were obtained from Monsanto Company (St. Louis, MO). The greenhouse trial was established in a randomized complete block design with four replications of each hybrid*pest treatment. The six maize hybrids were planted in three gallon pots with top soil and modified Cornell mix (2:1, v/v). Drainage openings in all pots were fitted with a fine (104 μm per opening) stainless steel mesh (TWP Inc., Berkley, CA) in order to prevent corn rootworm larvae from escaping from inoculated pots. Pots are irrigated daily and fertilized with nutrient solution containing 1.08 g of Peter's 15-16-17 L^{-1} weekly.

Carbon partitioning will be assessed prior to inoculating with CRW, immediately following the maximum root feeding by CRW and at maturity to measure accumulated carbon (total C) partitioning.

About 30 days after planting, immediately prior to inoculating pots in the pest pressure treatment with CRW larvae, 24 pots (6 hybrids x 4 replications) will be destructively harvested to assess biomass accumulation and total carbon content by roots and shoots and ADL content (Goering and Van Soest, 1970). Remaining pots in the pest pressure treatment will be inoculated with 100 western corn rootworm (*Diabrotica virgifera virgifera*) larvae. Then, insect mesh (0.6 mm opening, ECONET L, LS Americas Co., Charlotte, NC) will be used to cover all pots in order to prevent the escape of CRW adults from inoculated pots and prevent entry of CRW into uninoculated pots.

Based on previous observations, maximum root damage is evident when the larvae cease feeding and begin to pupate, approximately 25 days after being transferred onto the maize roots. At that time, another 48 pots (6 hybrids x 2 pest pressures x 4 replications = 48 pots) will be destructively harvested and biomass accumulation, total carbon content and ADL content in different plant parts determined.

The remaining pots will be grown to maturity and then destructively harvested. Different plant parts will be collected and cleaned, dried separately, weighed and analyzed for total C, acid detergent lignin content. Samples collected after the maize has matured will enable us to assess whether any recovery from pest damage is reflected in overall C partitioning. In addition, the final sampling will allow us to estimate the C content of the residues that would normally be added to field soil and thus would be influencing subsequent litter decomposition.

Residue Decomposition Rates

Corn

Residue decomposition rates were assessed for residue in litterbags placed at the surface or at 10cm depth in the field for 15.5 and 25 months in corn as described under Objective 2. Weight loss (%) of cobs and aboveground biomass (shoots and leaves; S+L) in litterbags was calculated by ash free dry weight (AFDW), and is shown in Figure 56. No significant effects of crop treatments were observed, but there was a significant interaction between plant parts and field history (P<0.05).

The rate of decomposition of shoots and cobs in litterbags indicates corn genotype had no significant effects on corn residue decomposition. However, planting history and depth had significant effects on the percent of residue weight remaining in 2005. In 2006, depth, plant part and the interaction between planting history and plant part had significant effects on the residue weight loss. Corn shoots (stalks and leaves) had a significant higher decomposition

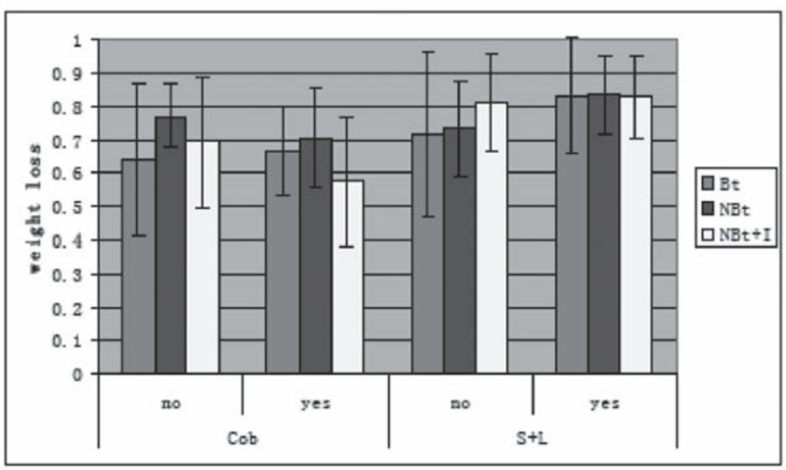


Figure 56. Weight loss (%) for cobs and aboveground biomass (shoots + leaves) from litterbags collected in 2006 fro Bt, non-Bt and non-BT+I plots, with (yes) and without (no) corn cropping history, after 25 months in the field.

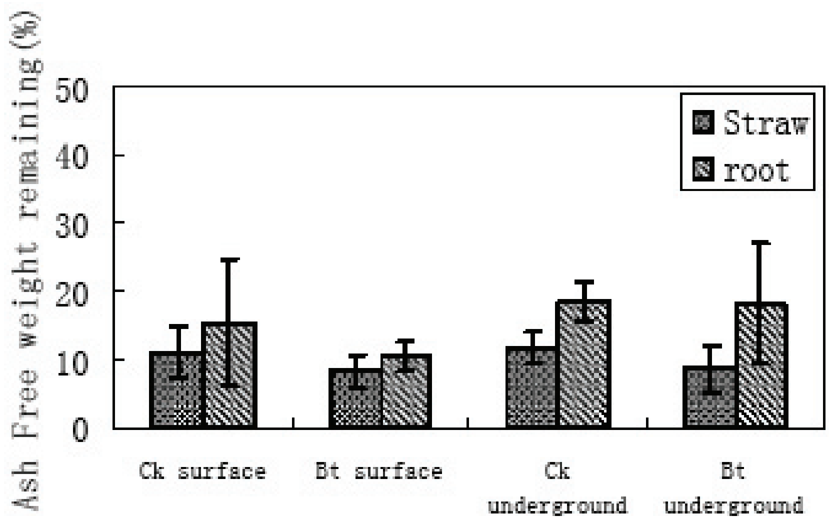


Figure 57. Ash-free weight loss (expressed as % weight remaining) of Bt and Ck (non-Bt rice) residues after 22 months of decomposition in the field. Straw and roots were placed separately in litter bags, either on the soil surface or incorporated into the soil at 10 cm depth. Error bars indicate standard deviation of the mean.

Table 43. Variation of total C, total N and C/N in Bt and non-Bt (Ck) rice straw and roots after 22 months of decomposition in the field.

	Status*	C %	N %	C/N
Bt straw	Control	34.4±0.47a	1.13±0.09a	30.7±1.42
Bt straw	surface sample	29.76±3.53b	2.12±0.21b	14.05±0.74a
Bt straw	Underground sample	32.35±4.21b	1.88±0.26b	17.25±0.80b
Ck straw	Control	35.40±0.19a	1.13±0.03a	31.30±0.45
Ck straw	Surface sample	29.84±3.84b	2.16±0.17b	13.74±0.74a
Ck straw	Underground sample	29.33±5.75b	1.87±0.34b	15.68±0.31c
Bt root	Control	38.60±0.14a	1.25±0.09a	30.80±1.55a
Bt root	surface sample	23.23±5.87b	1.71±0.34b	13.48±0.75cd
Bt root	Underground sample	24.03±6.37b	1.66±0.34b	14.29±1.24bc
Ck root	Control	37.90±0.16a	1.30±0.05a	29.20±0.95a
Ck root	Surface sample	23.73±2.43b	1.87±0.20b	12.71±0.16d
Ck root	Underground sample	25.23±6.49b	1.68±0.40b	14.91±0.78b

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

rate than cobs, and buried samples decomposed significantly faster than surface samples.

Rice

Replicate rice root and straw litterbags were placed either at the soil surface or at 10 cm depth in each rice plot in December 2004. The first set of litterbags was collected after rice harvest, 10 months after placement. The second set of litterbags was retrieved at rice harvest in Oct 2006, after being in the field for 22 months. A FlashEA1112 Automatic Elemental Analyzer measured Carbon and nitrogen contents in the remaining rice residues. Decomposition rates of Bt and non-Bt rice residues, based on ash-free weight loss and C/N ratio, are shown in Figure 56 and Table 43.

Significant changes in ash-free weight loss (Figure 57) and the total C, N and C/N ratio (Table 43) were observed in rice residues after almost two years in the field. In general, total C content and C/N ratio decreased, while the total N content in the relevant residues increased as compared to control residues which had been weighed fresh and not left in the field. Although significant differences in the C/N ratio of the remaining straw residue in buried treatments between Bt and Ck (non-B rice) were detected, there were no significant differences in total N content, C content, or percentage of ash-free weight loss between Bt and non-Bt rice residues after almost two years in the field, indicating that the transformation of the *cry*1Ab gene into the rice genome has had no negative effect on rice residue decomposition.

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

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

Summary

We have accomplished the goals established for Objective 1. These 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. After screening different artificial soil media, we identified a local sandy soil as one that offered minimum interference with MRI. In addition, we have identified a reliable protocol for MRI of roots with a 4.7 Tesla spectrometer. 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. In addition, the software for integrating all the root MRI signal for a scan has been developed and used to calculate the relative growth rate of roots non-destructively.

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 - Background

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).

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

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

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

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

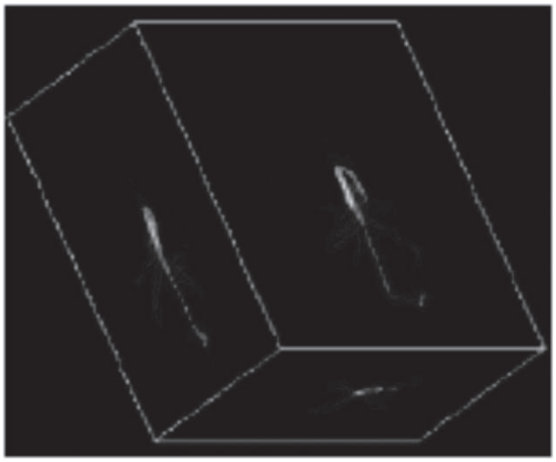


Figure 58. Project image of a 7-day old seedling.

Maximum Intensity Projection (MIP) and analyzed using pixel intensity thresh-holding using ParaVision XTIP Image Viewer (Figure 58).

Objective 1, Output 3: Development of a Probability Function for Roots and Quantitative Analysis of Root Growth

Our collaborative arrangement with Professor Baba Vemuri from the Computer and Information Sciences and Engineering Department at the University of Florida has proven very productive. A tensor model has being used to develop a set of algorithms that can trace the roots in a 3-D space (Figure 59). These root traces and images have been processed with a novel de-noising approach (Figure 60),

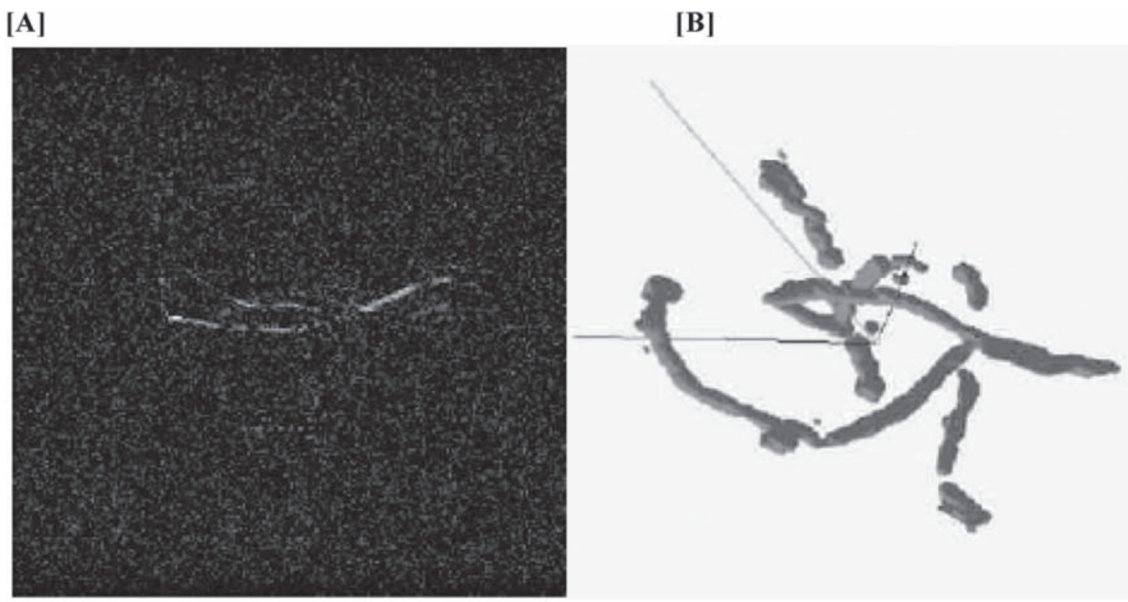


Figure 59. MRI data from an 8-day old seedling. A) Slice #119, B) Digitized trace.

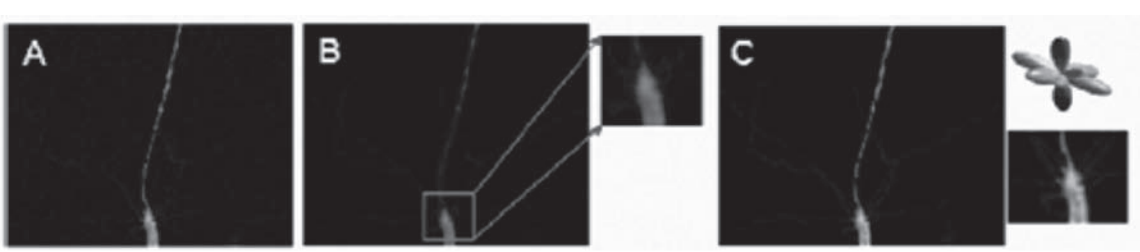


Figure 60. A: View of real MRI data (256 x 256 x 128 pixels. B: Edge enhancing anisotropic diffusion with local scale $\sigma = 0.5$, and 30 iterations. C: our feature-preserving smoothing method in 4 iterations together with a probability map illustrating the bifurcation structure.

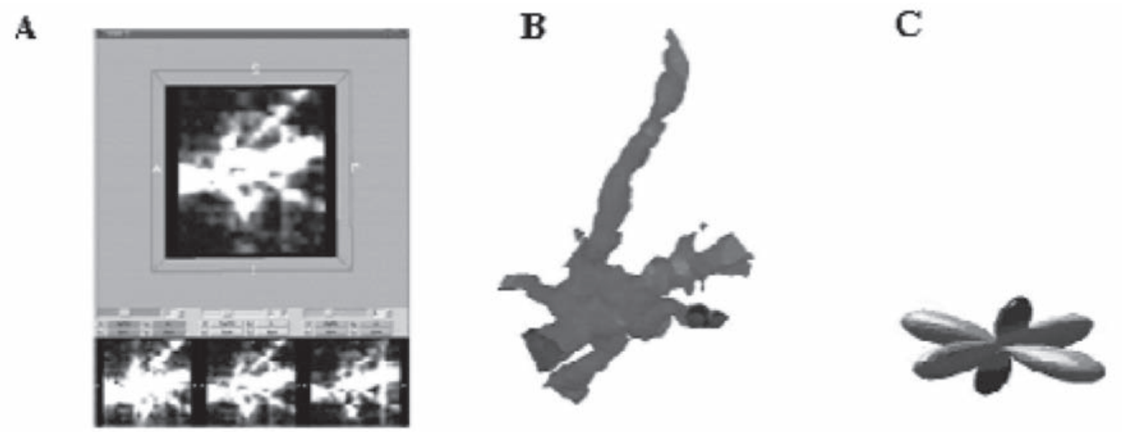


Figure 61. A: slice from the MRI scan of a bean root, and its three orthogonal views. B: de-noised volume visualizations of the root. C: the probability surface whose main maxima correspond to directions of the root branches.

and analyzed to derive a probability function that describes root volume, root density and branching patterns in 3-D (Figures 60 and 61).

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 assessment of genetic variability for root characters has been carried out using both a 2-D model and a 3-D model. The accessions that were screened included: the Andean breeding lines 'G19833' and 'Calima,' and the Mesoamerican landrace 'Jamapa'; the latter two are the parents of a recombinant inbred (RI) family (F_{10}) that can be used for mapping genes controlling root traits. J. Lynch has reported that accession G19833 has root responses that are adaptive to low phosphorous availability. Some wild accessions from Argentina to Mexico have also been evaluated and F_2 progenies among these lines have been generated for future genetic analysis if needed.

Measurements for the 2-D model were taken from rhizotron-grown roots. Two types of rhizotrons have been constructed for this purpose. The first type encases a layer of soil between black and clear Plexiglas sheets separated by 3 mm spacers placed at the lateral edges. A soil bed is attached to the top of the rhizotron to accommodate the large bean seed. 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 plexiglass 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 62 and 63). 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.

The second type of rhizotron was built without any soil because aeration in the middle appeared to be a limiting factor as roots tended to grow primarily towards the edges. This new rhizotron consists of two plexiglass sheets that are separated by two thin (25 mm wide X5 mm thick) gasket strips on both sides of the system. Germination paper (Anchor Paper Co., St. Paul, MN) is sandwiched between the gasket and one plexiglass sheet. The components of the system are then clamped together. Seedlings with 1 cm long tap roots are placed at the top between one of the plexiglass sheets and the nutrient-soaked(modified Hoaglands solution) germination

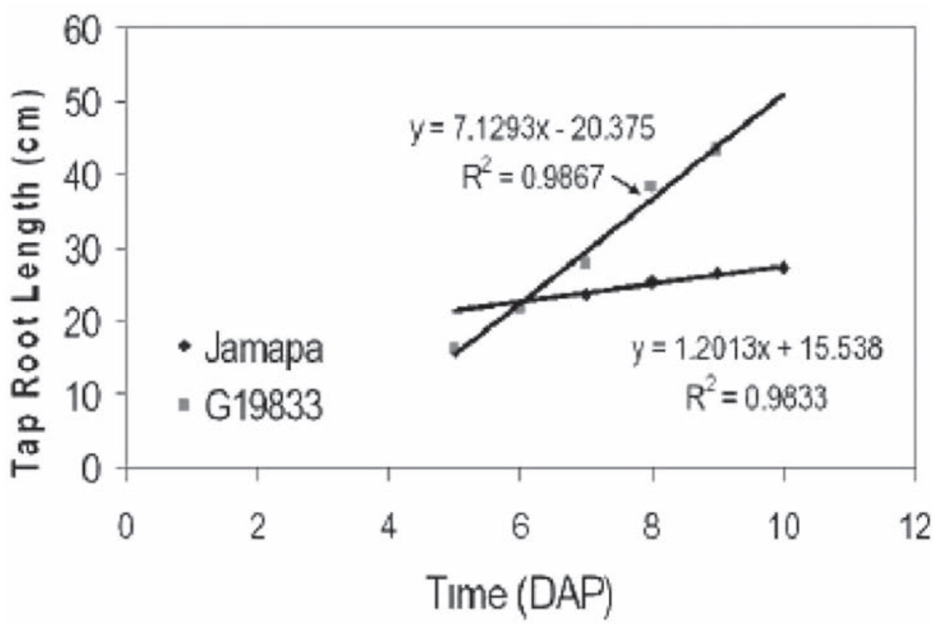


Figure 62. Tap root growth analysis in seedlings of Jamapa and G19833.

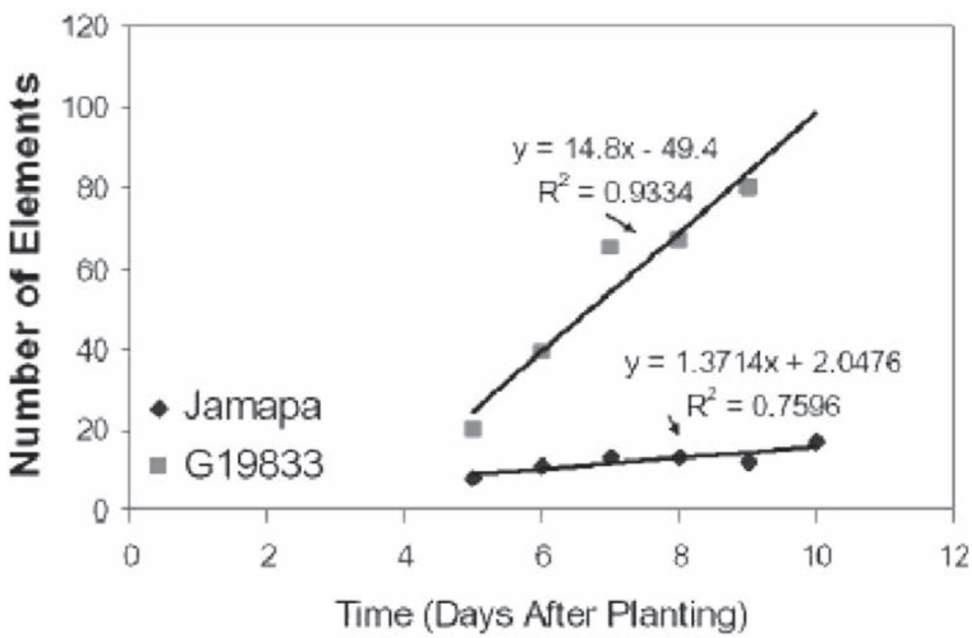


Figure 63. Analysis of root branching patterns in Jamapa and G19833.

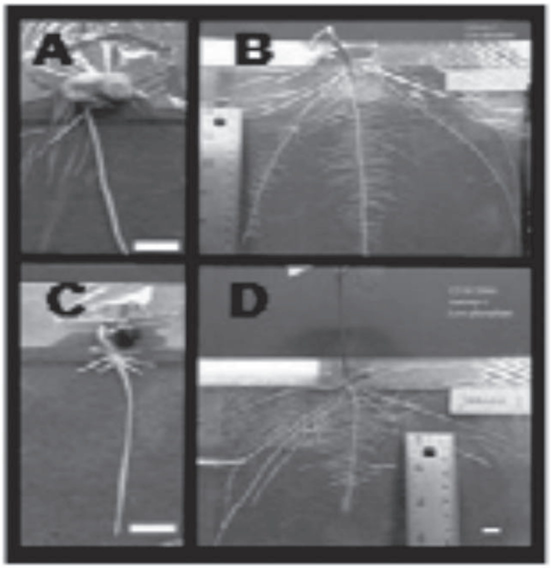


Figure 64. Roots of Calima (A & B) and Jamapa (C & D) from two-day old (A&C) and 10-day old (B&D) seedlings.

paper. The rhizotrons are then placed in 10 cm-deep nutrient solution in plastic containers. These are covered with cellophane and black foil to prevent light from reaching the roots and to reduce water evaporation. We are able to image the root system and identify traits that are segregating for specific root characteristics such tap, basal, and lateral root number, length and angles (Figure 64).

A comparison between the parental lines Jamapa and Calima showed very different root patterns. Calima roots grow at a much greater angle relative to the horizontal compared to Jamapa (Figure 64). Tap, basal and lateral roots from Jamapa elongated at a slower rate with fewer numbers of laterals compared to Jamapa. Indeed, the tap root from Jamapa was less than 1/2 the length of that from Calima after 10 days. The tap root length, basal root length, and number of laterals seem to slow their elongation rates after6 days for both Jamapa and Calima. Lateral root growth for both Jamapa and Calima continued in a linear fashion at 14 days after planting suggesting that while the number may not be increasing significantly, the laterals continue to elongate. For both Calima and Jamapa, the days 4 to 6 showed the greatest increase in the number and length of laterals. Unlike measurements that are performed at onetime point, these analyses give growth curves based on the logistic growth model for each genotype and can be used in the analysis using functional mapping.

The software developed to analyze 3-D images from MR scans was used to measure the growth of roots in soil in a non-destructive fashion. This was accomplished by integrating the root signal after de-noising. The results obtained here are in complete agreement with those obtained with the 2-D model and are depicted in Figure 65. Data were obtained from four time points. Each scan lasts approximately 3.5 h. Calima roots display a greater growth rate than those of Jamapa.

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 PY10.

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

No progress was made on Objective 4 in PY10.

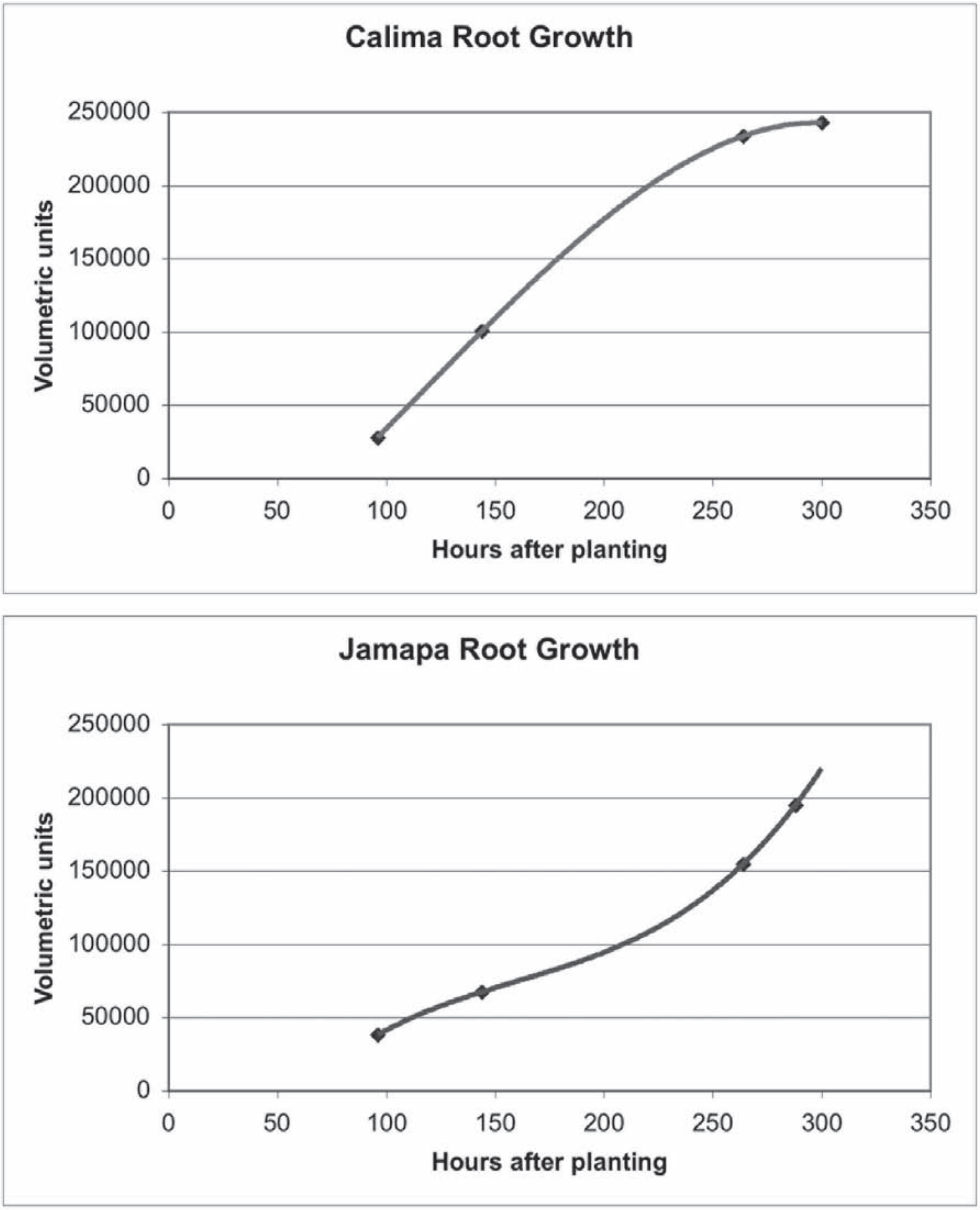


Figure 65. Patterns of total volume accumulation of Calima and Jamapa seedlings grown in mineral soil in 5-inch pots.

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

The SM CRSP introduced Integrated Crop Management (ICM) to Timor-Leste rice farmers in 2004 through a series of demonstration plots in farmers' fields. The success of the program was attributed to the increased yields (double previous production), adopting simple practices that included improved nutrient management, planting of healthy seedlings in rows and timely weed control. These practices not only boosted yields, but also dramatically reduced the amounts of fertilizer, labor and seed normally applied. USAID's support of the field support activity ended in January 2006.

The German Technical Cooperation (GTZ) wanted to expand their efforts in support of their food security program by involving more farmers. They recognized the impact of the ICM program introduced by the SM CRSP on local farmers. Subsequent communications between GTZ and Timor-Leste's Ministry of Agriculture, Forestry and Fisheries (MAFF) with the SM CRSP resulted in the extended implementation of the ICM technology in Timor-Leste.

In 2006, GTZ provided $85,000 to fund a joint project between the SM CRSP and MAFF. The objective was to train 14 extension agents in the rice production practices in a train-the-trainers program. The extension agents completed the training at the beginning of 2007. In turn, the extension agents trained 150 farmers from the districts in the western (Bobonaro) and eastern (Baucau, Viqueque, and Lautem) parts of the country. These farmers implemented the practices in 96 ha of rice paddies. In side-by-side tests, farmers saw that the new practices produced 3.3 ton rice/ha compared to 2.0 ton/ha from traditional practices. In a season that had drought, locust infestation and political/social turmoil, the rice yield demonstrated the resiliency of the management system to severe stresses. GTZ recognized the benefit of higher yield on its food security objective and continued to fund the program through 2007 and into 2008. This new phase will make the program independent of the SM CRSP by raising the expertise of the MAFF extension agents and enabling them to train new extension agents on their own.

PARTICIPATING AND COLLABORATING SCIENTISTS AND INSTITUTIONS/ ORGANIZATIONS

National Agricultural Research Systems (NARS)

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

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

National Agricultural Research Institute (INIAP)
Franklin Valverde

Potash & Phosphate Institute (INPOFOS)
Jose Espinosa

Gambia

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

Ghana

Savanna Agricultural Research Institute (SARI)
L. Abatania
Jesse Naab
C. Yamoah

University of Ghana
Samuel Adiku
Stella Assuming-Brempong
Gabriel Dowuona
Akwasi Mensah-Bonsu

Honduras

Food and Agriculture Organization (FAO)
Edgardo Navarro

International Tropical Agriculture Center (CIAT)
Miguel Ayarza
Gilman Palma
Idupulati Rao
Carlos Rodrigues
Marco Trejo

Non-governmental Organizations in Honduras
Crisanto Colinres (Grupo Guia
Marlon Martinez (FAO-SEL)
Santos Muñoz (PASBA)
Carlos Navarro (ASOCIAL)
Santiago Pineda (PASBA)
Tiburcio Santiago Vasques (FAO-PESA)

Kenya

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

World Agroforestry Center (ICRAF)
L. Verchot

Laos

National Agricultural and Forestry Research Institute (NAFRI)
Kouang Doungsila

Mali

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

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

Institut de l'Environnement et de Recherches Agricoles (INERA), Burkina Faso
Boubié Vincent Bado

Mexico

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

Mozambique

Instituto de Investigacões de Agicultura de Mozambique (IIAM)
C. Bias
Ricardo Maria
Candida Xavier

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 (LEI/WUR)
A. Kuyvenhoven (WUR)
G. Meierink (LEI/WUR)
Jetse Stoorvogel (WUR)

Nicaragua

Inter-American Institute for Cooperation on Agriculture (IICA)
Armando Ferrufino

International Center for Tropical Agriculture (CIAT)
Edwin Garcia

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

Panama

Panama Agricultural Research Institute (IDIAP)
Roman Gordon
Benjamin Name
M. Sarmiento
Jose Villareal

Philippines

Board of Soil and Water Management
Clarita Bacatio
Vic Barbera

Leyte State University, Visayas
Angela Almendras

Philippines Rice Research Institute
Madonna Casimero
Rodolfo Escabarte (Mindanao)

Southern Mindanao University
Flor Nicor
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)
Institut de Recherche pour le developpement (IRD)
B. Diagana
A. Dieng
P. N. Diéye
A. Fall
M.D. Faye
M. Guéye (ISRA-IRD)
M. Khouma
A Mankor
M. Ndiaye
C.M. Ndione
A. Niang
Modou Séne

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

Mahasarakham University
P. Khangkhun
M. Wongsawas

Timor-Leste

Ministry of Agriculture, Forestry and Fisheries (MAFF, currently MAF)
Adelino Rego

Uganda

Makerere University
I. Nakulenge

United States

Cornell University
G. Abawi
C. Adhikari (Nepal Country Coordinator)
Leslie Allee
S. De Gloria
Medha Devare
J. Duxbury
M. Easter (Natl. Research Ecol. Lab, Colorado State Univ.)
D. Harris (Univ. Wales/Dept. for Intl. Development-DFID)

P. Hobbs
S. Johnson (Intl. Rice Research Institute-IRRI)
J. Lauren
D. Lee
C. London (Educate the Children (ETC-Ithaca)
J. Losey
C. Meisner (Bangladesh: Country Coordinator)
G. Panaullah (Bangladesh)
D. Peck
J. Thies
N. Uphoff
S. Williams (Natl. Research Ecol. Lab, Colorado State Univ.)

Montana State University
John Antle
Roberto Valdivia

North Carolina State University
Sheri Cahill
Deanna Osmond
Jot Smyth
Jeffrey White
Michael Wagger

Texas A&M University
Frank Hons
Hamid Shahandeh

University of Florida
Stephen J. Blackband
Kenneth J. Boote
Melanie Correll
Samira Daroub
Arjan Gijsman
James Jones
Xeve S. Silver
C. Eduardo Vallejos
Baba Vemuri

University of Hawaii
Richard Kablan
Hu Li
Nguyen Hue
Richard Ogoshi
Gordon Tsuji
Goro Uehara
Russell Yost

USDA Plant Physiology/Nutrition
R. Welch (Cornell)

Virginia Tech University
K. Brannan

International Agricultural Research Centers (IARC)

International Maize and Wheat Improvement Center (CIMMYT)
N.E. Elahi (Bangladesh)
R.K. Gupta (RWC-India)
K. Sayre (Mexico)

International Potato Center (CIP)
L. Claessens (Kenya)
W. Kaguongo (Kenya)
R. Quiroz (Peru)

International Livestock Research Institute (ILRI)
Ernesto Gonzalez-Estrada (Kenya)
Mario Herrero (Kenya)
Philip Thornton (Kenya)

Private Sector
GY Associates
J. Gaunt

Understanding Systems, Inc.
Will Branch

Doyel Agro Industrial Ltd.
Md. M. Haque (Bangladesh)

East-West Seeds
M.G. Hossain (Bangladesh)
W. Zaman (Bangladesh)

TRAINING

Degree Programs

Name	Home Country	Gender	Degree
Cornell			
Cornell University			
Sanjay Gami	Nepal	M	PhD
Luz Marina Londoño	Colombia	F	MSc
Hao Hao Lu	China	M	MSc
Tarah Sullivan	USA	F	PhD
Liu Wei	China	F	PhD
Kai Xue	China	M	PhD
Bangladesh Agricultural Univ.			
Md. Bodruzzaman	Bangladesh	M	PhD
Tribhuvan University (Nepal)			
Nabin Dangel	Nepal	M	MSc
Rajendra Gautam	Nepal	M	MSc
Shyam Kandel	Nepal	M	MSc
Puspa Poudel	Nepal	M	MSc
Deepak Sapkota	Nepal	M	MSc
Florida			
Florida University			
Carrie Alberts	USA	F	MSc
Welch M. Bostick (deceased)	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 State			
Wageningen University			
Alejandra Vallejo	Chile	F	PhD
Reinier Ellenkamp	Netherlands	M	MS
Hawaii			
University of Hawaii			
Hamidou Konare	Mali	M	PhD
Antonio Querido	Cabo Verde	M	PhD
A. Sidibe-Diarra	Mali	F	PhD

Kasesart University (Thailand)			
K. Dounphady	Laos	M	MS
P. Limpatganangkul	Thailand	F	MSc
W. Nilawonk	Thailand	F	PhD
N. Saysathit	Laos	M	MS
N. Sipaseuth	Laos	M	PhD
V. Souvana	Laos	M	MS
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		
Cornell University		
Hao Hao Lu	China	M
Raquel Serohijos	Philippines	F
Hawaii		
University of Hawaii		
A. Bagayoko	Mali	M

Workshops

Workshops	Location	Date	No. Attended
Rice-Wheat (Cornell)	Nepal	01/07-09/07	36
		04/23-24/07	71
		05/02-04/07	
Rice-Wheat (Cornell)	Bangladesh	05/12-13/07	149
		05/15,16,27 29/07; 06/16; 17/07;	226
		11/05/06	300
		02/22/07	227
		06/12,14/07	132
Carbon (Hawaii)	Gambia	2007	14 males 1 females
NuMass (Hawaii)	Laos	1/8-14/07	25 males 15 females
	Laos	8/28/07	22 males 11 females

NuMass (North Carolina State)	Reynosa, Mexico	2007	49 males 2 females
	Braganca, Brazil	2007	34 males 7 females
	Siguatepeque, Honduras	2007	29 males 3 females
	Managua, Nicaragua	2007	25 males 2 females
Application of Crop-Soil Models (Florida)	Griffin, Georgia	2007	26 males 8 females
Application of DSSAT Models (Florida)	Arusha, Tanzania	8/04	21 males 5 females
Application of DSSAT Models (Florida)	Accra, Ghana	10/05	22 males 6 females
Tradeoff Analysis and DSSAT Models (Montana State)	Accra, Ghana	2/06	8 males 4 females
DSSAT Application (Florida)	Mombasa, Kenya	6/07	10 males 5 females
Integrated Crop (rice) Management (ICM) (Hawaii)	Timor-Leste		
MAFF ext. staff	Bobonaru district	9-10/06	7 males 1 female
Farmers			91 males 3 females
MAFF ext staff	Baucau, Viqueque Lautem districts	01/07	3 males 3 females
Farmers			53 males 2 females

PROJECT MANAGEMENT

Management Entity (ME)

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

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

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

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

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

Activities

Soil, Water and Eco-Systems Services CRSP

The SWES CRSP was listed as a new CRSP to replace the SM CRSP in the USAID desktop review of research priorities for AGR and NRM. The year 2009 was proposed as the start date of that new CRSP. In a conference call with the AGR and NRM directors from Denver on June 30, 2006 involving the CTO and the ME, both directors advised us that the SWES CRSP would not be on board until 2009 because of limited funding.

EEP Report

The report of the EEP was printed and distributed to USAID in September 2006. Copies could also be downloaded from the SM CRSP website. Arrangements for a meeting with the assistant administrator of EGAT and USAID were then made for an oral presentation of the report in Washington, D.C. on January 18, 2007.

No-Cost Extension

A request for a no-cost extension of the SM CRSP from September 30, 2007 to December 31, 2008 was submitted to the CTO and the Office of Acquisition and Accounting (OAA) in March 2007. An exchange of comments and questions resulted in at least two revisions of the request over the ensuing five months. Approval of the request was received in early September 2007.

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

There were no meetings of the Board in PY10. Minutes of previous 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."

There were no meetings of the Technical Committee in PY10. Members of the Committee were called upon to review and approve the request of a no-cost extension (NCE) to USAID in February 2007.

Members of the Technical Committee include the following:

- Dr. E.B. (Ron) Knapp, Retired, CIAT, Chair
- Dr. Thomas Walker, Retired, CIP and Michigan State University.
- 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 PY10. 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 (retired) and now with the Australian National University in Canberra, Australia.
- Amit Roy, President, International Fertilizer Development Center
- James Tiedje, Professor and Director of the Center for Microbial Ecology, Michigan State University

Dr. Eric Craswell served as chair of the EEP on-site review. Drs. E. Bronson Knapp and Thomas Walker, both external members of the Technical Committee, served as EEP members for the on-site review with the concurrence of EGAT/NRM director, Dr. David Hess.

USAID/CTO

Mike McGahuey, Jr. from the Natural Resources Management (NRM) division in EGAT served as the principal CTO for the SM CRSP. Carrie Stokes of EGAT/NRM and Robert Hedlund of EGAT/AGR provided backstopping support to McGahuey. Jeff Brokaw, Team Leader for the Land Resources Management team in NRM, also provided support in the absence of any or all of the CTOs. As the fiscal year for PY10 ended, the SM CRSP and three other CRSP programs were being moved back from NRM to the agriculture (AGR) division of EGAT. With that move, Adam Reinhart became the CTO for the SM CRSP.

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	BASIS/AMA	Wisconsin
Irv Widders	Bean and Cowpea/Pulses	Michigan State
Tag Demment	Global Livestock	California, Davis
John Yohe	INTSORMIL/ SMOG	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 No. 17 was the final incremental award to the Grant and was received in September 2006 (Table 44). Amendments to sub awards at Cornell, Florida, Montana State and North Carolina State were then implemented by the ME in subsequent weeks.

A request for a no-cost extension to the Grant was submitted to the CTO and OAA Grant Officer in March 2007. An amended request was re-submitted in May 2007 that included re-adjusting the proposed end date from December 31, 2008 to September 30, 2008. Subsequently, on June 25, 2007, responses were submitted by email to questions raised by the Agency with regards to our budget and participant training. Further meetings involving BIFAD and within the Agency were held in from July through August 2007. Finally, the no-cost extension request was granted after the ME modified its budget and scope of work to include plans for workshop(s) and information dissemination in West Africa. Modification No. 18 was received in the latter half of September 2007.

Expenditure Report

Tables 45a, 45b and 45c 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 work plans and budgets submitted by each Principal Investigator. In Table 45a, the UH totals reflect expenditure reports for two projects (NuMaSS and Carbon Sequestration) at UH with Russell Yost as PI, buyins from Timor-Leste 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 Biotech) and of two projects (Carbon Sequestration and Biotech) at the University of Florida (UF).

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

A twelve-month no-cost extension was requested and approved in August 2007 to extend the end date of the Grant to September 30, 2008.

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 44. Incremental funding awards to the SM CRSP for the period covering February 11, 1997 to September 30, 2007.

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 # 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[e]	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
Mod #17	10	$2,677,000	Oct. 1, 2006-Sept 30, 2007
Mod #18	10		Oct. 1, 2007-Sept 30, 2008

Notes: Superscripts a, b and c refer to field support funds received by the SM CRSP from the Office of Disaster Relief, the AID mission in Bangladesh, and the AID mission in Ethiopia, respectively. Superscript d & e refer to supplement funding to the core budget from AID for impact assessments and Biotechnology respectively. Superscript f refers to supplemental funding to the SM CRSP core budget for the following year. Superscript g & 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.

Table 45. Financial summary statement ($'000) of expenditure, cost sharing and funding for PY 10 (Oct 1, 2006 to Sept 30, 2007) from vouchers received.

a. Summary of Expenditures reported during PY 10 (Oct 1, 2006 to Sept 30, 2007)

Institution	MSU	NCSU	CU	TAMU	NifTAL	UFL	UH	ME	Total
	424	240	868	0	0	348	511 *(SM CRSP)*	500	2,891
Total	424	240	868	0	0	348	511	500	2,891

b. Cost Sharing for PY 10 (Oct 1, 2006 to Sept 30, 2007)

Institution	MSU	NCSU	CU	TAMU	NifTAL	UFL	UH	ME	Total
	137	105	174	0	0	246	116 *(UH)*	N/A	778
Total	137	105	174	0	0	246	116		778

c. Summary of Cumulative Core Funding (February 11, 1997 to September 30, 2007)

Institution	MSU	NCSU	CU	TAMU	NifTAL	UFL	UH	ME	Total
Mod #2	194	1,000	483	361	190	8	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	6	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
Mod #17	503	229	688	0	0	320	571	366	2,677

Notes: Superscripts a, b and c refer to field support funds received by the SM CRSP from the Office of Disaster Relief, the AID mission in Bangladesh, and the AID mission in Ethiopia, respectively. Superscript d & e refer to supplement funding to the core budget from AID for impact assessments and Biotechnology respectively. Superscript f refers to supplemental funding to the SM CRSP core budget for the following year. Superscript g & 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 PY10, there were no new buy-ins from missions. Closeout activities in Timor-Leste were completed in PY9 and that for Angola in PY8.

Timor-Leste

The Timor-Leste Agricultural Rehabilitation, Economic Growth and Natural Resources Management project ended on December 31, 2005. Additional activities are reported here although there were no USAID funds involved. In PY10, the GTZ (German Technical Assistance) in Timor-Leste requested assistance from the SM CRSP to extend implementation of the ICM (integrated crop management) system introduced to rice farmers and MAFF during the buy-in period. That activity is reported in the "Field Support to Missions" section of this report.

Candlenut oil exports from Baucau continued under an agreement between two small business enterprises in Timor-Leste and the United States, respectively.

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

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

Cost Sharing

Table 46 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 subagreement, including facilities, host country personnel services, and equipment and commodity purchases by a participating U.S. institution for use by a host country entity or by the U.S. institution in a host country.
- 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 46).

Table 46. 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	
ILRI, Kenya	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	360,000
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	5,000	
Ecoregional Fund (ISNAR)		
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	
RDRS, Bangladesh	10,000	

LiBird, Nepal	15,000	
FORWARD, Nepal	15,000	305,000
Biotech		
Zhejiang University	25,000	25,000
Field Support		
Timor-Leste		
MAFF	40,000	
GTZ	35,000	75,000
Angola		
World Vision	25,000	
CLUSA	5,000	
CRDA	5,000	35,000
TOTAL	1,720,000	

PUBLICATIONS, PRESENTATIONS AND REPORTS

Journal Series and Books

Antle, J.M. and J.J. Stoorvogel. 2007. Agricultural carbon sequestration, poverty and sustainability. Environment and Development Economics. *In press*.

Antle, J.M., J.J. Stoorvogel and R.O. Valdiviaa. 2007. Assessing the economic impacts of agricultural carbon sequestration: Terraces and agroforestry in the Peruvian Andes. Agriculture, Ecosystems and Environment 122:435-445.

Antle, J.M. and J.J. Stoorvogel. 2006. Predicting the supply of ecosystem services from agriculture. American Journal of Agricultural Economics 88(5):1174-1180.

Antle, J.M., J.J. Stoorvogel and R.O. Valdivia. 2006. Multiple equilibria, soil conservation investments and the resilience of agricultural systems. Environment and Development Economics 11(4):477-492.

Antle, J.M. J.J. Stoorvogel. 2006. Incorporating systems dynamics and spatial heterogeneity in integrated assessment of agricultural production systems. Environment and Development Economics 11(1):39-58.

Antle, J.M., R.O. Valdivia, C.C. Crissman, J.J. Stoorvogel and D. Yanggen. 2006. Spatial heterogeneity and adoption of soil conservation investments: Integrated Assessment of Slow Formation Terraces in the Andes. *In* D. Miljkovic (ed). New Topics in International Agricultural Trade and Development. New York: Nova Science Publishers, Inc. pp . 29-53.

Antle, J.M., Uehara, G., 2002. Creating incentives for sustainable agriculture: defining, estimating potential and verifying compliance with carbon contracts for soil carbon projects in developing countries. *In* Balas Bing, S. (ed). A Soil Carbon Accounting and Management System for Emissions Trading. SM CRSP 2002–4. University of Hawaii, Honolulu, HA, pp. 1–9.

Attanandana, T., Y. Yost and P. Verapattananirund. 2007. Empowering farmer leaders to acquire and practice site-specific nutrient management technology. Journal of Sustainable Agriculture 30:87-104.

Badini, O., C. Stockle, A. Kodio, J.W. Jones and M. Keita. 2007. Analyzing potential increases in productivity and soil carbon using rotational grazing. Agricultural Systems 94:87-96.

Bado, B.V., 2002. Ro^le des le´gumineuses sur la fertilite´ des sols ferrugineux tropicaux des zones guine´enne et soudanienne du Burkina Faso (in French, with English abstract). PhD Thesis. Universite´ Laval, Que´bec.

Bolker, B.M., Pacala, S.W., Parton, W.J., 1998. Linear analysis of soil decomposition: insights from the Century model. Ecol. Appl. 8(20):425-439.

Bostick, W.M., B.V. Bado, A. Bationo, C. Tojo Soler, G. Hoogenboom and J.W. Jones. 2006. Soil carbon dynamics and crop residue yields of cropping systems in the Northern Guinea Savanna of Burkina Faso. Soil and Tillage Research 93:138-151.

Brady, N.C., and R.R. Weil. 2002. The nature and properties of soils. Prentice Hall, Upper Saddle River, NJ.

Bradford MM. 1976. Rapid and sensitive method for quantitation of microgram quantities of protein utilizing principle of protein-dye binding. Analytical Biochemistry 72: 248-254.

Braimoh, A.K. and P.L.G. Vlek. 2004. The impact of land-cover change on soil properties in northern Ghana. Land Degradation & Development 15:65-74.

Brooks, R.J., Tobias, A.M., 1996. Choosing the Best Model: Level of Detail, Complexity, and Model Performance. Math. Comput. Model. 24(4):1-14.

Clune DJ. 2007. Glomalin: response to soil management, relationship with aggregate stability, source and quantification. M.S. thesis, Cornell University, Ithaca, NY.

Deenik, J. and R.S. Yost. 2006. Chemical properties of atoll soils in the Marshall Islands and constraints to crop production. Geoderma 136:666-681.

Devare, M., L.M. Londoño and J.E. Thies. 2007. Transgenic Bt corn and tefluthrin have no effect on microbial biomass and activity: A three-year field analysis. Soil Biology & Biochemistry 39:2038-2047.

Diaganqa, B., J.M. Antle, J.J. Stoorvogel and K. Gray. 2007. Economic potential for soil carbon sequestration in the Nioro Region of Senegal's Peanut Basin. Agricultural Systems 94:26-37.

Doraiswamy, P.C., G.W. McCarty, E.R. Hunt, Jr., R.S. Yost, M. Doumbia and A.J. Franzluebbers. 2007. Modeling soil carbon sequestration in agricultural lands of Mali. Agricultural Systems 94:63-74.

Fichtner, E.J., D.L. Hesterberg, T.J. Smyth and H.D. Shew. 2006. Differential sensitivity of *Phytophthora parasitica* var. *nicotianae* and *Thielaviopsis basicola* to monomeric aluminum species. Phytopathology 96:212-220.

Gigou, J., K. Traore, F. Giraudy, H. Coulibaly, B. Sogoba et M. Doumbia. 2006. Aménagement paysan des terres et reduction due ruissellement dans les savanes africaines. Cahiers d'Agriculture 15:1-6.

Gigou J., L. Coulibaly, B. Wennink et K.B. Traore. 1997. Aménagements des champs pour la culture en courbes de niveau au sud du Mali. Agriculture & Développement 14:47-57.

Goering, H.K. and Van Soest, P.J. 1970. Forage fiber analyses (Apparatus, Reagents, Procedures, and Some Applications). Agriculture Handbook No. 379, Agriculture Research Service, USDA, pp. 387-598.

González-Estrada E., Walen V.K., Naab J., Thornton P.K. and Herrero M. 2004. A farm-level analysis of carbon sequestration in Ghana using IMPACT linked to the DSSAT-Century, Household and Ruminant models. Proceedings of Regional Scientific Workshop on Land Management for Carbon Sequestration. February, 2004, Bamako, Mali. SANREM CRSP, http://www.sanrem.uga.edu/carbon/workshopProgram/index.html.

Immerzeel, W., J. Stoorvogel and J. Antle. 2007. Can payments for environmental services secure the water tower of Tibet? Agricultural Systems. *In press*.

Janik, L., Spouncer, L., Correll, R., Skjemstad, J., 2002. Sensitivity analysis of the Roth-C soil carbon model (Ver. 26.3 Excel©). Technical Report no. 30, National Carbon Accounting System, Australian Greenhouse Office, Canberra, ACT, Australia. ISSN: 14426838. 51p.

Jones, J.W., J. Koo, J. Naab, W.M. Bostick, S. Traore and W.D. Graham. 2007. Integrating stochastic models and in-situ sampling for monitoring soil carbon sequestration. Agricultural Systems 94:52-62.

Jones, J.W., W.D. Graham and D. Makowski. 2006. Application of extended and ensemble Kalman filters to soil carbon estimation. *In* D. Wallach, D. Makowski and J.W. Jones (eds). Working with Dynamic Crop Models: Evaluating, Analyzing, Parameterizing and using them. Amsterdam: Elsevier. Chapter 18.

Jones, J.W., W.D. Graham, D. Wallach, W.M. Bostick, and J. Koo. 2004. Estimating soil carbon levels using an Ensemble Kalman filter. Transactions of the Asae 47:331-339.

Kablan, R., K. Brannan, R.S. Yost., M. Doumbia, K. Traore, A. Yorote, Y. Toloba, S. Sissoo, O. Samake, M. Vaksman, L. Dion and M. Sissoko. 2007. Amenagement en courbes de niveau, increasing rainfall capture, storage and drainage in soils of Mali. (Accepted by Arid Lands Research and Management)

Koo, J., W.M. Bostick, J.B. Naab, J.W. Jones, W.D. Graham and A.J. Gijsman. 2007. Estimating soil carbon in agricultural systems using Ensemble Kalman Filter and DSSAT-CENTURY. Transactions of ASAE. *In press*.

Larocque, G.R., Bhatti, J.S., Gordon, A.M., Luckai, N., Liu, J., Liu, S., Arp, P.A., Zhang, C.-F., Komarov, A., Grabarnik, P., Wattenbach, M., Peng, C., Sun, J., White, T., 2006. Dealing with uncertainty and sensitivity issues in process-based models of carbon and nitrogen cycles in northern forest ecosystems. *In* Voinov, A., Jakeman, A.J., Rizzoli, A.E. (eds). Proceedings of the iEMSs Third Biennial Meeting: "Summit on Environmental Modelling and Software". International Environmental Modelling and Software Society, Burlington, USA, July 2006. ISBN 1-4243-0852-6.

Lauren, J.G., G. Shah, M.I. Hossain, A.S.M.H.M. Talukder, J.M. Duxbury, C.A. Meisner and C. Adhikari. 2007. Research station and on-farm experiences with permanent raised beds through the Soil Management Collaborative Research Support Program. *In* E. Humphreys and C. Roth (eds). Permanent Beds and Rice Residue Management for Rice-Wheat Systems in the Indo-Gangetic Plains. Australian Centre for International Agricultural Research (ACIAR) Proceedings, Canberra, Australia. *In press*.

Lima, A.M., I.R. Silva, J.C. Neves, R.F. Novais, N.F. Barros, E.S. Mendonça, T.J. Smyth, M.S. Moreira and F.P. Leite. 2006. Soil organic carbon dynamics following afforestation of degraded pastures with eucalyptus in southeastern Brazil. For. Ecol. and Management 235:219-231.

Maria, R.M. and Russell Yost. 2006 A Survey of Soil Fertility Status of Four Agro-ecological Zones of Mozambique (*Accepted* by Soil Science - 2006)

Nilawonk, W., T. Attanandana, R. Yost and X. Shuai. 2007. Potassium release in representative maize-producing soils of Thailand. (*Accepted* by Soil Sci. Soc. Am. J.)

Novais, R.F., T.J. Smyth and F.N. Nunes. 2007. Fósforo.pp. 472-550. *In* R.F. Novais *et al* (eds). Fertilidade do Solo. Brazilian Soil Science Society, Viçosa, Minas Gerais, Brazil.

Osei, W.Y. and S.mAryeetey-Attoh. 1997. The Physical Environment. p. 1-34. *In* S.Aryeetey-Attoh (ed). Geography of Sub-Saharan Africa. Prentice Hall, Upper Saddle River, New Jersey.

Osmond, D.L., T.J. Smyth, R.S. Yost, D.L. Hoag, W.S. Reid, W. Branch, X. Wang and H. Li. 2007. Nutrient Management Support System (NuMaSS), v. 2.2, Software installation and user's guide. Soil Management Collaborative Research Support Program, Technical Bulletin No. 2007-01, North Carolina State University, Raleigh, NC. 36p.

Shuai, X. and R.S. Yost. 2007. Transport process identification for column experiments via the frequency domain approach. J. of Contaminant Hydrology 94:86-98.

Sipaseuth, N., T. Attanandana, V. Vichukit and R. Yost. 2007. Subsoil nitrate and maize root distribution in two important maize growing soils in Thailand. Soil Science 172:861-875.

SM CRSP. 2006. 2006 Soil Management CRSP Annual Report, University of Hawaii, Honolulu.

Thies, J.E. 2007. Soil microbial community analysis using terminal restriction length polymorphisms analysis. Soil Science Society of America Journal 71:579-591.

Thies, J.E. and M. Devare. 2007. An ecological assessment of transgenic crops. Journal of Development Studies 43(1):97-129.

Traoré, P.C.S., W.M. Bostick, J.W. Jones and B.V. Bado. 2007. Simplifying RothC for biomass data assimilation in C sequestration contracts. International Symposium on Innovations for a Green Revolution in Africa: Exploring the Facts. Arusha, Tanzania. Sept. 17-21, 2007.

Van Tuinen D, E. Jacquot, B. Zhao, A. Gollotte and V. Gianiazzi-Pearson. 1998. Characterization of root colonization profiles by a microcosm community of arbuscular mycorrhizal fungi using 25S rDNAtargeted nested PCR. Molecular Ecology 7: 879-887.

Yampracha, S., T. Attanandana, A. Sidibe-Diarra, A. Shrivihok and R.S. Yost. 2006. Generalizing and predicting the dissolution of four rock phosphates in flooded acid sulfate soils of Thailand. Soil Science 171:200-209.

Yoshida, S. 1981. Fundamentals of rice crop science. Int. Rice Res. Inst., Los Banos, Laguna, Philippines.

Yost, R.S. and A. Ares. 2007. Nutrient management decision support systems for tree crops. J. Hawaiian and Pacific Agriculture 14:5-16.

Yost, R.S. and A. Ares. 2007. Phosphorus and lime requirements of tree crops in tropical acid soils: A review. J. of Tropical Forest Science 19:176.

Wei, L., H-H. Lu, W. Wu, Q. Wei, Y. Chen and J.E. Thies. 2007. Rhizosphere soil enzyme activities and microbial community composition are affected by applying triazophos but not by cultivating Bt transgenic rice. Soil Biology & Biochemistry. *In press*.

Wright S.F. and A. Upadhyaya. 1996. Extraction of an abundant and unusual protein from soil and comparison with hyphal protein of arbuscular mycorrhizal fungi. Soil Science 161: 575-586.

Presentations and Reports

Adhikari, C., J.G. Lauren and J.M. Duxbury. 2007. Improved Root Health with Solarization Increases Rice and Vegetable Production. 8th National Outreach Workshop. June 19-20, 2007. NARC On-Farm Research Division, Kathmandu, Nepal.

Adhikari, C. 2007. Grow Healthy Seedlings for More Production. Krishi Patrika Magazine. Jestha-Ashadh 2064 (June-July 2007). 4 pp.

Antle, J.M. 2007. Tradeoff Analysis and Beyond: Integrating Science and Economics to Support Informed Policy Decision Making. Seminar presented at the International Potato Center, Lima, May 29.

Antle, J.M. 2007. Measuring Ecosystem Services to Implement Efficient Payment Mechanisms in Agriculture. Paper presented at the annual meetings of the American Ag. Econ. Assn., Portland, August.

Antle, J.M. and J.J. Stoorvogel 2006. Tradeoff Analysis: Coupling Bio-Physical and Economic Models to Support Agricultural and Environmental Policy. Seminar presented at the Agricultural Research Service, USDA, Fort Collins, CO., October 27.

Antle, J.M. 2006. Minimum Data analysis of Ecosystem Service Supply. Training Workshop, Northern Plains Research Center, Agricultural Research Service, USDA, Mandan, NK. November 1.

Antle, J.M. 2006. Analysis of Ecosystem service Supply: The Minimum Data Approach. Seminar presented at IDIAP, Panama City, Panama, November 16.

Ayarza, M., J. Smyth, M. Trejo, E. Garcia and E. Navarro. 2007. Sistema experto de manejo de nutrientes (NuMaSS): herramienta de decisión para mejorar la eficiencia de la fertilización nitrogenada en el cultivo del maíz en Honduras y Nicaragua. XVII Latin American Congress of Soil Science, Leon, Mexico, 17-21 September, 2007.

Brasil, E.C. 2007. Funcionamento do laboratório de análise de solo da EMBRAPA e bases para recomdendações de abubação e calagem. August 14, 2007. NuMaSS Training Workshop, Bragança, Brazil.

Claessens, L. 2006. Minimum Data (MD) approaches to model tradeoffs Between productivity and the environment: examples from SSA and LAC. Available as abstract. Presented at CIP Annual Review and Planning meeting, Lima, Peru, October 30 to November 10, 2006.

Cravo, M.S. 2007. Características físico-químicas dos solos do Nordeste Paraense. August 14, 2007. NuMaSS Training Workshop, Bragança, Brazil.

Cravo, M.S. 2007. Avaliação da necessidade de K para arroz, milho e feijão-caupi em Terra Alta e Tracuateua. August 14, 2007. NuMaSS Training Workshop, Bragança, Brazil.

Cravo, M.S. 2007. Avaliação da necessidade de calagem em Terra Alta e Tracuateua. August 14, 2007. NuMaSS Training Workshop, Bragança, Brazil.

Department of Agriculture. 2003. Statistics of chemical fertilizer import 2002. Database on chemical fertilizer import, Bangkok, Thailand.

Department of Land Development. 1991. Suitable soil management research report for rice, sugarcane, cassava, maize and pineapple, Bangkok, Thailand.

Diagana, B., A. Mankor, C. Sadibou Fall, A. Guéye, J. Antle and J. Stoorvogel. 2007. Agricultural Technology and Policy Options to Enhance Sustainability and Alleviate Poverty in the Senegal Peanut Basin. Tradeoff Analysis Project Stakeholder Workshop, Dakar, Senegal, July 9.

Londono- R., L.M., M. Devare and J.E. Thies. 2006. Populations of arbuscular mycorrhizal fungi appear unaffected by interactions with Bt corn as compared with its non-transgenic isoline. 11th International Society for Microbial Ecology, Vienna, Austria.

Marina, F.A., N.W. Kaguongo and L. Claessens. 2006. Involving policy makers in Evaluation of Farming systems and Agricultural Interventions for Enhanced Sustainable Land Management: A Tradeoff Analysis model application. Available as abstract. Presented at the 10th Soil Science Society of East Africa Conference on Strengthening Stakeholders Participation in Natural Resource Management: A Key towards Improved Livelihoods, Masaka, Uganda, November 20-24, 2006.

Office of Agricultural Economics. 2002. Agricultural Statistics of Thailand, Crop year 2002/2003, Bangkok, Thailand. (www.oae.go.th/statistic/yearbook/2002-2003)

Royal Irrigation Department. 2003. Irrigated area of Thailand, Bangkok, Thailand. (www.rid.go.th)

Sah, G., N. Ansari, D.B. Gharti, J.G. Lauren, J.M. Duxbury and C. Adhikari. 2007. Assessment of permanent bed planting method under rice-wheat system. 25th National Summer Crops Research Workshop. June 21-23, 2007. NARC. Kathmandu, Nepal.

Smyth, T.J. 2007. Adoption and adaption of NuMaSS in Honduras and Nicaragua. March 19, 2007. Annual Planning Workshop, Consortium on Integrated Management of Steeplands, Int. Center for Tropical Agriculture (CIAT), Lago Yojoa, Honduras.

Smyth, T.J. 2007. Formas de absorción de nutrimentos por las plantas. February 24, 2007. NuMaSS Training Workshop, Reynosa, Mexico.

Smyth, T.J. 2007. La materia orgánica y la fertilización nitrogenada. February 24, 2007. NuMaSS Training Workshop, Reynosa, Mexico.

Smyth, T.J. 2007. Manejo de fósforo en suelos alcalinos. February 24, 2007. NuMaSS Training Workshop, Reynosa, Mexico.

Smyth, T.J. 2007. Descripción del programa computacional NuMaSS. February 24, 2007. NuMaSS Training Workshop, Reynosa, Mexico.

Smyth, T.J. 2007. Avaliação da necessidade de P para milho, arroz, feijão-caupi e mandioca em Terra Alta e Tracuateua. August 14, 2007. NuMaSS Training Workshop, Bragança, Brazil.

Smyth, T.J. 2007. Avaliação da necessidade de N e S para arroz, milho e feijão-caupi em Terra Alta e Tracuateua. August 14, 2007. NuMaSS Training Workshop, Bragança, Brazil.

Smyth, T.J. 2007. Estrutura e funcionamento do programa NuMaSS. August 15, 2007. NuMaSS Training Workshop, Bragança, Brazil.

Smyth, T.J. 2006. Developing a Nutrient Management Support System for 'Palmito'. X Ecuadorian Soil Science Congress, Guayaquil, Ecuador, 22-24 Nov., 2006.

Stoorvogel, J.J. and J.M. Antle. 2007. Tradeoff Analysis and the Integrated Assessment of Agricultural Systems. Keynote address presented at the 2007 Farming Systems Design Conference, European Society of Agronomy, Sicily, September.

Trejo, M.S., M. Ayarza, T.J. Smyth and D. Finney. 2006. Use of the Nutrient Management Expert System (NuMaSS) to improve management of nitrogen in maize-based systems in hillsides of Honduras and Nicaragua. Int. Soil Sci. Congress, Philadelphia, PA.

Xue, K., R.C. Serohijos, M. Devare and J.E. Thies. 2006. Microbial communities colonizing residues and rates of residue decomposition do not differ between Cry3Bb Bt and Non-Bt corn hybrids in the field. American Society of Agronomy Abstracts, Indianapolis, IN, November 2006.

ACRONYMS

ACIAR	Australian Centre for International Agricultural Research
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
CARB	Centre for Action Research-Barind (Bangladesh NGO)
CARE	International NGO
CCX	Chicago Climate Exchange
CERAAS	Centre d'étude régional 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
DADO	District Agricultural Development Office (Nepal)
DAE	Department of Agricultural Extension (Bangladesh)
DAP	Diammonium phosphate
DFID	Department for International Development (UK)
DICTA	Agricultural Science and Technology Directorate
DLD	Department of Land Development
DOA	Department of Agriculture
DSR	Direct seeded rice
DSSAT	Decision Support System for Agrotechnology Transfer
DT	Deep tillage
ECEC	Exchangeable cation exchange capacity
EEP	External Evaluation Panel

ENEA	Ecole Nationale d'Economie Applique
EnKF	Ensemble Kalman Filter
EMBRAPA-CPATU	Brazilian Agricultural Research Enterprise-Humid Tropic Research Center
ETC	Educate the Children – Nepal NGO
ExKF	Extended Kalman Filter
FAF	Focal Area Forum
FAO	Food and Agriculture Organization
FFS	Farmer Field School
FHIA	Honduran Foundation for Agricultural Research
FORWARD	Local non-governmental organization (Nepal)
FYM	Farmyard manure
GIS	Geographic Information Systems
GO	Government organization
GO-Interfish	CARE, rice-fish program in Bangladesh
HKI	Helen Keller International
HST	Healthy Seedlings Technology
HYV	High yielding variety
IAAS	Institute for Agriculture and animal Science (Rampur, Nepal)
IBTA	Bolivian Institute for Agricultural Technology
IC	Inter-cooperation
ICRAF	International Center for Research in Agroforestry
ICRISAT	International Center for Research in the Semi-Arid Tropics
ICTA	Institute for Agricultural Science and Technology
IDE	International Development Enterprises
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 Senegalaise de Recherces de Agricole, Senegal

ITDC	IPM Technology Dissemination Campaign (Nepal NGO)
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
LTFE	Long-term soil fertility experiment
MD	Minimum data
MOA	Ministry of Agriculture (Thailand)
MOET	Minus one element technique
MOU	Memorandum of Understanding
MOVIMONDO	Vecinos Mundiales, Grupo Guia and CCD)
MRI	Magnetic resonance imaging
N	Nitrogen
NAFI	National Agricultural and Forestry Research Institute
NARC	Nepal Agricultural Research Council
NARES	National Agricultural and Extension Systems
NARI	National Agricultural research Institute, The Gambia
NATP	National Agricultural Technology Program (Bangladesh)
NGO	Non Governmental Organization
NMR	Nuclear magnetic resonance
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
PRB	Permanent Raised Beds Technology
PROINPA	Foundation for Andean Products Research and Promotion, Bolivia
RDRS	Rangpur-Dinajpur Rural Service – Bangladesh NGO
RW	Rice Wheat (cropping system)
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

SMCRSP	Soil Management Collaborative Research Support Program
SOC	Soil organic carbon
SOM	Soil organic matter
SRI	System of Rice Intensification
SS	Surface seeding
SSNM	Site specific nutrient management
TAES	Texas Agricultural Experiment Station
TDR	Time dormain reflectometry
TOA	Tradeoff Analysis
TOC	Total organic carbon
TPR	Transplanted rice
TRF	Thailand Research Fund
TTMU	Technology Transfer Monitoring Unit (Bangladesh)
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	Walkey-Black method carbon analysis
WINROCK	International NGO
WRC	Wheat Research Centre (Bangladesh)
WUR	Wageningen University Research Center (Netherlands)
Zamorano	Pan-American School, Honduras
ZT	Zero tillage (surface seeding)